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Habitat Fragmentation due to Transportation Infrastructure

Subject : National State of the Art Report – Norway (May 2000)

COST 341/8-N

Contents:

Chapter 1. Introduction

By Bekker, G.J. (2002) Introduction. In: Trocmé, M.; Cahill, S.; De Vries, J.G.; Farrall, H.; Folkeson, L.; Fry, G.; Hicks, C. and Peymen, J. (Eds.) COST 341 - Habitat Fragmentation due to transportation infrastructure: The European Review, pp. 15-17.

Fragmentation of natural habitats has been recognised as a significant factor which contributes towards the decline of biodiversity in Europe and has become a major concern for all those working in the nature conservation and management field. Previous research has established that linear transportation infrastructure (roads, railways and waterways in particular) can cause serious habitat fragmentation problems. In some parts of Europe, infrastructure development has been identified as *the* most significant contributor towards the overall fragmentation effect; other factors include intensive agriculture, industrialisation and urbanisation (which will not be considered in this publication). The European Review aims to provide an overview of the scale and significance of the fragmentation problem caused by transportation infrastructure in Europe, and to examine the strategies and measures that are currently being employed in an attempt to combat it.

Habitat Fragmentation: The problem

Habitat fragmentation can be described as the splitting of natural habitats and ecosystems into smaller, more isolated patches. The process of fragmentation is driven by many different factors, but the direct loss or severance of natural habitat is the most evident. Other contributing factors include disturbance (in terms of noise and visual nuisance) and pollution (causing changes in local microclimate and hydrology), which act to reduce the suitability of adjacent areas for wildlife. The infrastructure itself contributes significantly towards habitat fragmentation by creating a barrier to animal movement. This may result in the isolation and extinction of vulnerable species. The steadily growing number of animal casualties associated with roads, railways and, to a lesser extent, waterways is a further clear indicator of the fragmentation effect. Fauna mortality, in particular, has served to raise the public perception of the problem, due to its inherent link to traffic safety. The construction of infrastructure can also lead to less obvious 'secondary effects' related to increased human activity (*i.e.* subsidiary development such as housing, industry, etc.). These areas fall outside the remit of this report, but it is important to recognise that they may intensify the fragmentation problem.

Development of Transportation infrastructure

For more than 2000 years, roads, railways and waterways have been built in Europe to provide an efficient means of transportation for labour, goods and information. Many historic roads have developed from paths used for local communication, constructed where topography permitted. As a result of its long history, infrastructure was embedded and integrated in the landscape. During the last century, however, technical innovations have liberated planners and engineers from the natural constraints of the terrain. This has meant that modern transportation infrastructure can be superimposed on almost any prevailing landscape pattern, resulting in greater disruption of ecological linkages and processes. Across Europe, the length of roads and railways planned for construction in the future is significant: *i.e.* more than 12,000 km and 11,000 km respectively in Western Europe by 2010 (EEA, 2000; EEA, 1998). This is in addition to even higher levels of new construction in central and Eastern Europe (CEC, 2001). With the increasing spatial demands of infrastructure facilities and the predicted continued growth in traffic flows, conflicts between infrastructure and the natural environment are inevitably set to increase in the future.

A Challenging Problem

The challenge across Europe is to adapt the existing and future transportation infrastructure to produce an ecologically sustainable transportation system. In practice, solutions must be found to the current fragmentation problems and a strategy for extending future infrastructure without intensifying fragmentation must be applied. The realisation amongst experts working in the transport and nature conservation fields in Europe of the scale of the problem and the need for co-operation in this field was the catalyst for the development of COST 341.

Background to COST 341

In 1997, the representatives of several European countries belonging to the Infra Eco Network Europe (IENE) group identified the need for co-operation and exchange of information in the field of habitat fragmentation caused by infrastructure at a European level (Teodorascu, 1997) The IENE members, recognising the need for support from the European Commission (EC), thus initiated COST 341: 'Habitat fragmentation due to Transportation Infrastructure', the aim of which was to assemble existing knowledge on the subject throughout Europe, review it critically and offer clear guidelines for those involved in future transport planning. COST 341 commenced in 1998 with a planned duration of between 4 and 5 years. The following countries and organisations have been official participants:

Austria (A)	Hungary (H)	Spain (E)
Belgium (B)	The Netherlands (NL)	Sweden (S)
Cyprus (CY)	Norway (N)	Switzerland (CH)
Czech Republic (CZ)	Portugal (P)	United Kingdom (UK)
Denmark (DK)	Republic of Ireland (IRL)	European Centre for Nature
France(F)	Romania (RO)	Conservation (ECNC)

Several countries and organisations outside the official membership have also contributed to COST 341. Recognition should be given to contributors from Estonia, Italy and the Worldwide Fund for Nature (WWF).

The goals of COST 341 were to:

- Review the current situation with regard to habitat fragmentation and de-fragmentation in Europe and publish the results in the form of a European Review;
- Publish a European Handbook which presents best practice guidelines, methodologies and measures for avoiding, mitigating against and compensating for the fragmentation effect;
- Create an online database containing information on relevant existing literature, projects and mitigation measures related to habitat fragmentation; and
- Publish a final report describing the entire project and the implementation of its results.

This European Review of 'Habitat Fragmentation due to Transportation Infrastructure' is therefore one of a package of COST 341 products. It is a synthesis of the information presented in individual National State-of-the-Art Reports produced by the participating countries (annexed to this document as a CD-ROM). Most of the National Reports are also published separately in the originating country and can be downloaded from http://cost341.instnat.be/. The European Review is aimed primarily at infrastructure planners, designers, engineers and other professions involved in the construction and/or management of infrastructure. However, other target groups include: the technical and scientific research community, organisations involved in the fields of transportation and environmental protection; policy makers (at EC, national and local level); and members of the public.

The following text attempts to give an idea of the full scope and extent of the habitat fragmentation problem across Europe and identify the range of solutions which are currently used to address it. Chapter 2 presents some basic ecological concepts that are integral to the understanding of the effects of fragmentation, the details of which are discussed in Chapter 3. Chapter 4 goes on to identify the main habitat types that are threatened by fragmentation, the causes of that fragmentation and the policy responses to it. This is followed by an overview of the scale and significance of the habitat fragmentation problem caused by transportation infrastructure, presented in Chapter 5. A description of how various planning instruments can be used to minimise habitat fragmentation is given in Chapter 6, whilst Chapter 7 examines the range of specific measures available for addressing the problem. It also gives recommendations with regard to the monitoring and maintenance of the measures in order to establish their levels of effectiveness. Chapter 8 deals with the safety and economic aspects associated with fragmentation (fauna collisions in particular) and Chapter 9 discusses the integrated and strategic approaches that should be applied in the planning of future infrastructure. Finally, Chapter 10 presents the general conclusions from the research and recommendations and principles for dealing with the problem in the future.

Chapter 2. Key ecological concepts

By Seiler, A. (2002) Key Ecological Concepts. In: Trocmé, M.; Cahill, S.; De Vries, J.G.; Farrall, H.; Folkeson, L.; Fry, G.; Hicks, C. and Peymen, J. (Eds.) COST 341 - Habitat Fragmentation due to transportation infrastructure: The European Review, pp. 19-29.

This chapter introduces some of the major ecological concepts that aid an understanding of the large-scale effects of infrastructure on wildlife: the concepts of landscape, scale and hierarchical organisation; the process of habitat fragmentation; the importance of habitat connectivity and corridors for animal movement; and metapopulation dynamics. There is a focus on landscape pattern and structure, particularly how these interact to determine the impact of infrastructure on wildlife. The chapter emphasises the importance of planning at a landscape scale and explains why the use of a broader, landscape ecological approach may shed new light on barrier and isolation effects.

Habitat fragmentation caused by transportation infrastructure is an issue of growing concern (Prillevitz, 1997). Possible effects of fragmentation on wildlife have been recognised and an impressive amount of empirical studies illustrate the widespread impact on species and ecosystems (see Chapter 3). The growing demand for information on efficient mitigation has, however, highlighted that the current understanding of the long-term, large-scale ecological consequences of infrastructure provision is insufficient (Treweek *et al.*, 1993; RVV, 1996; Seiler and Eriksson, 1997; Forman, 1998). It is apparent that impacts cannot be evaluated from a local perspective alone. Infrastructure planning must therefore involve a landscape wide, holistic approach that integrates technical, human and ecological requirements. Landscapes and habitats are two fundamental aspects that infrastructure planners must consider. This chapter clarifies the definitions of these, and other important terms and concepts relevant to habitat fragmentation.

2.1. Landscapes and habitats

The definition of the term *landscape* varies considerably between European countries and scientific domains. For the purposes of this document, it is defined as 'the total spatial entity of the geological, biological and human-made environment that we perceive and in which we live' (Naveh and Lieberman, 1994). Landscapes are composed of a *mosaic* of individual patches embedded in a matrix (Forman, 1995). The *matrix* comprises the wider ecosystem or dominating landuse type in the mosaic and usually determines the 'character' of the landscape, *e.g.* agricultural, rural, or forested. Landscape *patches* are discrete spatial units that differ from each other due to local factors such as soil, relief, or vegetation *e.g.* an area of forest surrounded by grassland, or a pond within a forest. Landscape patches may also be termed 'habitat'. In ecology, the term *habitat* is a species-specific concept of the environment in which a plant or animal finds all necessary resources for survival and reproduction (Whittaker *et al.*, 1973; Schaefer and Tischler, 1983). The size of a habitat is therefore entirely dependant upon the individual species' requirements: it can be anything from a pond, a meadow, a forest or even the entire landscape mosaic. The diversity of habitats within a landscape and the spatial arrangement of individual habitat patches together determine the biodiversity value of the landscape (Gaston, 1998). *Biodiversity* denotes the total variation among living organisms in their habitats, including the processes that link species and habitats.

2.2. Landscape change and habitat fragmentation

Historically, human activities (driven by politics, economics, and cultural traditions) have altered landscape patterns, habitat quality and the 'natural' distribution of species (Stanners and Bourdeau, 1995; Jongman *et al.,* 1998). Across Europe, traditional small-scale landuse has been replaced by intensified methods that require large, homogeneous production units (Burel, 1992; Jedicke, 1994; Ihse, 1995; Skånes and Bunce, 1997). In modern rural landscapes, wildlife habitats have been reduced to small remnants scattered throughout the intensively used matrix. In addition, extensive natural areas, *e.g.* open marshland or contiguous forests, have been increasingly fragmented by infrastructure including roads, railways, waterways, drainage ditches, and power lines (*e.g.* Bernes and Grundsten, 1992; Kouki and Löfman, 1999; and Figure 2.1). As a result, species have come to depend on increasingly smaller patches of remnant semi-natural habitat and green corridors such as hedgerows, wooded field margins, infrastructure verges and small forest patches.

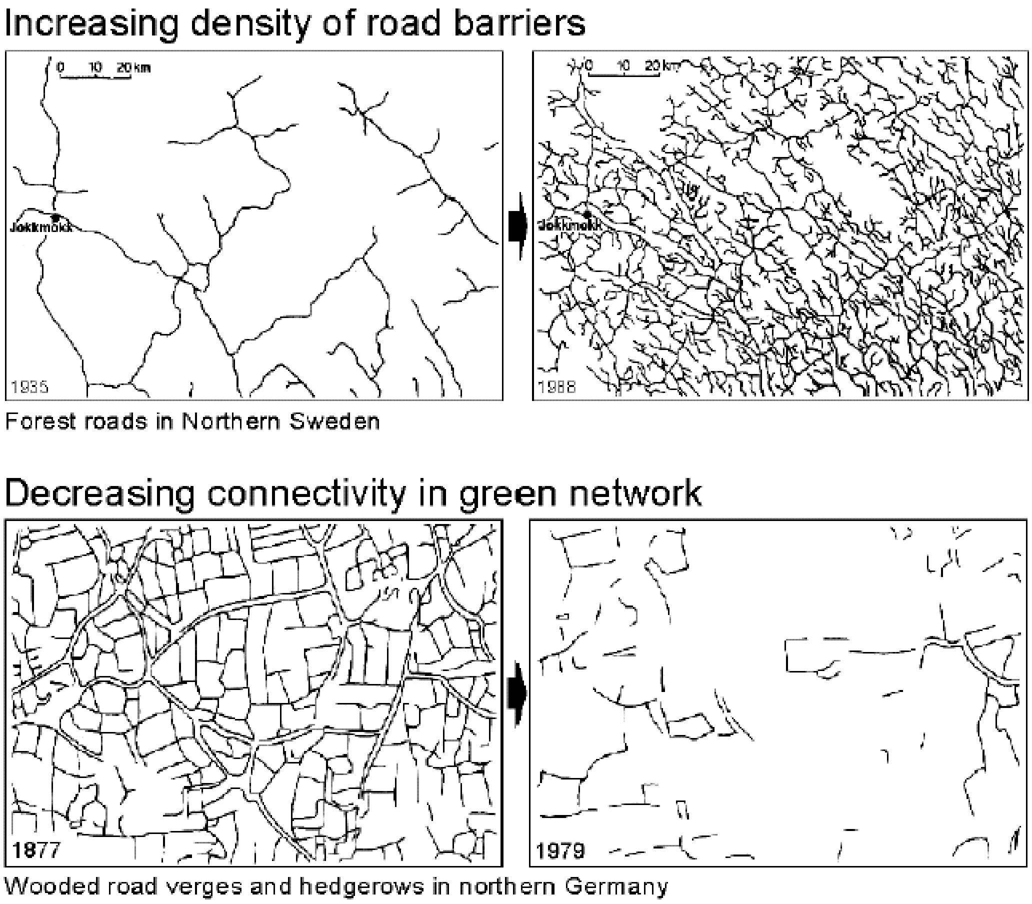

Figure 2.1 - Landscape change due to fragmentation and loss of connectivity. Top - Increase in forest road network in the Jokkmokk area in northern Sweden between 1935 and 1988 (after Bernes and Grundsten, 1992). Lower - Loss of vegetated corridors (tree rows, hedgerows, road verges) in the agricultural landscape of northern Germany between 1877 and 1979. (After Knauer, 1980)

Together, forestry, agriculture and urbanisation have significantly reduced landscape heterogeneity and the extent of 'natural' habitats (Richards, 1990; Jongman, 1995; and Figure 2.2). Globally, this loss of landscape heterogeneity and the fragmentation of large, previously undisturbed habitats has created a major threat to biodiversity (Burgess and Sharpe, 1981; Wilcox and Murphy, 1985; Gaston, 1998). To promote the sustainable use of landscapes, people must learn to think and plan at a larger scale, integrating the local considerations into a broader functional context (Forman, 1995; Angelstam, 1997).

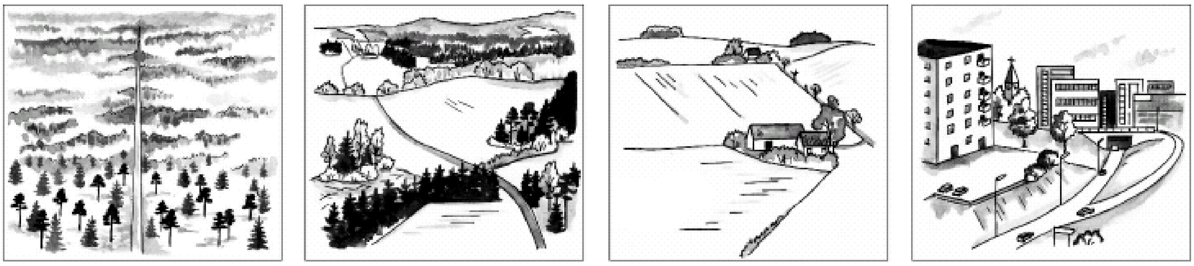

Figure 2.2 - Four types of landscapes that differ in the degree of human impact: A) A natural forested landscape containing a variety of natural ecosystems and habitats with little or no human influence; B) A mosaic, rural landscape where pastures, fields blend with forests that connect through hedgerows and strips of woody vegetation along small watercourses; C) A landscape dominated by agriculture and extensive land cultivation where remnants of the natural vegetation may be found in gardens and along infrastructure verges; 4) An urban landscape, strongly affected by infrastructure and built-up areas with little or no space for wildlife. (Drawings by Lars Jäderberg)

Habitat fragmentation is a process that splits contiguous habitat into smaller patches that become more and more isolated from each other. At the beginning of the fragmentation process, the loss of habitat is the driving force reducing species diversity in the landscape. Towards the end of the process, isolation effects become more important (Harris, 1984). Empirical studies indicate that the number of species drops significantly when more than 80% of the original habitat is lost and as habitat remnants become isolated (Andrén, 1994). The exact fragmentation thresholds depend on species' habitat requirements and mobility, and the mosaic pattern of habitats in the landscape. Where habitat remnants are connected through 'green' corridors or by small, suitable patches which serve as stepping stones (see Section 2.5), isolation effects may be minimised. The landscape may then support a higher diversity of species than would be expected from the overall area of remnant habitat. However, where roads or railways cause additional separation of habitats (see Chapter 3), critical thresholds of fragmentation may be reached much earlier (Figure 2.3). It is essential that infrastructure planning should therefore consider the existing degree of fragmentation in the landscape, species' characteristics and the ecological scale at which the fragmentation effect may be most severe (Seiler and Eriksson, 1997).

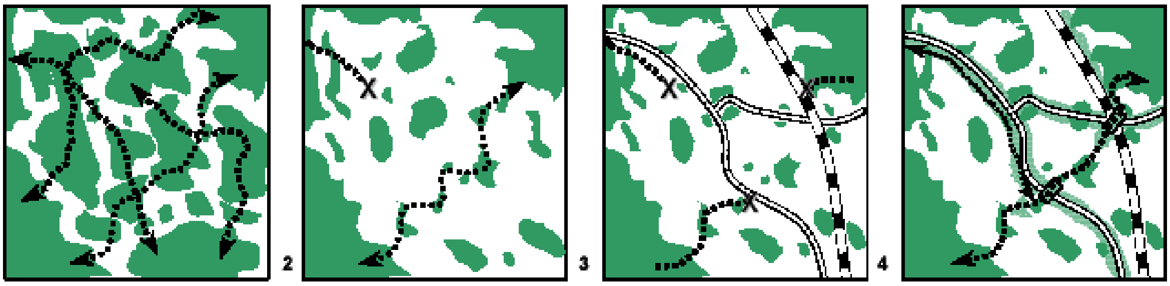

Figure 2.3 - (1) Fragmentation of an animals' habitat (shaded areas) reduces the ability of individuals to move across the landscape. (2) Some connectivity may be sustained through small habitat fragments or corridors. (3) Infrastructure imposes additional movement barriers and strengthens the isolation effect caused by habitat fragmentation. (4) Mitigation measures such as fauna passages and integrated road verge management can help to re-establish or even improve habitat connectivity in the landscape.

The consequences of habitat fragmentation to wildlife are complex, as species respond differently to the loss and isolation of their habitat. In general, species with limited mobility, large area requirements, or strong dependence on a certain type of habitat will be among the first to suffer the effects of habitat loss and isolation. These species generally respond to habitat fragmentation by modifying their individual behaviour patterns. Conversely, species that are abundant at a landscape scale, that utilise a variety of habitats and are more resilient to disturbance may not be affected so significantly. Although infrastructure may represent a significant barrier to their movement, local populations can be sustained so long as the habitat remnants remain sufficiently large. Isolation effects manifest themselves in this group of species through long-term demographic and genetic change within the population. Applying this knowledge in infrastructure planning is the key to preventing the ultimate consequence of habitat fragmentation - species extinction. In terms of defragmentation strategies, wide-roaming species will benefit most from improved habitat connectivity whilst for the smaller and less mobile species, more effort should be put into protecting and enlarging local existing habitats (Fahrig and Merriam, 1994).

2.3. Metapopulations, sinks and sources

Two ecological theories, regarding metapopulations (Levins, 1969) and sink and source population dynamics (Pulliam, 1988), contribute to the understanding of the complex processes of colonisation and extinction of populations in the landscape. These approaches help ecologists to predict the wider effects of habitat fragmentation and design effective strategies for the conservation of fragmented populations (Harris, 1984).

A *population* is a group of individuals of the same species that live in the same habitat, and breed with each other. When a habitat is fragmented, a system of local populations is formed. Where these are located close enough to permit successful migration of individuals, but are sufficiently isolated to allow independent local dynamics, the system is called a *metapopulation* (Hanski and Gilpin, 1991). The migration of individuals between the local *source* (where the number of births exceeds the number of deaths) and *sink* (with a negative birth to death ratio) populations has a stabilising effect on metapopulation dynamics (Pulliam, 1988). However, when the two populations are separated by new infrastructure barriers, sink populations will loose the essential input of individuals from their sources and consequently face a rapid decline and ultimately extinction (Watkinson and Sutherland, 1995; and Figure

2.4). Despite this theoretical knowledge, sink and source dynamics are extremely difficult to recognise and quantify from simple field observations.

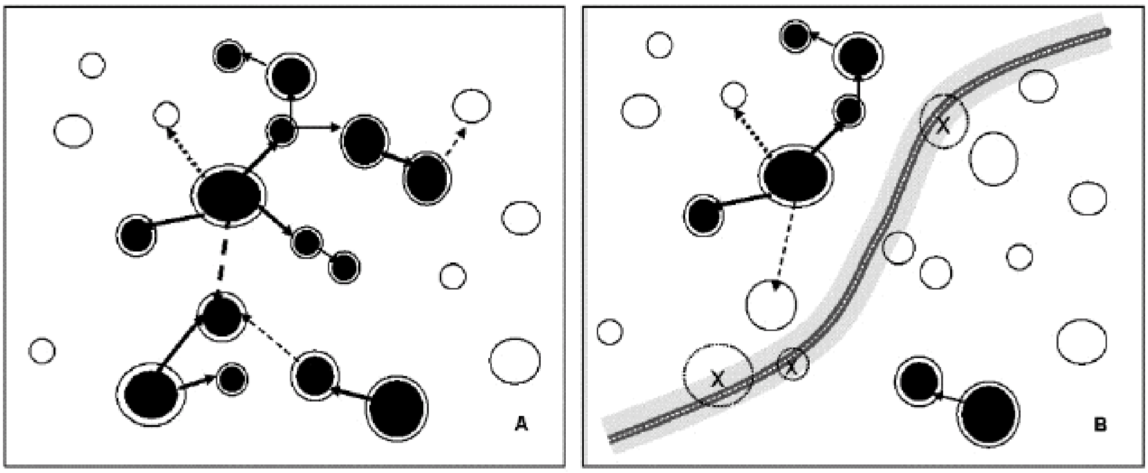

Figure 2.4 - Barrier effects on populations: (A) A metapopulation consists of a network of local populations that may vary in size and local dynamics, but are linked to each other through dispersal. Small local populations are more likely to go extinct than large populations, but the risks of this are minimised if they are well connected to surrounding populations from where they can be re-colonised; (B) Infrastructure construction causes a disturbance and loss of local populations within the network. In addition, infrastructure imposes a dispersal barrier that can prevent re-colonisation and isolate local populations from the rest of the metapopulation. If important source populations are cut off from the remaining sink populations, the entire metapopulation may be at risk of extinction.

2.4. Plant and animal movements

The movement of organisms is a fundamental property of life. Plants 'move' passively via natural (*e.g.* wind, water, and animals) or human (*e.g.* vehicles) vectors that transport their pollen or seeds (Verkaar, 1988; Wace, 1977). Few studies have been carried out to investigate the effect of infrastructure on plant movements, but there is evidence that weeds and many exotic plant species spread along infrastructure verges into adjacent habitats (see Section 3.3). Animals are more directly affected by infrastructure barriers, but to understand the problem and evaluate the conflict between the barriers and animal movements, it is necessary to recognise differences in the type of movements and the scale at which these occur (Verkaar and Bekker, 1991). Animals move within and between foraging areas, home ranges, regions and even continents. These movements are necessary for the daily survival of individuals as well as for the long-term persistence of populations. Broadly, four categories of movements can be distinguished (Figure 2.5 and Table 2-1).

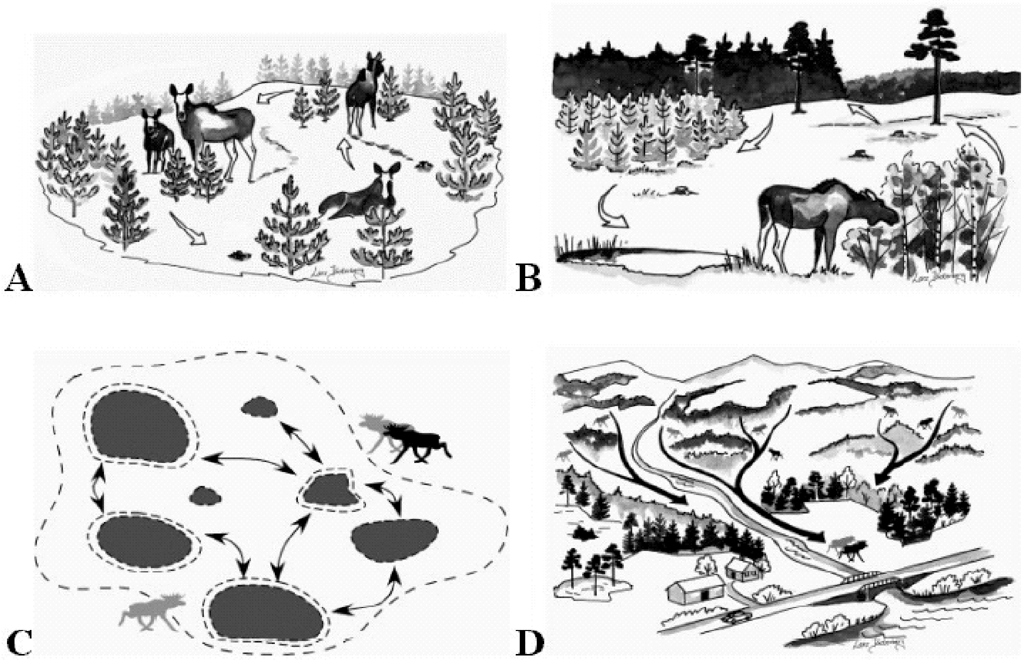

Figure 2.5 - Four basic types of animal movements: (A) Foraging movements of an individual within a forest stand; (B) diurnal or commuting movements between forest patches within the home range of an individual; (C) dispersal movements (emigration and immigration) between local populations; (D) migratory movements between seasonal habitats by local populations. These movement types refer to different spatial and temporal scales, but may occur simultaneously in the landscape. (Drawings by Lars Jäderberg)

Table 2.1 - Classification of Animal Movement Patterns.

Movement	Features
Foraging	Made in order to access food sources within a habitat patch (Figure 2.5 A); they are small-scaled, convoluted and rather diffuse.
Diurnal or commuting	Made regularly in the home range of an individual between different resources, *e.g.* between breeding site, foraging areas, water and shelter (Figure 2.5 B); they are generally straight (often along guiding structures such as forest edges, hedgerows or rivers) and directed towards a goal (*e.g.* Saunders and Hobbs, 1991; Baudry and Burel, 1997).
Dispersal	Made when individuals leave their birthplace or parental home range in order to establish their own territory. Occurs once, or a few times, during the lifetime of an individual and serves to sustain local populations within a metapopulation (Figure 2.5 C). Little is known about patterns of dispersal but structures and corridors used in diurnal movements are often utilised.
Migratory	Cyclic, long-distance movements between seasonal habitats, often conducted by groups of individuals or even entire local populations. Represents an adaptation to a seasonally changing environment and is essential to the survival of many species. Animals often migrate along traditional paths used by previous generations for hundreds of years that cannot easily be changed in response to a new barrier (Figure 2.5 D).

Where infrastructure dissects a foraging, commuting, dispersal or migration route, animals will have to cross the barrier and encounter a higher risk of mortality from traffic impact (Verkaar and Bekker, 1991). Most traffic accidents involving deer, for instance, occur during the hours around sunset and sunrise, when the animals are moving to and from their preferred feeding sites (Groot Bruinderink and Hazebroek, 1996). Migratory species are especially vulnerable to the barrier and mortality effects associated with infrastructure. Amphibians, for example, migrate as entire populations between breeding ponds and terrestrial habitats and consequently suffer extreme losses due to traffic mortality (Sjögren-Gulve, 1994; Fahrig *et al.*, 1995). The migration of larger ungulates, such as moose (*Alces alces*) in northern Scandinavia (Sweanor and Sandegren, 1989; Andersen, 1991) and red deer (*Cervus elaphus*) in the Alps (Ruhle and Looser, 1991) also causes particular problems in relation to traffic safety.

Animal movements are an important consideration in wildlife management and conservation. Knowledge about the type and the extent of animal movement may help to increase traffic safety, reduce road mortality and/or find adequate places for mitigation measures such as fences and fauna passages (Putman, 1997; Finder *et al.*, 1999; Pfister, 1993; Keller and Pfister, 1997). Empirical data on animal movement is still limited and more field research is required in order to understand where, and how, artificial or semi-natural structures can be used to lead animals safely across infrastructure barriers.

2.5. Connectivity, corridors and ecological networks

Habitat connectivity denotes the functional connection between habitat patches. It is a vital, species-specific property of landscapes, which enables the movement of an animal within a landscape mosaic (Baudry and Merriam, 1988; Taylor *et al.*, 1993). Connectivity is achieved when the distances between neighbouring habitat patches are short enough to allow individuals to cross easily on a daily basis. In fragmented landscapes, connectivity can be maintained through: i) a close spatial arrangement of small habitat patches serving as stepping-stones; ii) corridors that link habitats like a network and; iii) artificial measures such as fauna passages over roads and railways (Figure 2.6).

Hedgerows and field margins, wooded ditches, rivers, road verges and power-lines are all ‘ecological corridors’ (Merriam, 1991). These support and direct movements of wildlife, but may also serve as a refuge to organisms that are not able to survive in the surrounding landscape (see Section 3.3.2). Most of the empirical data on the use of ecological corridors by wildlife refers to insects, birds and small mammals (*e.g.* Bennett, 1990; Merriam, 1991; Fry, 1995; Baudry and Burel, 1997) (see also Chapter 5). Little is known yet about the use of these rather small-scale structures by larger mammals (Hobbs, 1992).

Figure 2.6 - Hedgerows and woody road verges ('Knicks') in northern Germany provide the only bush and tree vegetation available in the landscape. Together they create a network of green corridors on which many species in that area depend for shelter and food. Naturally, these corridors also have a strong impact on the movement of species that shy away from the open fields and pastures. (Photo by Andreas Seiler)

The re-creation of ecological corridors is envisioned as the most effective strategy against habitat fragmentation in Europe. Recently, the concept of an ecological infrastructure - promoting the movement of wildlife in an otherwise hostile environment (Van Selm, 1988), has become adopted as a conservation tool by landscape architects (Dramstad *et al.*, 1996), and road planners (Saunders and Hobbs, 1991; Seiler and Eriksson, 1997; Jongman, 1999). Strategic ecological networks, such as the NATURA 2000 network or the Pan-European Ecological Network (Bennett and Wolters, 1996; Bennett, 1999; Opstal, 1999) attempt to apply the concept on a European scale by seeking to link areas designated for nature conservation (Jongman, 1994). Considering these 'networks' in the planning of infrastructure may help to highlight critical bottlenecks in habitat connectivity and identify where special mitigation measures may be required in the future.

2.6. Scale and hierarchy

The concepts of scale and hierarchy are essential to the understanding of ecological pattern and processes in the landscape (Urban *et al.*, 1987; Golley, 1989; Wiens, 1989). *Scale* defines the spatial and temporal dimensions of an object or an event within a landscape; every species, process or pattern owns its specific scale (Figure 2.7). For the purposes of environmental impact assessment (EIA), the scale at which ecological studies are undertaken is a fundamental consideration which determines the type of mitigation solutions that are designed. If an EIA is limited to an individual habitat, the wider (and potentially more serious) impacts at the landscape scale will be overlooked. Conversely, if too large a scale is selected for study, small sites that together comprise important components of the ecological infrastructure in the landscape may be ignored.

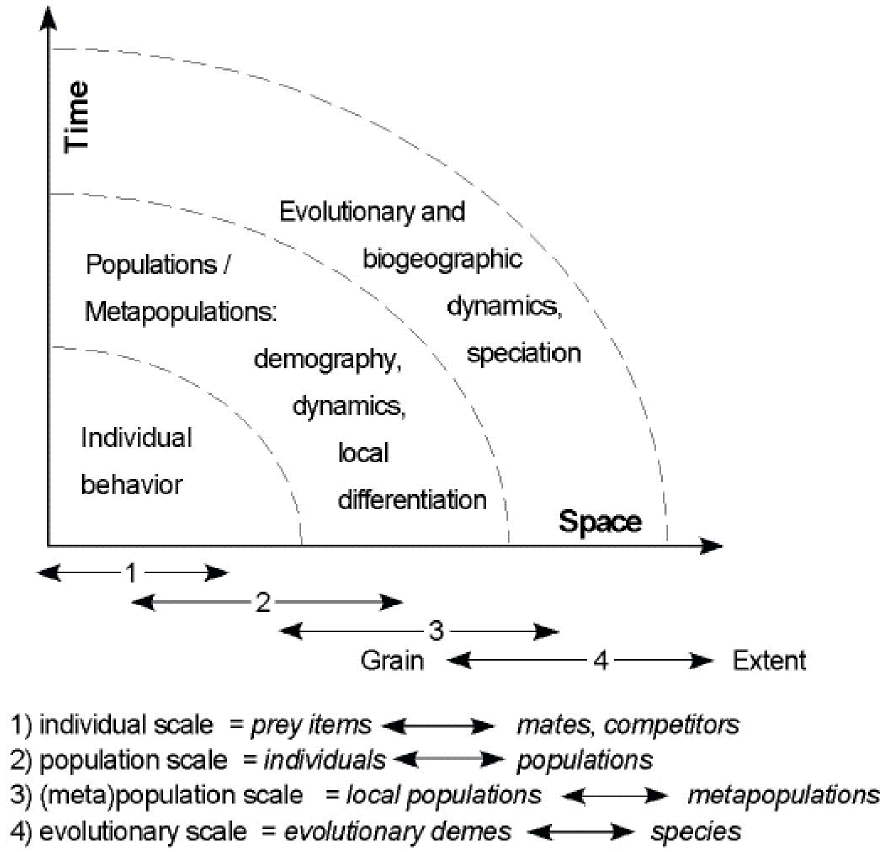

Figure 2.7 - Domains of scale in space and time. Enlarging the scale shifts the focus towards higher organisational levels that reveal new processes and dynamics. Nb. large spatial scales refer to small scales in map dimension. (Combined from Wiens, 1989 and Haila, 1990)

Closely related to scale is the hierarchical structuring of nature in which any system at a given scale is composed of a number of sub-systems at smaller scales (O'Neill et al., 1986). For example, a metapopulation is comprised of local populations, which in turn are made up of many individuals (Figure 2.8).

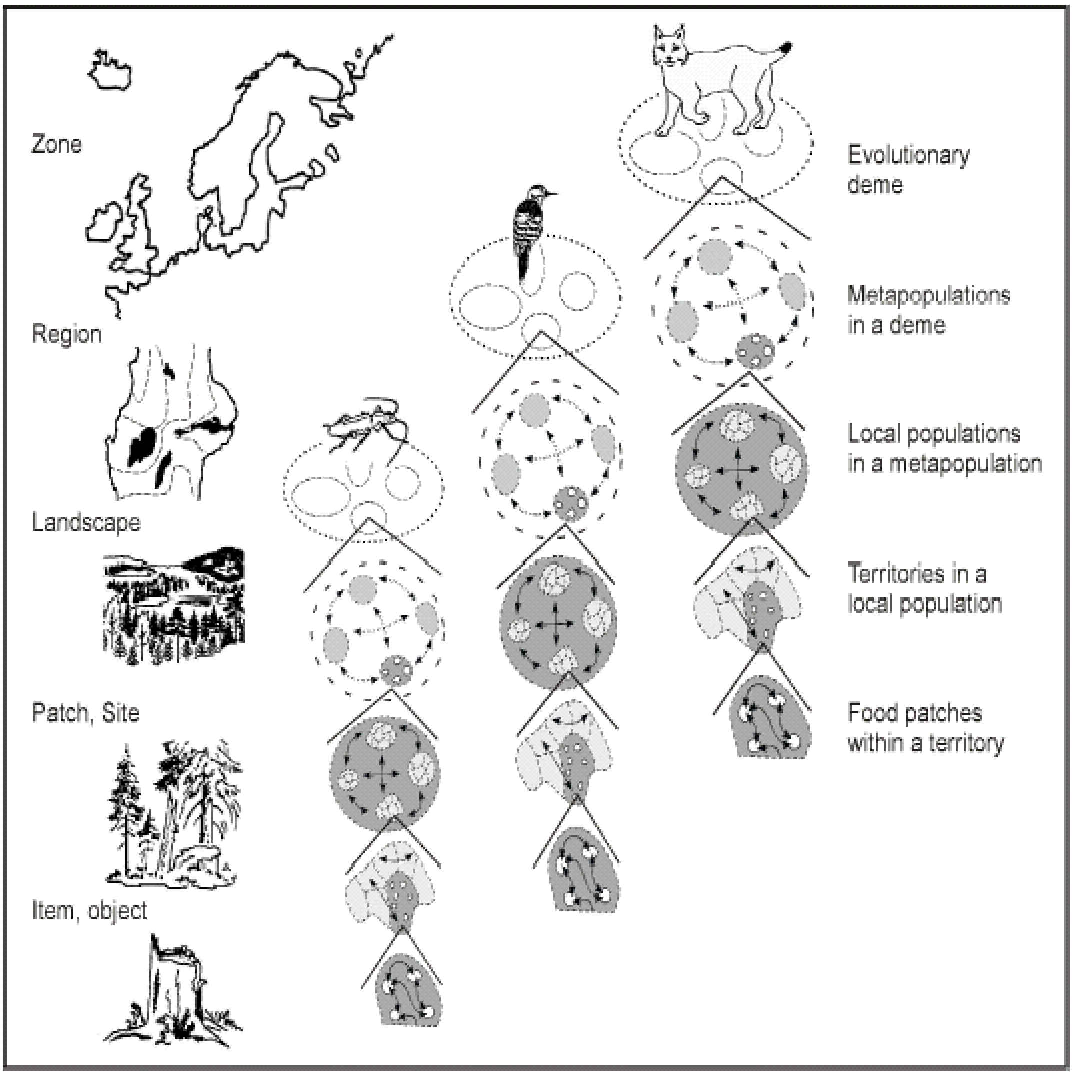

Figure 2.8 - Hierarchical layering in ecology. Food patches are nested in individuals' territories, which make up the habitat of a local population. In turn, these local populations make up metapopulations that together comprise the evolutionary deme of a species. At each hierarchical level (i.e. site, landscape, region, zone), the spatial entities are linked trough the movement of individuals. (Redrawn after Angelstam, 1992)

In order to predict the effects of habitat fragmentation in relation to ecological properties at a given level (*e.g.* for a population), both of the adjacent levels in the hierarchical system (*i.e.* individual and metapopulation) must be considered (Senft *et al.*, 1987; Bissonette, 1997). In terms of the application of this principle to infrastructure planning, a theoretical example is outlined below.

Imagine a new railway that is to be built through a forest. On a topographical map, the forest may comprise a rather homogeneous green area. From a biological point of view, however, the forest is home to numerous local populations of animals, such as beetles that live on old growth trees (see Figure 2.8), and it forms the territory of an individual lynx. A new railway through this landscape will affect the beetle primarily at the population level due to the destruction of their habitat and increased separation of local populations. Disturbance and barrier effects of the new infrastructure may drive some of the local populations to extinction, but the metapopulation may still persist. For the lynx, the railway matters mostly at the individual level. Traffic increases mortality risk and the railway barrier may dissect the lynx's home range into smaller, unviable fragments. The lynx is a relatively rare species, in which the loss of one single individual can be significant to the population in a region.

Depending on the vulnerability of a species at regional scale, the effects on individuals or the population(s) have to be evaluated on a case-by-case basis and mitigation strategies designed accordingly. If studied solely from a local perspective, the importance of barrier and fragmentation effects is likely to be underestimated, because consequences to the populations will first become apparent at a larger spatial scale.

2.7. Summary

This chapter has introduced some specific ecological concepts that are relevant to the better understanding of landscape pattern and process in infrastructure planning. For further reading on the presented topics, see Forman (1995), Bissonette (1997), Farina (1998), Sutherland (1998), or Jedicke (1994). The most important principles can be summarised as follows:

- *The effects of infrastructure on nature cannot be evaluated solely from a local perspective; infrastructure planning must focus on the landscape scale.*
- *Habitat connectivity across the landscape is essential for ensuring the survival of wildlife populations. Connectivity can be provided by ecological 'green' corridors, 'stepping stones', or technical mitigation measures e.g. constructing a bridge between severed habitats.*
- *The impact of habitat fragmentation on wildlife is dependent on individual species and landscape characteristics. Where the impact is below a critical threshold, populations can be sustained, but beyond this threshold, seemingly small changes in the environment may cause unexpected and irreversible effects (e.g. the extinction of local populations). The larger the spatial scale concerned, the longer the time-lag until effects may be detectable.*
- *Infrastructure planning needs to integrate both regional and local-scale issues. A hierarchical approach can help to identify the most important problems and their solutions at each planning level. People should 'think globally, plan regionally but act locally' (sensu Forman, 1995).*

There is still a long way to go before ecological tools are fully developed and implemented in road planning, but since the problems and their solutions are universal, joint research and combined international efforts are required. Only through interdisciplinary work (between planners, civil engineers and ecologists) can effective tools for assessing, preventing and mitigating against the ecological effects of infrastructure, be developed and applied.

Landscape and wildlife ecology together provide a body of theories and methodologies for the assessment of ecological impacts such as habitat fragmentation. Empirical studies are, however, scarce and more research is needed to investigate the critical thresholds beyond which populations cannot be sustained. The construction and daily use of transportation infrastructure can result in wide ranging ecological impacts that need to be identified and addressed. The specific nature of these impacts is discussed in more detail in Chapter 3.

Chapter 3. Effects of Infrastructure on Nature

By Seiler, A. (2002) Effects of Infrastructure on Nature. In: Trocmé, M.; Cahill, S.; De Vries, J.G.; Farrall, H.; Folkeson, L.; Fry, G.; Hicks, C. and Peymen, J. (Eds.) COST 341 - Habitat Fragmentation due to transportation infrastructure: The European Review, pp. 31-50.

This chapter presents an overview of the major ecological impacts of infrastructure, with a particular focus on those effects that impact upon wildlife and their habitats. The focus of this chapter is on the primary effects of transportation infrastructure on nature and wildlife, as these are usually the most relevant to the transport sector. Secondary effects following the construction of new roads or railways, *e.g.* consequent industrial development, or changes in human settlement and landuse patterns, are dealt with in more depth in Chapter 5 (Section 5.5). For more discussion and data on secondary effects see Section 5.5.

The physical presence of roads and railways in the landscape creates new habitat edges, alters hydrological dynamics, and disrupts natural processes and habitats. Maintenance and operational activities contaminate the surrounding environment with a variety of chemical pollutants and noise. In addition, infrastructure and traffic impose movement barriers to most terrestrial animals and cause the death of millions of individual animals per year. The various biotic and abiotic impacts operate in a synergetic way locally as well as at a broader scale. Transportation infrastructure causes not only the loss and isolation of wildlife habitat, but leads to a fragmentation of the landscape in a literal sense.

An increasing body of evidence relating to the direct and indirect ecological effects of transportation infrastructure on nature includes the comprehensive reviews of van der Zande *et al.* (1980); Ellenberg *et al.* (1981); Andrews (1990); Bennett (1991); Reck and Kaule (1993); Forman (1995); Spellerberg (1998); Forman and Alexander (1998); and Trombulak and Frissell (2000). Impressive, empirical data has also been presented in the proceedings of various symposia (*e.g.* Bernard *et al.*, 1987; Canters *et al.*, 1997; Pierre-LePense and Carsignol, 1999; Evink *et al.*, 1996, 1998 and 1999; and Huijser *et al.*, 1999). Bibliographies on the topic have been compiled by Jalkotzky *et al.* (1997), Clevenger (1998), Glitzner *et al.* (1999), and Holzang *et al.* (2000). Readers are encourages to consult these complementary sources for further information on the topics discussed in brief below.

3.1. Primary ecological effects

Most empirical data on the effects of infrastructure on wildlife refers to primary effects measured at a local scale. Primary ecological effects are caused by the physical presence of the infrastructure link and its traffic. Five major categories of primary effects can be distinguished (Figure 3.1; see also: van der Zande *et al.* (1980); Bennett (1991); Forman (1995)):

- *Habitat loss* is an inevitable consequence of infrastructure construction. Besides the physical occupation of land, disturbance and barrier effects in the wider environment further decrease the amount of habitat that is suitable or available for wildlife.
- *Disturbance/Edge effects* result from pollution of the physical, chemical and biological environment as a result of infrastructure construction and operation. Toxins and noise affect a much wider zone than that which is physically occupied.

- *Mortality* levels associated with traffic are steadily rising (millions of individuals are killed on infrastructure each year in Europe), but for most common species this, traffic mortality it is not considered as a severe threat to population survival. Collisions between vehicles and wildlife are also an important traffic safety issue, and attract wider public interest for this reason.
- *Barrier* effects are experienced by most terrestrial animals. Infrastructure restricts the animals' range, makes habitats inaccessible and can lead to isolation of the population.
- *Corridor* habitats along infrastructure can be seen as either positive (in already heavily transformed low diversity landscapes) or negative (in natural well conserved landscapes where the invasion of non native, sometimes pest species, can be facilitated).

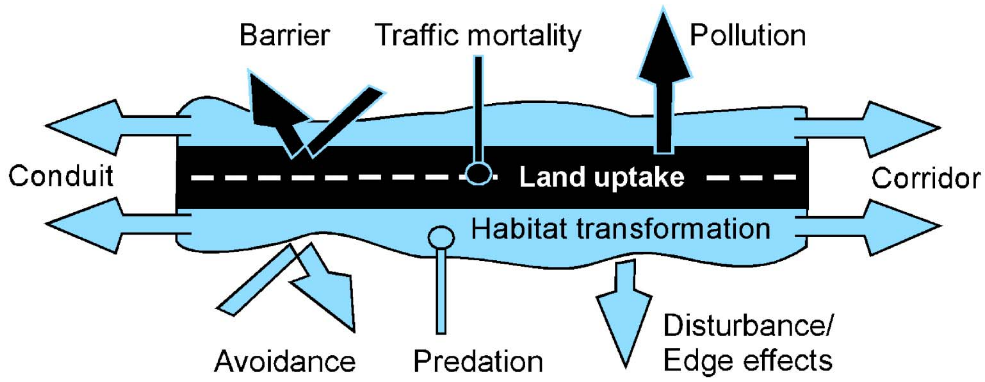

Figure 3.1 - Schematic representation of the five primary ecological effects of infrastructure which together lead to the fragmentation of habitat. (Modified from van der Zande et al., 1980)

The impact of these primary effects on populations and the wider ecosystem varies according to the type of infrastructure, landscape, and habitat concerned. Individual elements of infrastructure always form part of a larger infrastructure network, where synonymous effects with other infrastructure links, or with natural barriers and corridors in the landscape, may magnify the significance of the primary effects. The overall fragmentation impact on the landscape due to the combined infrastructure network may thus not be predictable from data on individual roads and railways. When evaluating primary (ecological) effects of a planned infrastructure project it is essential to consider both the local and landscape scales, and fundamentally, the cumulative impact of the link when it becomes part of the surrounding infrastructure network.

3.2. Habitat loss

3.2.1. Land take

Motorways may consume more than 10 hectares (ha) of land per kilometre of road and as a large part of that surface is metalled/sealed it is consequently lost as a natural habitat for plants and animals. Provincial and local roads occupy less area per kilometre, but collectively they comprise at least 95% of the total road network and hence their cumulative effect in the landscape can be considerably greater. If all the associated features, such as verges, embankments, slope cuttings, parking places, and service stations etc. are included, the total area designated for transport is likely to be several times larger than simply the paved surface of the road (Figure 3.2). In most European countries, the allocation of space for new infrastructure is a significant problem for landuse planning. It is not surprising therefore that landtake is a fundamental consideration in Environmental Impact Assessment (EIA) studies and forms a baseline for designing mitigation and compensation measures in modern infrastructure projects (OECD, 1994, see also Section 5.4.1).

The physical occupation of land due to infrastructure is most significant at the local scale; at broader scales it becomes a minor issue compared to other types of landuse. Even in rather densely populated countries such as The Netherlands, Belgium or Germany, the total area occupied by infrastructure is generally estimated to be less than 5-7% (Jedicke, 1994). In Sweden, where transportation infrastructure is sparser, roads and railways are estimated to cover about 1.5% of the total land surface whilst urban areas comprise 3% (Seiler and Eriksson, 1997; Sweden Statistics, 1999).

Figure 3.2 - Slope cuttings along a road in Spain. (Photo by Martí Pey/Minuartia Estudis Ambientals)

3.3. Disturbance

The total area used for roads and railways is, however, not a reliable measure of the loss of natural habitat. The disturbance influence on surrounding wildlife, vegetation, hydrology, and landscape spreads much wider than the area that is physically occupied and contributes far more to the overall loss and degradation of habitat than the road body itself. In addition, infrastructure barriers can isolate otherwise suitable habitats and make them inaccessible for wildlife. The scale and extent of the spread of disturbances is influenced by many factors including: road and traffic characteristics, landscape topography and hydrology, wind patterns and vegetation type and cover. In addition, the consequent impact on wildlife and ecosystems also depends on the sensitivity of the different species concerned. To understand the pattern, more has to be learned about the different agents of disturbance.

Many attempts have been made to assess the overall width of the disturbance zone around infrastructure developments (Figure 3.3). Depending on which impacts have been measured, the estimations range from some tens of metres (Mader, 1987a) to several hundred metres (Reichelt, 1979; Reijnen *et al.*, 1995; Forman and Deblinger, 2000) and even kilometres (Reck and Kaule, 1993; Forman *et al.*, 1997). Thus, despite its limited physical extent, transportation infrastructure is indeed one of the more important actors in the landscape and its total influence on landuse and habitat function has probably been widely underestimated. Forman (2000) estimated that transportation infrastructure in the USA directly affects an area that is about 19 times larger than the 1% of the USA land surface that is physically occupied.

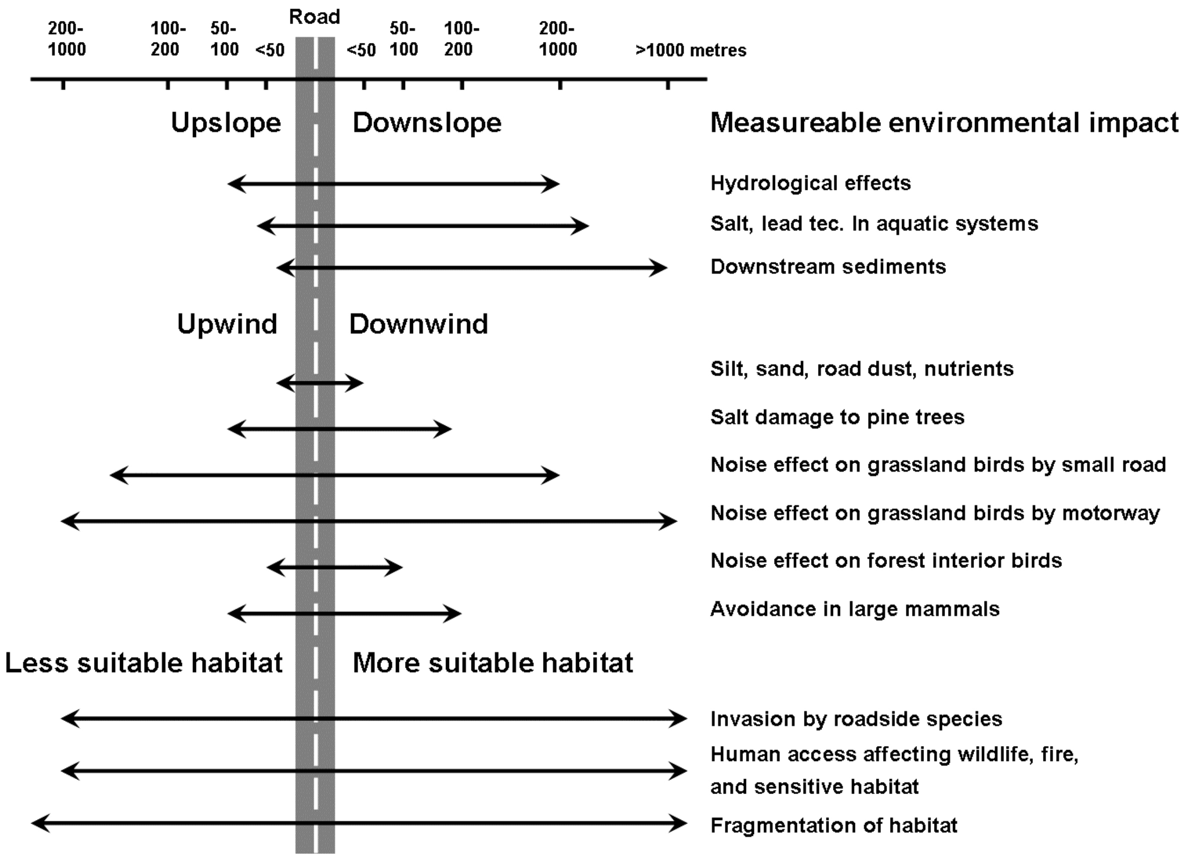

Figure 3.3 - Disturbance effects spreading from a road into the surrounding landscape. The distance over which disturbances affect nature depends on topography, wind direction, vegetation and the type of disturbance. The width of the affected zone is likely to be larger than some hundred meters on average. (Redrawn after Forman et al., 1997)

3.3.1. Physical disturbance

The construction of infrastructure affects the physical environment due to the need to clear, level, fill, and cut natural material. Construction work changes soil density, landscape relief, surface- and groundwater flows, and microclimate, and thus alters land cover, vegetation and habitat composition. Wetlands and riparian habitats are especially sensitive to changes in hydrology *e.g.* those caused by embankments (Findlay and Bourdages, 2000) and cuttings which may drain aquifers and increase the risk of soil erosion and extensive earthslides that have the potential to pollute watercourses with sediments (*e.g.* Forman *et al.*, 1997; Trombulak and Frissell, 2000). The canalisation of surface water into ditches can also significantly change water run-off and debris flows, and thereby modify disturbance regimes in riparian networks (Jones *et al.*, 2000).

The clearance of a road corridor changes microclimatic conditions: it increases light intensity, reduces air humidity, and creates a greater daily variation in air temperature. These changes are naturally strongest where the road passes through forested habitats *e.g.* Mader (1987a) observed changes in forest microclimate up to 30 metres from the edge of a forest road. Artificial edges produced by road construction are usually sharp and can be compared to the new edges created by clear cutting in forests (Jedicke, 1994). The opening of the forest canopy will adversely affect the occurrence of forest interior species such as lichens or mosses, but can favour species adapted to open and edge habitats (*e.g.* Ellenberg *et al.*, 1981; Jedicke, 1994).

3.3.2. Chemical disturbance

Chemical pollutants such as road dust, salt, heavy metals, fertiliser nutrients, and toxins are agents which contribute towards the disturbance effect caused by transportation infrastructure. Most of these pollutants accumulate in close proximity to the infrastructure but, in some cases, direct effects on vegetation and fauna can be observed at distances over several hundreds of metres away (*e.g.* Evers, 1976; Santelmann and Gorham, 1988; Bergkvist *et al.*, 1989; Hamilton and Harrison, 1991; Reck and Kaule, 1993; Forbes, 1995; Angold, 1997).

Dust, mobilised from the infrastructure, is transported and deposited along verges and in nearby vegetation; epiphytic lichens and mosses in wetlands and arctic ecosystems are especially sensitive to this kind of pollution (*e.g.* Auerbach *et al.*, 1997). De-icing and other salts (*e.g.* $NaCl$, $CaCl_2$, KCl, $MgCl_2$) can cause extensive damage to vegetation (especially in boreal and alpine regions (Blomqvist, 1998) and to coniferous forests), contaminate drinking water supplies and reduce the pH-level in soil (which in turn increases the mobility of heavy metals) (Bauske and Goetz, 1993; Reck and Kaule, 1993). Heavy metals and trace metals *e.g.* Pb, Zn, Cu, Cr, Cd, Al (derived from petrol, de-icing salts, and dust) can accumulate in plant and animal tissues and can affect their reproduction and survival rates (Scanlon, 1987 and 1991). Traffic exhaust emissions contain toxins such as polycyclic aromatic hydrocarbons, dioxins, ozone, nitrogen, carbon dioxide, and many fertilising chemicals. Changes in plant growth and plant species diversity have been observed and directly attributed to traffic emissions in lakes (Gjessing *et al.*, 1984) and in heathland at a distance of over 200 metres away from the road (Angold, 1997).

3.3.3. Traffic noise

Although disturbance effects associated with noise are more difficult to measure and less well understood than those related to chemicals, it is considered to be one of the major factors polluting natural environments in Europe (Vangent and Rietveld, 1993; Lines *et al.*, 1994). Areas free from noise disturbance caused by traffic, industry or agriculture have become rare at a European scale and tranquillity is perceived as an increasingly valuable resource (Shaw, 1996). Although noise seldom has an immediate physiological effect on humans, long exposure to noise can induce psychological stress and eventually lead to physiological disorder (*e.g.* Stansfeld *et al.*, 1993; Lines *et al.*, 1994; Job, 1996; Babisch *et al.*, 1999). Whether wildlife is similarly stressed by noise is questionable (see Andrews, 1990), however, timid species might interpret traffic noise as an indicator of the presence of humans and consequently avoid noisy areas. For instance, wild reindeer (*Rangifer tarandus*) avoid habitats near roads or utilise these areas less frequently than would be expected from their occurrence in the adjacent habitat (Klein, 1971). Traffic noise avoidance is also well documented for elk, caribou and brown bear (Rost and Bailey, 1979; Curatolo and Murphy, 1986). However, whether this avoidance is related to the amplitude or frequency of traffic noise is not known.

Birds seem to be especially sensitive to traffic noise, as it directly interferes with their vocal communication and consequently their territorial behaviour and mating success (Reijnen and Foppen, 1994). Various studies have documented reduced densities of birds breeding near trafficked roads (*e.g.* Veen, 1973; Räty, 1979; van der Zande *et al.*, 1980; Ellenberg *et al.*, 1981; Illner, 1992; Reijnen and Foppen, 1994). Extensive studies on willow warblers (*Phylloscopus trochilus*) in The Netherlands showed the birds suffered lower reproductivity, lower average survival, and higher emigration rates close to trafficked roads (Foppen and Reijnen, 1994). Box 3.1 details some of the major studies that have contributed towards knowledge in this field.

It has been shown that environmental factors such as the structure of verge vegetation, the type of adjacent habitat, and the relief of the landscape will influence both noise spread and species density, and thus alter the amplitude of the noise impact (*e.g.* Reijnen *et al.*, 1997; Kuitunen *et al.*, 1998; Meunier *et al.*, 1999). If verges provide essential breeding habitats that are rare or missing in the surrounding landscape, species density along infrastructure may not necessarily be reduced, even though disturbance effects may reduce the environmental quality of these habitats (Laursen, 1981; Warner, 1992; Meunier *et al.*, 1999). Although strategic research regarding the disturbance thresholds of species in relation to infrastructure construction and operation is lacking, the species with the following attributes are considered to be most vulnerable to disturbance and development impacts (Hill *et al.*, 1997):

- large species;
- long-lived species;
- species with relatively low reproductive rates;
- habitat specialists;
- species living in open (*e.g.* wetland) rather than closed (*e.g.* forest) habitats;
- rare species;
- species using traditional sites; and
- species whose populations are concentrated in a few key areas (UK-SoA, 5.4.3).

3.3.4. Visual and other disturbance

The effects of traffic also include visual disturbance *e.g.* from artificial lighting or vehicle movement but these impacts do not generally receive as much attention as traffic noise or toxins. Artificial lighting has a conflicting effect on different species of fauna and flora: it can act as a valuable deterrent to deer and a readily accessible insect food supply to bats, but at the same time it can disrupt growth regulation in plants (Campbell, 1990; Spellerberg, 1998), breeding and behaviour patterns in birds (Lofts and Merton, 1968; Hill, 1992), bats (Rydell, 1992), nocturnal frogs (Buchanan, 1993), and moth populations (Frank, 1990; Svensson and Rydell, 1998). A study on the influence of road lights on a black-tailed godwit (*Limosa*

Box 3.1 - Studies on the effect of traffic noise on breeding birds

Between 1984 and 1991, the Institute for Forest and Nature Research in The Netherlands has carried out extensive studies of the effect of motorways and roads with traffic intensities between 5,000 and 60,000 vehicles a day on populations of breeding birds (Reijnen *et al.*, 1992; Reijnen, 1995). Two types of landscape, forest (Reijnen *et al.*, 1995a) and open grassland (Reijnen *et al.*, 1996) were compared. For 33 of the 45 forest species and 7 of 12 open grassland species, a road traffic effect was established and bird densities declined where the traffic noise exceeded 50 decibels (dbA). Birds in woodland reacted at noise levels of only 40 dbA. It was concluded that road traffic has an effect on the total density of all species and that there are clear indications that traffic noise is the main disturbing factor responsible for reduced densities of breeding birds near roads.

Based on the observed relationship between noise burden and bird densities, Reijnen, Veenbaas and Foppen (1995) proposed a simple model predicting the distance over which breeding bird populations might be affected by traffic noise (Figure 3.4). According to this model, roads with a traffic volume of 10,000 vehicles per day and a traffic speed of 120 km/h, passing through an area with 70% woodland, would significantly affect bird densities at distances between 40 and 1,500 m. When the model is applied to the entire area of The Netherlands, it suggests that at least 17% of bird habitats are affected by traffic noise (Reijnen *et al.*, 1995b).

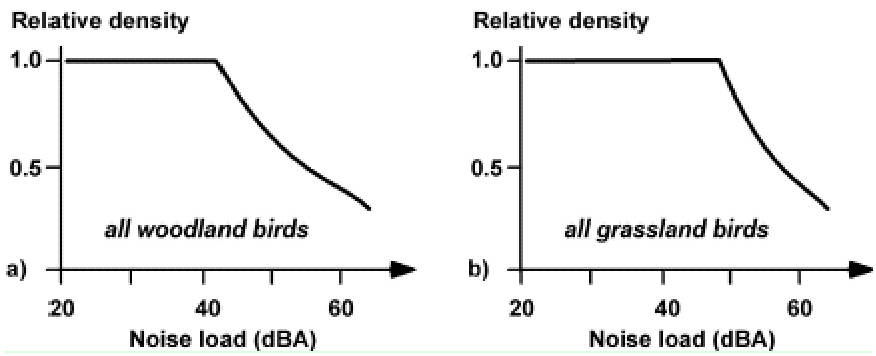

Figure 3.4 - Schematic representation of the impact of traffic noise on breeding bird populations in The Netherlands. When the noise load exceeds a threshold of between 40 and 50 dBA, bird densities may drop significantly. The sensitivity to noise and thus the threshold is different between species and between forest and open habitats. (From Reijnen, Veenbaas and Foppen, 1995)

Helldin and Seiler (2001) tested the predictions of Reijnen *et al.* (1995a) model for Swedish landscapes and found that the expected reduction in breeding bird densities could not be verified. On the contrary, some species even tended to increase in densities towards the road. It was concluded that the Dutch model might not be directly applicable in other countries and that habitat changes as a consequence of road construction under some circumstances could override the negative effects of traffic noise on the surroundings (S-SoA, 5.4.3).

limosa) population in The Netherlands, for example, indicated that the breeding density of this species was significantly reduced in a zone of 200 to 250 metres around the lights (De Molenaar *et al.*, 2000).

Certain types of road lights, such as white (mercury vapour) street lamps are especially attractive to insects, and therefore also to aerial-hawking bat species such as pipistrelles (*Pipistrellus pipistrellus*) (Rydell, 1992; Blake *et al.*, 1994). This increases the exposure of bats to traffic and may entail increased mortality due to collisions with vehicles. Furthermore, lit roads can constitute linear landscape elements, which bats may use to navigate in open areas (UK-SoA).

Species are negatively affected due to the artificial lighting upsetting their natural biological systems which are reliant on day length, and disturbing their spatial orientation and diurnal activity patterns. It is therefore possible that mitigation measures will also have conflicting effects on different species. From the studies that have been carried out, the following basic principles for reducing the impact of road lighting are suggested:

- Avoid lighting on roads crossing natural areas; and
- Use methods of lighting which are less alluring, especially for insects.

The movement of vehicles (probably in combination with noise) can also alter behaviour and induce stress reactions in wildlife. Madsen (1985), for instance, observed that geese foraging near roads in Denmark were more sensitive to human disturbance than when feeding elsewhere. Reijnen *et al.* (1995a) did not observe any effect of the visibility of moving cars on breeding birds, however, Kastdalen (*pers. comm.*) reported that moose (*Alces alces*) approaching a fauna passage under a motorway in Norway ran off as large trucks passed overhead. Heavy trucks and, more especially, high-speed trains produce intensive, but discontinous noise, vibration and visual disturbance which has the effect of frightening many mammals and birds. It is documented that many larger mammals avoid habitats in the vicinity of trafficked roads and railways (*e.g.* Klein, 1971; Rost and Bailey, 1979; Newmark *et al.*, 1996), but this avoidance results from many different interacting factors, amongst which noise and visual disturbance from vehicles comprise a small part.

3.3.5. Conclusions

Artificial lighting, traffic noise, chemical pollutants, microclimatic and hydrological changes, vibration and movement are just a few sources of disturbance that alter the habitats adjacent to infrastructure. In many situations, such disturbances are probably of marginal importance to wildlife, and many animals habituate quickly to constant disturbance (as long as they do not experience immediate danger). This does not imply, however, that disturbance should not be considered during the EIA process. On the contrary, because measures to mitigate against these types of disturbance are usually simple and inexpensive to install, they can easily be considered and integrated during the planning and design process. Many of the studies cited above were not specifically designed to directly investigate the disturbance effect of infrastructure, nor to inform the development of tools for impact evaluation or mitigation. However, to assess the width and intensity of the road-effect zone, research is needed that specifically addresses the issue of the spread of disturbance and the effect thresholds for individual species. Until there is a better understanding of such issues, the precautionary principle should be applied in all cases to prevent unnecessary negative effects.

3.4. Corridor function

Planted areas adjacent to infrastructure are highly disturbed environments, often hostile to many wildlife species, yet they can still provide attractive resources such as shelter, food or nesting sites, and facilitate the spread of species. In heavily exploited landscapes, infrastructure verges can provide valuable refuges for species that otherwise could not survive. Verges, varying in width from a few metres up to several tens of metres, are multipurpose areas, having to fulfil technical requirements such as providing free sight for drivers thus promoting road safety, and screening the road from the surrounding landscape. Typically, traffic safety requires that the vegetation adjacent to roads is kept open and grassy but farther away from the road, verges are often planted with trees and shrubs for aesthetic reasons, or to buffer the spread of salt and noise (Figure 3.5). Balancing technical and biological interests in the design and management of verges is a serious challenge to civil engineering and ecology. It offers a great opportunity for the transport sector to increase and protect biodiversity at large scale (Mader, 1987b; Van Bohemen *et al.*, 1991; Jedicke, 1994).

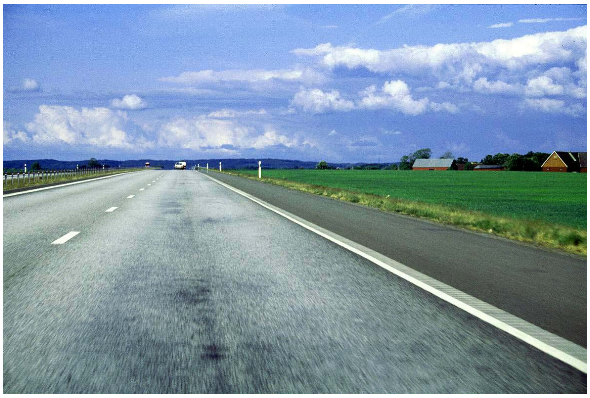

Figure 3.5 - Verges can vary considerably between different landscapes and countries. Left: A motorway in southern Sweden consisting only of an open ditch. Toxins and salt from the road surface can easily spread onto the adjacent agricultural field. Right: A highway in Germany. Densely planted shrubs and trees along roads provide potential nesting sites for birds and screen the road and its traffic from the surrounding landscape. (Photos by A. Seiler)

3.4.1. Verges as habitat for wildlife

Numerous inventories indicate the great potential of verges to support a diverse range of plant and animal species (*e.g.* Hansen and Jensen, 1972; Mader *et al.*, 1983; Van der Sluijs and Van Bohemen, 1991; Sjölund *et al.*, 1999). Way (1977) reported that verges in Great Britain supported 40 of the 200 native bird species, 20 of 50 mammalian, all 6 reptilian species, 5 of 6 amphibian, and 25 of the 60 butterfly species occurring in the country. In areas, where much of the native vegetation has been destroyed due to agriculture, forestry or urban development, verges can serve as a last resort for wildlife (Loney and Hobbs, 1991). Many plant and animal species in Europe that are associated with traditional (and now rare) grassland and pasture habitats, may find a refuge in the grassy verges along motorways and railways (Sayer and Schaefer, 1989; Melman and Verkaar, 1991; Ihse, 1995; Auestad *et al.*, 1999). Shrubs and trees can provide valuable nesting sites for birds and small mammals (Adams and Geis, 1973; Laursen, 1981; Havlin, 1987; Meunier *et al.*, 1999) and also offer food and shelter for larger species (Klein, 1971; Rost and Bailey, 1979).

Other elements of the infrastructure itself can also provide attractive, yet sometimes hazardous, habitat for wildlife. For instance, stone walls and drainage pipes under motorways in Catalonia, Northeast Spain, are often populated by lizards and common wall geckos (*Tarentola mauritanica*) (Rosell and Rivas, 1999). Cavities in the rocky embankments of railways may be used as shelter and breeding sites by lizards (Reck and Kaule, 1993) and bats may find secure resting sites underneath bridges (Keeley and Tuttle, 1999). However, caution needs to be given to the inherent hazards associated with these structures. In the UK, for example, drainage pipes are recognised as representing a significant mortality risk to reptiles (Tony Sangwine, *pers comm.*). Careful design, management and maintenance of these structures is required in order to minimise the potentially negative impacts on the wildlife utilizing them. The first objective should be to identify which engineering elements may be of benefit to which species, and the second to determine how this benefit can be maximised without compromising the primary function of the structure.

Many wildlife species can benefit from verges if they provide valuable resources that are rare or missing in the surrounding landscape. However, it is unlikely that these human-made habitats will develop the ecological value of comparable natural habitat types found some distance from the infrastructure. The composition of species found in transportation infrastructure verges is generally skewed towards a higher proportion of generalists and pioneers that can cope with high levels of disturbance (Hansen and Jensen, 1972; Adams and Geis, 1973; Niering and Goodwin, 1974; Douglass, 1977; Mader *et al.*, 1983; Blair, 1996). It is not surprising that species, which regularly visit road corridors to forage or nest, feature frequently in traffic mortality statistics (see Section 3.5). In this respect, infrastructure corridors may act as an ecological trap, outwardly offering favourable habitat conditions but with the hidden high risk of mortality. When designing and managing verges, it is therefore advisable to consider the risk of creating an ecological trap that may kill more species than it sustains.

3.4.2. Verges as movement corridors for wildlife

As well as providing a habitat for wildlife, verges may also serve as a conduit for species movement (active or passive) like ‘natural’ corridors in the landscape (see Section 2.4). In The Netherlands, bank voles (*Clethrinomys glareolus*) have colonised the Zuid-Beveland peninsula after moving along wooded verges of railways and motorways (Bekker and Mostert, 1998). Getz *et al.* (1978) documented that meadow voles (*Microtus pennsylvanicus*) dispersed over about 100 km in six years along grassy verges in Illinois, USA. Kolb (1984) and Trewhella and Harris (1990) observed that the movement of foxes (*Vulpes vulpes*) into the Edinburgh area of the UK was strongly influenced by the presence and direction of railway lines. Badgers living in the city of Trondheim, Norway, are known to use riverbanks and road verges to move within the city (Bevanger, *pers. comm.*). The actual surface of the infrastructure (mainly small roads with little traffic) may also be used as pathways by larger mammals. Vehicle and human movement along the infrastructure may also serve as a vector for plants, seeds or small, less mobile animals (Schmidt, 1989; Bennett, 1991). For instance, Wace (1977) found seeds of 259 plant species in the sludge of a car-washer in Canberra, Australia, some of which derived from habitats more than 100 km away. This accidental transport of seeds may offer an explanation for the high proportion of exotic and weed species found along verges (Mader *et al.*, 1983; Tyser and Worley, 1992; Ernst, 1998) that are considered a severe threat to native flora (Usher, 1988; Spellerberg, 1998).

It is clear that infrastructure verges can facilitate animal movement and enable the spread of plants and other sessile species. It may therefore seem feasible to integrate infrastructure corridors into the existing (natural) ecological network (Figure 2.6). However, several important characteristics distinguish verges from 'natural' corridors and may hamper a successful linkage between technical and ecological infrastructure (Mader 1978b; Mader *et al.*, 1990). Habitat conditions (particularly microclimatic and hydrological) vary considerably within verges and infrastructure networks have intersections where animals face a higher risk of traffic mortality than if they had travelled along another natural corridor in the landscape (Madsen *et al.*, 1998; Huijser *et al.*, 1998; 1999).

Also, the predation pressure within verges may be increased compared to the surrounding habitat, because carnivores are attracted to traffic casualties as a food source.

Thus, the overall corridor effect is ambiguous. Verges may provide valuable habitats for wildlife, but primarily for less demanding, generalist species that are tolerant of disturbance and pollution and are resilient to the increased mortality risk associated with the traffic. Verges can support wildlife movements, but also serve as a source of 'unwanted' or alien species spreading into the surrounding habitats. The overall corridor function of infrastructure verges will most likely be influenced by the ecological contrast between the vegetation/structure in the corridor and the surrounding habitat (Figure 3.6). To better understand this complexity and give practical advice to road planners, more empirical studies are needed.

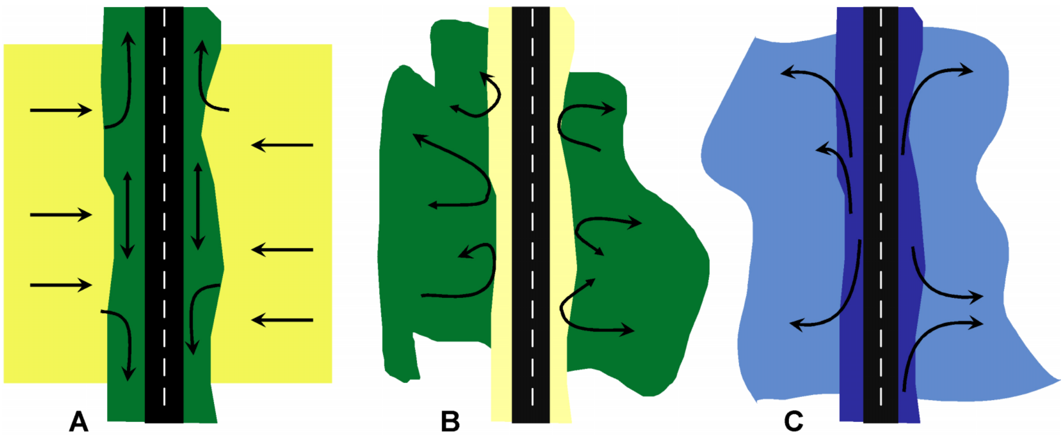

Figure 3.6 - The corridor function differs with respect to the surrounding landscape: A) Open, agricultural landscapes: richly vegetated verges can provide a valuable habitat for wildlife and facilitate movement. B) Forested landscapes: open and grassy verges introduce new edges and can increase the barrier effect on forest interior species. C) Verges may also serve as sources of species spreading into new habitats or re-colonising vacant areas. (Modified from Mader, 1987b)

3.5. Fauna casualties

3.5.1. The phenomenon

Road mortality is probably the most widely acknowledged effect of traffic on animals, as carcasses are a common sight along trafficked roads (Figure 3.7). The number of casualties appears to be constantly growing as traffic increases and infrastructure expands (Stoner 1925;

Trombulak and Frissell, 2000). Forman and Alexander (1998) concluded that ‘sometime during the last three decades, roads with vehicles probably overtook hunting as the leading direct human cause of vertebrate mortality on land’. The scale of the problem is illustrated by the numbers of known road kills.

Figure 3.7 - Wildlife casualties – a common view along roads and railways. (Photos by H. De Vries, B. Iuell and C. Rosell)

The quantity of road kills is such that collisions between vehicles and wildlife comprise a growing problem not only for species conservation and game management, but also for traffic safety, and the private and public economy (Harris and Gallagher, 1989; Hartwig, 1993; Romin and Bissonette, 1996; Putman, 1997). In most countries, traffic safety is the driving force behind mitigation efforts against fauna casualties (see Chapter 8) and although human fatalities are a relatively rare outcome in wildlife-vehicle collisions, the number of injured people and the total economic costs, including damage to vehicles, can be substantial. Police records in Europe (excluding Russia) suggest more than half a million ungulate-vehicle collisions per year, causing a minimum of 300 human fatalities, 30,000 injuries, and a material damage of more than 1 billion Euro (Groot Bruinderink and Hazebroek, 1996). From an animal welfare point of view, there is also concern about road casualties: many animals that are hit by vehicles are not immediately killed, but die later from injuries or shock. Hunters complain about the increasing work to hunt down injured game (Swedish Hunters Association, *pers. comm.*) and train drivers in northern Sweden complain about the unpleasant experience of colliding with groups of reindeer and moose (Åhren and Larsson, 1999).

3.5.2. Ecological significance of wildlife-traffic collisions

Evaluating the ecological importance of road mortality for a species involves considering the species’ population size and recruitment rate. Large numbers of casualties of one species may not necessarily imply a threat to the survival of that species, but rather indicate that it is abundant and widespread. For many common wildlife species, such as rodents, rabbits, foxes, sparrows, or blackbirds, traffic mortality is generally considered insignificant, accounting only for a small portion (less than 5%) of the total mortality (Haugen, 1944; Bergmann, 1974; Schmidley and Wilkins, 1977; Bennett, 1991; Rodts *et al.*, 1998; see also Table 5.7). Even for red deer (*Cervus elaphus*) , roe deer (*Capreolus capreolus*) or wild boar (*Sus scrofa*), traffic mortality generally accounts for less than 5% of the annual spring populations in Europe (Groot Bruinderink and Hazebroek, 1996). In contrast to natural predation, traffic mortality is non-compensatory, and the kill rate is independent of density. This implies that traffic will kill a constant proportion of a population and therefore affect rare species most significantly. In general, species that occur in small isolated populations, and those which require large extensive areas for their home ranges, or exert long migratory movements, are especially sensitive to road mortality. Indeed, for many endangered or rare species around the world, traffic is considered as one of the most important sources of mortality (Harris and Gallagher, 1989).

3.5.3. Factors that influence the occurrence of wildlife-traffic collisions

There are various factors that determine the risk of animal-vehicle collisions (Figure 3.8). The numbers of collisions generally increase with traffic intensity and animal activity and density. Temporal variations in traffic kills can be linked to biological factors which determine the species' activity *e.g.* the daily rhythm of foraging and resting, seasons for mating and breeding, dispersal of young, or seasonal migration between winter and summer habitats (Van Gelder, 1973; Bergmann, 1974; Göransson *et al.*, 1978; Aaris-Sorensen, 1995; Groot Bruinderink and Hazebroek, 1996). Changes in temperature, rainfall or snow cover can also influence the occurrence and timing of accidents (Jaren *et al.*, 1991; Belant, 1995; Gundersen and Andreassen, 1998).

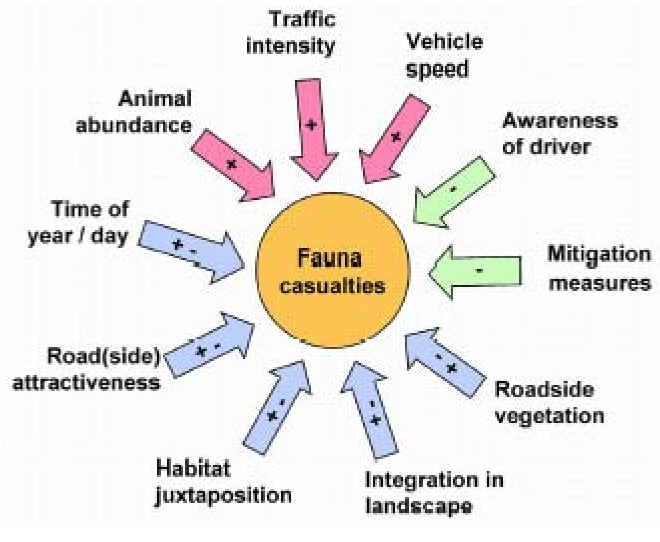

Figure 3.8 - Factors influencing the number of wildlife traffic accidents.

Roadkills seem to increase with traffic intensity to an optimum point, after which they level off. It seems that very high traffic volumes, noise and vehicle movements have the effect of deterring many animals, hence mortality rates do not increase further with higher traffic flows (Oxley *et al.*, 1974; Berthoud, 1987; Van der Zee *et al.*, 1992; Clarke *et al.*, 1998; see Figure

3.10). The occurrence of mitigation measures such as fences or passages and the programme of verge management clearly affects the local risk of accidents. The clearance of infrastructure verges of deciduous vegetation, for instance, has proven to reduce the number of moose (*Alces alces*) casualties in Scandinavia by between 20% and 50% (Lavsund and Sandegren, 1991; Jaren *et al.*, 1991). On the other hand, where verges provide attractive resources to wildlife, the risk of vehicle-animal collisions is likely to be increased (Feldhamer *et al.*, 1986; Steiof, 1996; Groot Bruinderink and Hazebroek, 1996).

Spatial pattern in road kills clearly depends on animal population density and biology, habitat distribution and landscape structure, but also on road and traffic characteristics (Puglisi *et al.*, 1974'; Ashley and Robinson, 1996, Finder *et al.*, 1999). In species with limited mobility and specific habitat requirements, such as many amphibians, it can be relatively simple to identify potential conflict areas. Most amphibian casualties occur during a short period in spring, when the animals migrate to and from their breeding ponds and are concentrated where roads dissect the migration routes (van Gelder, 1973). Roads that pass close to breeding ponds, wetlands and the animals' foraging habitats, are likely to cause a much greater kill rate than roads outside the species' migratory range *i.e.* about 1 km (see Vos and Chardon, 1998; Ashley and Robinson, 1996).

Other species, especially larger mammals, depend less on specific habitat types and utilise the landscape at a broader scale, which makes it more difficult to locate possible collision 'hotspots' (Madsen *et al.*, 1998). However, where favourable habitat patches coincide with infrastructure, or where roads intersect other linear structures in the landscape (*e.g.* hedgerows, watercourses, and other (minor) roads and railways), the risk of collisions is usually increased (Puglisi *et al.*, 1974; Feldhamer *et al.*, 1986; Kofler and Schulz, 1987; Putman, 1997; Gundersen *et al.*, 1998; Lode, 2000). For example, collisions with white-tailed deer (*Odocoileus virginianus*) in Illinois are associated with intersections between roads and riparian corridors, and public recreational land (Finder *et al.*, 1999). Traffic casualties amongst otters (*Lutra lutra*) are most likely to occur where roads cross over watercourses (Philcox *et al.*, 1999). Road-killed hedgehogs (*Erinaceus europaeus*) in The Netherlands are often found where roads intersect with railways (Huijser *et al.*, 1998). Also foxes and roe deer (*Capreolus capreolus*) in Denmark are more often found near intersections than elsewhere along roads (Madsen *et al.*, 1998).

The different factors influencing wildlife-traffic accidents must be fully understood before any local need for mitigation can be evaluated, and effective measures designed and constructed (Romin and Bissonette, 1996; Putman, 1997). GIS-based analysis of traffic kills and wildlife movements, in relation to roads and landscape features, may provide the necessary insight to enable predictive models for impact assessment and the localisation of mitigation measures to be developed and applied (Gundersen *et al.*, 1998; Finder *et al.*, 1999; see also Section 6.4).

3.6. Barrier effect

3.6.1. The components of the barrier effect

Of all the primary effects of infrastructure, the barrier effect contributes most to the overall fragmentation of habitat (Reck and Kaule, 1993; Forman and Alexander, 1998). Infrastructure barriers disrupt natural processes including plant dispersal and animal movements (Forman *et al.*, 1997). The barrier effect on wildlife results from a combination of disturbance and avoidance effects (*e.g.* traffic noise, vehicle movement, pollution, and human activity), physical hindrances, and traffic mortality that all reduce the number of movements across the infrastructure (Figure 3.9). The infrastructure surface, gutter, ditches, fences, and embankments may all present physical barriers that animals cannot pass. The clearance of the infrastructure corridor and the open verge character creates habitat conditions that are

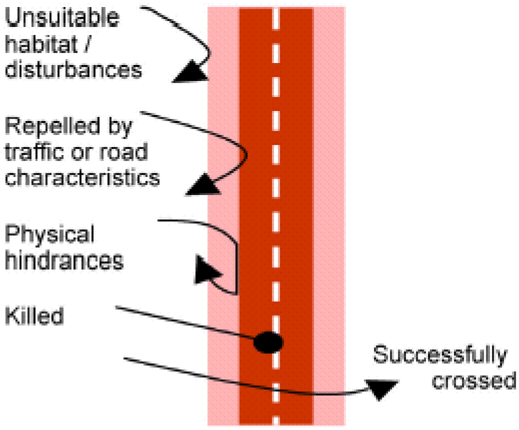

Figure 3.9 - The barrier effect of a road or railway results from a combination of disturbance/deterrent effects, mortality and physical hindrances. Depending on the species, the number of successful crossings is but a fraction of the number of attempted movements. Some species may not experience any physical or behavioural barrier, whereas others may not try to even approach the road corridor. To effectively mitigate the barrier effect, the relative importance of the inhibiting factors on individual species must be established.

unsuitable or hostile to many smaller species (see Section 3.3.1). Most infrastructure barriers do not completely block animal movements, but reduce the number of crossings significantly (Merriam *et al.*, 1989). The fundamental question is thus: how many successful crossings are needed to maintain habitat connectivity?

The barrier effect is a non-linear function of traffic intensity, which along with vehicle speed appear to have the strongest influence on the barrier effect. Infrastructure width, verge characteristics, the animals' behaviour and its sensitivity to habitat disturbances are also key factors (Figure 3.10). With increasing traffic density and higher vehicle speed, mortality rates usually increase until the deterrent effect of the traffic prevents more animals from getting killed (Oxley *et al.*, 1974; Berthoud, 1987; Kuhn, 1987; Van der Zee *et al.* 1992; Clarke *et al.* 1998). Exactly when this threshold in traffic density occurs is yet to be established but Müller and Berthoud (1997) propose five categories of infrastructure/traffic intensity with respect to the barrier impact on wildlife:

- Local access and service roads with very light traffic: can serve as partial filters to wildlife movements; may have a limited barrier impact on invertebrates and eventually deter small mammals from crossing the open space; larger wildlife may benefit from these roads as corridors or conduits.
- Railways and minor public roads with traffic below 1,000 vehicles per day: may cause incidental traffic mortality and exert a stronger barrier/avoidance effect on small species, but crossing movements still occur frequently.
- Intermediate link roads with up to 5,000 vehicles per day: may already represent a serious barrier to certain species; traffic noise and vehicle movement are likely to have a major deterrent effect on small mammals and some larger mammals meaning the

increase in the overall barrier impact is not proportional to the increase in traffic volume.

- Arterial roads with heavy traffic between 5,000 and 10,000 vehicles per day: represent a significant barrier to many terrestrial species, but due to the strong repellence effect of the traffic, the number of roadkills remains relatively constant over time; roadkills and traffic safety are two major issues in this category.
- Motorways and highways with traffic above 10,000 vehicles per day: impose an impermeable barrier to almost all wildlife species; dense traffic deters most species from approaching the road and kills those that still attempt to cross.

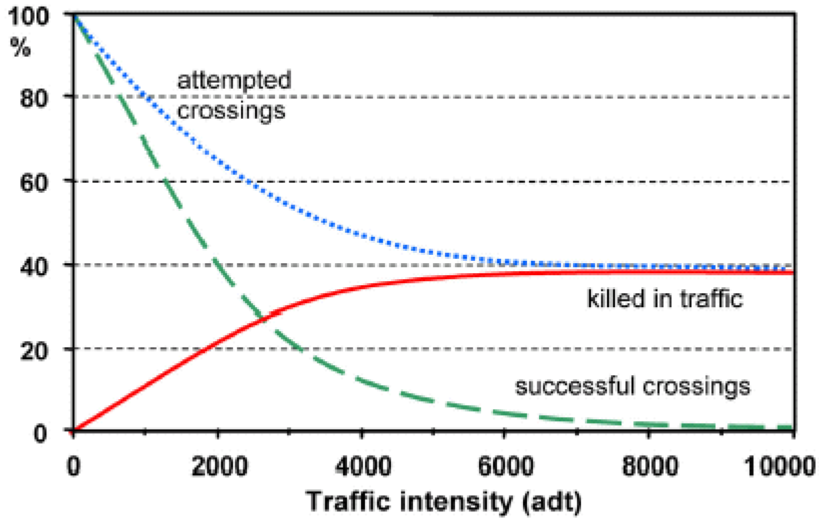

Figure 3.10 - Theoretical model illustrating the relationship between traffic intensity and the barrier effect: with increasing traffic, the number of roadkills increases in a linear fashion until noise and vehicle movements repel more animals from attempting to cross the road; at very high traffic volumes, the total mortality rate could decrease until the barrier effect reaches 100% i.e. preventing all crossings. (Redrawn from Müller and Berthoud, 1997)

3.6.2. Evidence from field studies

Transportation infrastructure inhibits the movement of practically all terrestrial animals, and many aquatic species: the significance of the barrier effect varies between species. Many invertebrates, for instance, respond significantly to differences in microclimate, substrate and the extent of openness between road surface and road verges: high temperatures, high light intensity and lack of shelter on the surface of paved roads have been seen to repel Lycosid spiders and Carabid beetles (Mader 1988; Mader *et al.*, 1990). Land snails may dry out or get run over while attempting to cross over a paved road (Baur and Baur, 1990). Also amphibians, reptiles, and small mammals may be sensitive to the openness of the road corridor, the road surface and traffic intensity (Joule and Cameron, 1974; Kozel and Fleharty, 1979; Mader and Pauritsch, 1981; Swihart and Slade, 1984; Merriam *et al.*, 1989; Clark *et al.*, 2001). Even birds can be reluctant to cross over wide and heavily trafficked roads (Van der Zande *et al.*, 1980). Semi-aquatic animals and migrating fish moving along watercourses are often be inhibited by bridges or culverts that are too narrow (Warren and Pardew, 1998).

Most empirical evidence for the barrier effect derives from capture-recapture experiments on small mammals. For example, Mader (1984) observed that a 6 m wide road with 250 vehicles/hour completely inhibited the movement of 121 marked yellow-necked mice (*Apodemus flavicollis*) and bank voles (*Clethrionomys glareolus*) (see Figure 3.11). Similarly, Richardson *et al.* (1997) found that mice and voles were reluctant to cross paved roads wider than 20-25 m although they did move along the road verge. Oxley *et al.* (1974) documented that white-footed mice (*Peromyscus leucopus*) would not cross over highway corridors wider than 30 m although they frequently crossed over smaller and only lightly trafficked forest roads.

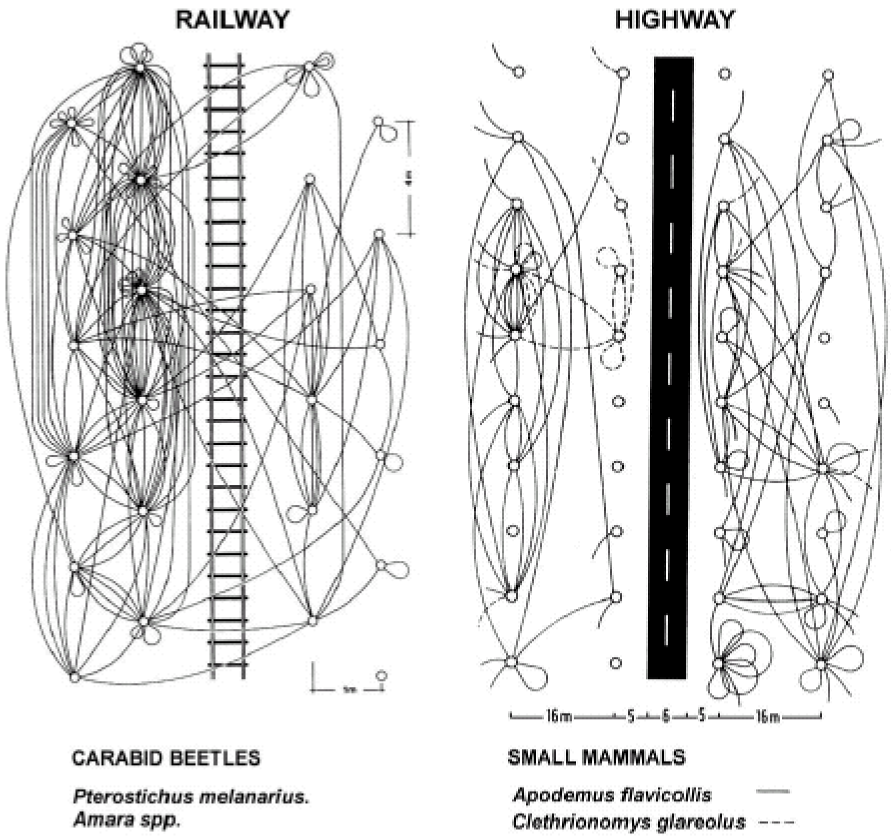

Figure 3.11 - Mobility diagram illustrating animal movements along and across a railway and road, based on capture-recapture data of: (left) carabid beetles (redrawn from Mader et al., 1990); and (right) small mammals. (Redrawn from Mader, 1984)

For larger animals, roads and railways do not represent a physical barrier, unless they are fenced or their traffic intensity is too high. Most mammals, however, are sensitive to disturbance by humans and scent, noise and vehicle movement may deter animals from approaching the infrastructure corridor. For example, Klein (1971) and Curatolo and Murphy (1986) observed a strong avoidance of roads by feral reindeer (but not by domestic reindeer) and Rost and Bailey (1979) reported that mule deer (*Odocoileus hemionus*) and elk (*Cervus canadensis*) avoided habitats closer than around 100 m to trafficked roads.

However, to what extent this avoidance effect reduces the number of successful or attempted movements across roads is not clear. More data is required on the actual movements (spatial and temporal) of larger mammals in relation to infrastructure in order to judge the inhibitory effect of roads and traffic.

3.6.3. Consequences at a population level

When do infrastructure barriers really become a problem for wildlife conservation? How much permeability is needed to maintain sufficient habitat connectivity? How large a barrier effect can be tolerated by individual species and populations? To answer these questions, the consequences at population level must be considered. Depending on the number of successful crossings relative to the size of the population, the barrier effect can be significant to population dynamics, demographic or genetic properties. If the species does not experience a significant barrier effect and individuals still move frequently across the road, the dissected populations will continue to function as one unit. If the exchange of individuals is reduced but not completely inhibited, the populations may diverge in demographic characters, *e.g.* in terms of density, sex ratio, recruitment and mortality rate. Also genetic differences may emerge, as the chance for mating with individuals from the other side of the infrastructure barrier may be reduced. These changes may not necessarily pose a threat to the dissected populations; except for sink populations dependent on steady immigration for continued survival (see Section 2.3). If the barrier effect is even stronger, the risk of inbreeding effects and local extinctions will increase rapidly.

Evidence of the effect on population genetics derives from studies on rodents and amphibians. For example, Reh and Seitz (1990) observed effects of inbreeding, in the form of reduced genetic diversity, in small populations of the common frog (*Rana temporaria*) that were isolated by roads over many years. Merriam *et al.* (1989) found indications of genetic divergence in small-mammal populations separated by minor roads. However, populations dissected by one single barrier may not automatically suffer from inbreeding depression, unless they are critically small or do not have contact with other more distant populations in the landscape. To evaluate the consequences of a new infrastructure barrier, the combined isolation effects of all the existing surrounding infrastructure and other natural and artificial barriers must be considered. The denser the infrastructure network and the more intense its traffic, the more likely it will cause significant isolation of local populations. By definition, small isolated populations (particularly of rare and endemic species) are more sensitive to barrier effects and isolation than populations of abundant and widespread species. Species with large area requirements and wide individual home ranges will more frequently need to cross over road barriers than smaller and less mobile species.

It is the combination of population size, mobility, and the individuals' area requirements that determines a species' sensitivity to the barrier impact of infrastructure (Verkaar and Bekker, 1991). A careful choice between alternative routes for new infrastructure may thus help to prevent the dissection of local populations of small species, but cannot reduce the barrier effect for larger, wide roaming species. In most cases, technical/physical measures, such as fauna passages or ecoducts, will be required to mitigate against barrier impacts and re-establish habitat connectivity across the infrastructure.

3.7. Fragmentation

The previous discussions show that the total impact of roads and railways on wildlife cannot be evaluated without considering a broader landscape context. Roads and railways are always part of a wider network, where synergetic effects with other infrastructure links occur, which cause additional habitat loss and isolation. Studies on the cumulative effects of fragmentation caused by transportation infrastructure must address larger areas and cover longer time periods than studies that simply address the primary effects of a single road or railway link.

Evaluating the degree of fragmentation due to infrastructure is not a simple task. The significance of fragmentation is highly species-specific and dependent on the amplitude of barrier and disturbance effects, the diversity and juxtaposition of habitats within the landscape, and the size of the unfragmented areas between infrastructure links (*i.e.* the density of infrastructure). Forman *et al.* (1997) suggested the use of infrastructure density as a simple but straightforward measure of fragmentation (Figure 3.12). This measure could be improved by adding information on traffic density, speed, infrastructure width and design.

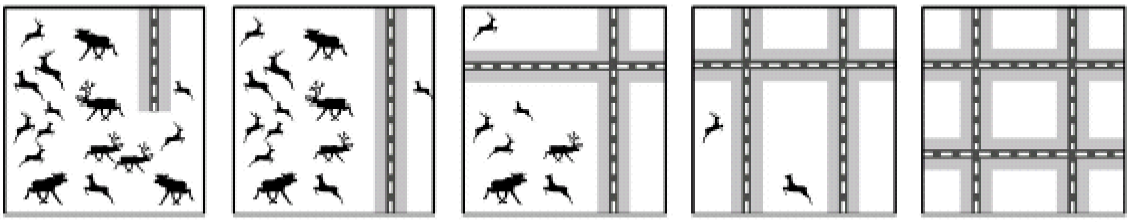

Figure 3.12 - Infrastructure causes a loss and degradation of habitat due to disturbance effects (grey corridors) and isolation. With increasing infrastructure density, areas of undisturbed habitat (white) are reduced in size and become inaccessible. Remnant fragments of suitable habitat may eventually become too small and isolated to prevent local populations from going extinct. The critical threshold in road density is species-specific, but will also depend on landscape and infrastructure characteristics.

Several studies have described critical thresholds in road density for the occurrence of wildlife species in the landscape. For example, Mladenoff *et al.* (1999) observed that wolves and mountain lions did not sustain viable populations in regions of Minnesota, USA with road densities above 0.6 km/km^2 (Thiel, 1985; Van Dyke *et al.*, 1986). Also, the presence of other large mammals in the USA such as elk, moose and grizzly bear, appears to be negatively influenced as road densities increase (Holbrook and Vaughan, 1985; Forman *et al.*, 1997).

The observed fragmentation effect may however not be associated with the direct impact of infrastructure and traffic, but rather with the increased access to wildlife areas that roads in particular (especially forest roads) offer hunters and poachers (Holbrook and Vaughan, 1985; Gratson and Whitman, 2000). In Europe, areas remote from roads or with only low road density, low traffic volumes, and a high proportion of natural vegetation, are considered as core areas in the ecological network (*e.g.* Jongman, 1994; Bennett, 1997). Determining how much undeveloped habitat is needed and how large the infrastructure-free landscape fragments need to be to ensure a given species survival is a task for future research. Clearly, the best option to counteract the fragmentation process is the reclamation of nature areas for wildlife through the removal of roads, or by permanent or temporary road closure. Road closure helps to reduce motorised access to wildlife habitat and enlarges undisturbed core areas, yet the physical barrier and its edge effects still remain. The physical removal of roads is the ultimate solution. In some countries, such as on federal land in the USA, attempts are being made to integrate road removal as a part of the Grizzly Bear Conservation Program (see Evink *et al.*, 1999; Wildlands CPR, 2001). To ensure the survival of grizzlies in the core areas of their distribution, it has been suggested to establish road-free habitats of at least 70% of the size of an average female home range. In regions designated for grizzly bear conservation and where road densities are higher than that required for the secure habitats, it is recommended that roads should consequently be removed.

In Europe, temporary closure of (local) roads is an action primarily applied in order to maximise the protection of seasonally migrating amphibians (Dehlinger, 1994). Applying speed limits on local roads can also offer a simple tool for changing traffic flows and reducing disturbance and mortality impacts in wildlife areas. In situations where roads cannot be removed or closed, or traffic reduced, technical mitigation measures such as fauna passages and ecoducts may be necessary to minimise fragmentation and reconnect wildlife habitats (*e.g.* DWW, 1995).

3.8. Summary

In this chapter some of the major literature on the ecological effects of infrastructure has been reviewed. There is a growing concern about habitat fragmentation caused by roads and railways all around the world. The increasing demand for avoidance and mitigation makes it clear that there is still much to be understood before the cumulative potential impacts can be assessed in an efficient and practical way. A considerable amount of research has been carried out already, yet many of the studies are descriptive, dealing with problems of individual roads or railways, but without considering the more strategic issues integral in the planning of ecologically friendly infrastructure.

How much habitat is actually lost due to construction and disturbance effects of infrastructure? How wide is the impact zone along roads and how does the width of this zone change with traffic intensity and type of surrounding habitat? How can transportation infrastructure be integrated into the 'ecological' infrastructure in the landscape without causing an increase in the risk of animal-vehicle collisions? Where and when are mitigation measures against road wildlife mortality necessary or affordable? How much infrastructure is too much in areas designated for wildlife? What are the ecological thresholds that must not be surpassed and how can the best use be made of the potential in a road or railway project to improve the current situation?

Finding answers to these questions is a challenge to landscape ecologists, biologists and civil engineers alike (Forman, 1998; Cuperus *et al.*, 1999). To develop effective guidelines and tools for the planning of infrastructure, research needs to be focussed on ecological processes and patterns, using experiments and simulation models to identify critical impact thresholds. Empirical studies are necessary to provide the basic data that will help to define evaluation criteria and indices. Remotely sensed landscape data, GIS-techniques, and simulation models offer promising tools for future large-scale research (see Section 6.4), but they must rely on empirical field studies at local scales. Clearly, a better understanding of the large-scale long-term impact of fragmentation on the landscape is required, yet the solution to the problems will more likely be found at a local scale. Richard T.T. Forman, a pioneer in landscape and road ecology at Harvard University, Massachusetts, put it simply: We must learn to 'think globally, plan regionally but act locally' (*sensu* Forman, 1995).

Chapter 4. National context

4.1. Introduction

Norway comprises the western portion of the Scandinavian Peninsula sharing a long border with Sweden in the east and shorter borders with Finland and Russia in the north. The land area of Norway is 323,752 km^2 excluding the islands comprising Svalbard and Jan Mayen. The population of Norway is 4.419 million (SSB 1999). In 1900 only about 35% of the then ca. 2M population lived in urban areas, whereas in 1999 around 75% (3.2 million) of the population live in towns or other settlements. In 1997 there were 889 built areas with more than 200 inhabitants. Of these, only Oslo, Bergen, Trondheim and Stavanger had more than 100,000 inhabitants, and together these towns house nearly a third of the Norwegian population. The population is very unevenly spread with the highest concentrations around Oslofjord and the major coastal towns. For example, in the county of Akershus around Oslofjord more than 86% of the population are urban, whereas in the inland forested county of Hedmark the figure is only 49% (SSB 1999). The trend towards urbanisation of the Norwegian population continues, even though the impact of urbanisation is relatively low on compared with most of Europe with a total land cover of urban areas of only 0.7%. The growth of urban populations is increasing pressures on the existing transport infrastructure. Urban development also constitutes a significant barrier to the movement of wildlife and increase habitat fragmentation. The major transport systems in Norway follow the coast and the major valley systems crossing mountain plateaux.

There has been a dramatic increase in the volume of traffic in Norway since 1950 with 150,579 motor vehicles (all types) to 2,986,381 in 1993. Private cars increased from 65,000 in 1950 to 1,633,088 in 1993. However, the rate of increase has slowed in recent years. Road development in Norway has followed this development reaching a plateau in the 1990s (Tables 4.1 and 4.2).

Table 4.1. - The extent of linear transport infrastructure networks in Norway (Source: Norwegian Public Roads Administration 1999)

	Roads	**Railways**	**forest/farm roads**
Total Norway	91 254 km	4 000 km	88 000+ km

The national figures for road density and traffic volume hide large regional variations. There are also large seasonal variations of traffic volume to coastal and mountain resort areas which can increase the fragmentation impact of roads during these periods. The areas around Oslofjord in SE Norway and around the cities Trondheim, Bergen and Stavanger, are the most developed parts of Norway with the most intensive road networks and highest traffic densities (see Figure 4.1). The county of Vestfold in south-east Norway is a relatively small county with major road systems and a dense population resulting in a relatively high density of major roads, while the inland areas of Finmark county, have the least intensive road network. Sogn og Fjordane county has a relatively low population density but several long fjords forcing roads to follow coastal routes. This has resulted to a relatively high density of roads pr. inhabitant.

Table 4.2. - Road length and density in Norway 1950-98 (Source: SSB 1999)

Year	Km road total	Meter road pr vehicle	Meter road pr km2
1930	37443	716	116
1935	39237	551	121
1940	42598	416	132
1945	43980	452	136
1950	44673	309	138
1955	47388	170	146
1960	51233	97	158
1965	65737	80	203
1970	72262	65	223
1975	77101	58	238
1980	81717	48	252
1985	85882	40	265
1990	88922	38	275
1995	90262	36	279
1998	90741	34	280

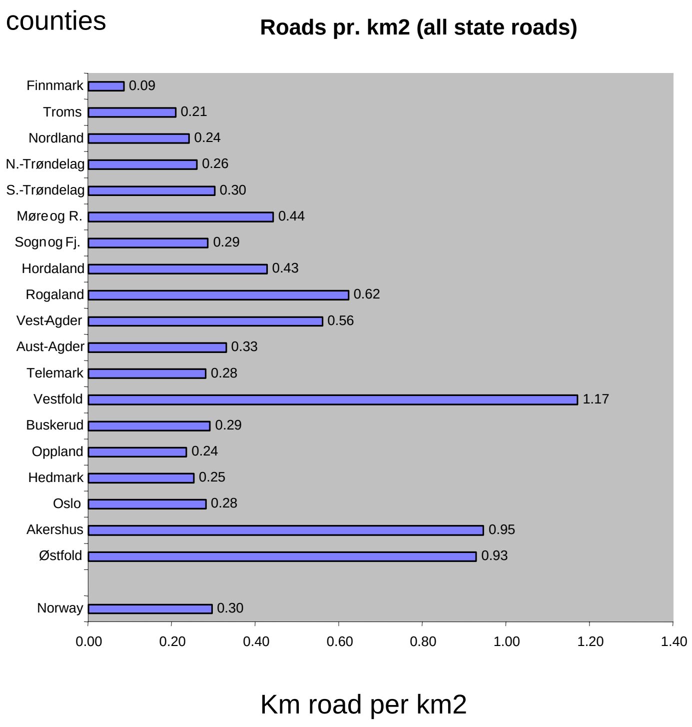

Figure 4.1. - The regional variation (by county) in road density. The average for the nation is ca. 0.30 km road pr. km2. (Source: National Road Database, Statens Vegvesen, 1999).

The regional variations in the density of the road network are a reflection of historical trends in demography related to the physical conditions and resource availability for industry, agricultural, forestry and fishery production that have affected the development of transport networks. The rugged topography and deeply indented coastline limited the development of transport networks in outlying districts until advances in engineering combined with high national wealth permitted extensive bridge and tunnel projects.

More and more of the transport of domestic goods are carried out on the road net during the last decades (Table 4.3.).

Table 4.3. - Domestic goods transport in Norway, by mode of transport. 1965 - 1999 (Source: Estimates made by Institute of Transport Economics and Statistics Norway.)

Mode of transport	**1965**	**1970**	**1975**	**1980**	**1985**	**1990**	**1995**	**1997**	**1998**	**1999**
Million tons carried										
Total	**181**	**226**	**270**	**282**	**295**	**339**	**356**	**421**	**437**	**447**
Railway	8	7	8	9	9	7	5	5	6	6
Road	138	170	204	210	216	231	223	261	265	265
Million ton-kilometres										
Total	**11 107**	**14 984**	**16 014**	**17 109**	**20 328**	**26 589**	**33 039**	**44 007**	**46 116**	**49 245**
Railway	1 160	1 448	1 508	1 657	1 771	1 632	1 647	1 949	1 934	1 817
Road	2 183	3 194	4 569	5 252	6 485	8 231	9 654	11 838	12 636	12 796

4.2. Biogeographical description

4.2.1. Geography & geology

Norway has two main environmental gradients, north-south and east-west. There is a north-south axis representing a longitudinal climatic gradient from 57˚ 58' to 71˚ 7' north, although the effects are moderated by the gulf stream. The east-west gradient has a strong impact on climate. In the west the climate is oceanic zone with high annual rainfall (up to 4000 mm rain per year), cool summers and mild, wet winters. Inland and eastern Norway has a more continental dryer climate (3-500 mm rain per year) with warm summers and cold winters. Large topographic variation, often within a short distance, between the coast or valley floor and mountain plateau produces further gradients. Thus, local climate and vegetation are dependent on latitude, terrain, height above sea level and distance from the coast.

Norway is situated on the margin of the Eurasiatic continent. The bedrock consists mainly of Precambrian granites and gneisses as well as Palaeozic rocks of mostly sedimentary origin. The dominance of hard and crystaline rocks limit the richness of soils and vegetation and render large areas vulnerable to soil and surface water acidification. The country experienced a significant land upheaval during the Tertiary, which gave birth to a predominant hilly and mountainous landscape that experienced significant changes during the Quaternary. Several ice ages have left a heritage of classical glacial landscape forms at all scales. The fjords are perhaps the best known tourist feature of this landscape. Other typical glacial features are the

U-shaped glacial valleys, fjord lakes, abundance of large lakes, alpine features, and coastal flats with a well developed scerry landscape (Figure 4.2.).




Figure 4.2. - Different Norwegian landscapes. From upper left; the flat south eastern parts, the fjords in the west, the alpine areas and the valleys. (Photos: B. Iuell.)

Surface deposits are generally patchy or absent in Norway, although they can locally dominate the landscape. These are mostly related to ice-margin features. A continuous till cover is found in the eastern part of Finnmark (the northernmost county of Norway) and the eastern part of central south Norway. Due to upheaval of the land after the last glaciation, marine clays, known for their unstable nature (quick clay), are found in some low-lying areas especially around the cities of Oslo and Trondheim.

These landform and bedrock characteristics have had a major influence on human settlement and infrastructure. Norway's geology has also created a number of natural barriers which have affected the distributions of plant and animal species. At a biogeographical scale, Norway´s location and topography have hindered the colonisation of species westward after the last ice age. For example, some forest trees are confined to coastal or eastern regions, e.g. Norwegian spruce (*Picea abies*). Freshwater fish have been slow to re-colonise northwards and eastwards into Norway partly because the barrier of salt water of the Baltic hindered dispersal and partly because of the rugged river systems of Norway which lack major eat-west waterways.

Apart from the mountain ranges which act as barriers to plant and animal dispersal, there are many deep fjords that dissect upland plateaux for more than 200 km inland. As a result, the linear distance between north and south Norway is only 1,750 km but the indented coastline is 2,650 km long. If we include islands and fjords, there is more than 57,000 km of coastline.

Norway has many freshwater lakes of which 455,000 are registered on 1:50,000 scale maps. Almost 400 of these lakes has a surface area of more than 5 km^2. In total, lakes comprise ca. 5% of mainland Norway.

Norway is a mountainous country with ca. 60% of the mainland situated above the timberline, which varies between ca. 1000 m above sea level in the south, to about sea level in the north. The highest mountain is Galdhøpiggen at 2,469 m a.s.l.

4.2.2. Protected areas in Norway

Norway is fortunate in possessing relatively large areas of almost untouched wilderness, even though most, if not all, show some evidence of cultural influences and use. These mountain areas, coastal cliffs, mires, wetlands and forests are of great importance for biodiversity.

In addition to possessing large areas of semi-natural habitat, Norway has also a large resource of cultural landscapes shaped by a long history of use. These areas are often in marginal farming areas and rich in traditional hay meadows and wooded pastures as well as heather (*Calluna vulgaris*) heaths in the west.

Table 4.5. - Protected areas, classes and sizes. Areas protected in accordance with the Nature Conservation Act as of 1 January 1998 (Source: Direktoratet for Naturforvaltning, 2000)

	Number	**Area (km^2)**	**Percentage of Norway[1)]**
National parks	18	13 788	4.26
Nature reserves	1318	2 413	0.75
Protected landscape areas	86	5 059	1.56
Natural monuments	88[2)]	2	0.00
Other protected areas[3)]	76	110	0.03
Total	1586	21372	6.60

[1)] Excluding Svalbard

[2)] 86 of these natural monuments are geological. In addition, approximately 180 trees or groups of trees are protected as botanical natural monuments.

[3)] Concerns areas where plants, birds or animals are protected along with their biotope. At some other localities, species have been protected without their biotope being protected.

Many of the remaining patches of natural and cultural biotopes in Norway are small remnants of once larger contiguous blocks. These remaining patches are becoming increasingly smaller and more isolated and increasingly suffer the problems associated with fragmentation including loss of undisturbed core areas and critically small population sizes of habitat specialists.

The wide range of natural and semi-natural habitats in Norway has provided a rich biological resource. However, despite extensive conservation efforts and several success stories, there have also been serious losses of important biotopes during the last fifty years. Especially threatened are the remaining large continuous areas of natural mountain plateau, stands of ancient coniferous forest, wetlands, cultural landscapes, unregulated river ecosystems and coastal habitats. Approximately 6.4% of the mainland is protected today (Table 4.5.), but current plans for National Parks and county conservation plans aim at extending the area to ca. 13%. According to IUCN, countries should aim at a level of protection that would secure approximately 10% of all major biotopes. Norway will achieve this for mountain areas once the current national park plan is complete. However, some land classes are under-represented in the current plans, especially lowland productive areas that are biologically rich, yet face some of the greatest land use conflicts.

Of the 14,637 species recorded in Norway, 3,062 are «Red list» species, although both invertebrates and lower plants require much further work to ascertain their status. About 103 species are known to have become extinct in Norway during the last 50 years, and 292 species are endangered. In addition, there are a further 4 levels of red list species; namely, those which are vulnerable because of on-going threats causing decline, those species which are rare, those in rapid decline but not yet directly threatened, and those species whose status requires monitoring. Norway's biogeographic position at the transition between the Atlantic and more continental regions has resulted in many plants and animals reaching their longitudinal or latitudinal limits here.

4.2.3. Cultural landscapes

The geological and climatic conditions in Norway have limited the development of agriculture, and the percentage of agricultural land is very low. Continuous areas of farmland are small, and the average farm is only about 14 hectares in size. Grass for pasture and fodder is the most important crop taking 55% of the cultivated area, with cereals next with 35%, and the remainder comprising various fodder crops, potatoes and vegetables. Dairy farming is important, but herd sizes are relatively small. Agricultural policy has concentrated cereal production in the best agricultural areas of south and central Norway, and livestock production in the north and west. On the most productive farmland, intensification has led to a uniform agricultural landscape, with larger cereal monocultures and fewer small biotopes. Together with the growing use of chemical inputs, these land use trends have reduced biological diversity. A further pressure on the cultural landscape is that settlements are concentrated on or near the small areas of arable agricultural land, increasing the disturbance and fragmentation pressures on remaining areas.

Areas that have had a long continuity of management by traditional farming practices, such as pastures, species-rich hay meadows, maintain summer farms and coastal heaths are all habitats of special interest for their biodiversity, cultural and aesthetic interests. They occur mostly in areas of marginal farming land. Such areas are undergoing rapid changes due to abandonment of farming and replacement by secondary forest either through planting or natural regeneration. Farming marginal land, especially in outlying districts is still declining rapidly, with about half of the 155,000 farms in use in 1969 abandoned by 1999, leaving just 75,000 farms. Small farms are abandoned first (<5 ha) from 32,000 in 1989 to 16,000 in 1999. This resulted in an increase in the average size of farm from 10 ha in 1989 to 14.5 ha in 1999. (SSB 2000). Semi-natural hay meadows accounted for more than 10 % of the total agricultural area in 1959, by 1989 this had dropped to less than 5 % over large parts of the country and to less 0.5 % in certain areas. The remaining meadows are fragmented remnants of former extensive meadow systems and vulnerable to further loss or barrier effects caused by infrastructure development. The dispersal of meadow flora and associated insect fauna is a conservation priority.

More than 300 species in the cultural landscape are considered endangered or vulnerable, while at least 600 species require special consideration because we lack sufficient knowledge to assess their status. About 3% of Norwegian plant species and about 10% of bird species are considered threatened by changes in the agricultural landscape. About a quarter of the red listed higher plants registered in Norway are found in cultural landscapes such as meadows, pastures and heaths.

4.2.4. Forest

Norwegian forests are an important part of the boreal coniferous forest belt around the Northern Hemisphere. The wide variation in climate and habitats, provide Norway with many different forest communities with several types of forest not found elsewhere in Europe such as the extensive sub-alpine birch forests and the west-coast wet conifer forests. Forests are, therefore very important for the conservation of biological diversity. About half of the species of plants and animals registered in Norway and half of the Norwegian endangered and rare species are associated with forest.

More than 37% of mainland Norway is forested and half of this is used for commercial forestry. Norwegian forests have been commercially harvested for several hundred years, very intensively at times, resulting in an overexploitation of forest resources in the 19th century. During the last 70 years, improvements in management have resulted in a significant increase in the amount and quality of timber production. However, threats including the long-range transport of pollutants (e.g. acid rain), industrial development, hydro-power installations etc. have led to a reduction of forest area in some parts of the country. The area of virgin forest has declined to less than 0.5% of the total forested area yet less than 1% of the productive forest area is protected. Remaining areas of old forest are especially vulnerable to fragmentation by transport infrastructure and changes in forest management. Only 68 areas of forest larger than 10 km^2 and unaffected by infrastructure development have been registered.

Fifty alien tree species have been planted, but only a few species are used commercially. The most important of these introduced tree species are sitka spruce (*Picea sitchensis*) and lodge pole pine (*Pinus contorta*). There is considerable concern over the ecological impacts of introducing alien tree species and extending the range of the native Norway spruce. If these trees spread naturally they can constitute a severe threat to the integrity of Norwegian forests and result in major ecological change. Several on-going surveys aim at identifying the distribution of introduced species and their effects on forest ecosystems. A further concern is the extensive network of forest roads which has developed during the past 50 years. This network of small roads is greater in length than the state roads system and of special importance as they intrude deep into otherwise undisturbed areas of forest and along remote mountain valleys. The effects of this infrastructure are unknown.

4.2.5. Inland waters

Untouched rivers and river ecosystems in Europe are restricted to the few examples still to be found in the Nordic countries and northern Russia. Norway has the greatest range in terms of biological diversity, size and type of river system. This diversity includes 455,000 lakes of which 400 are larger than 5 km^2, 9 of the 20 highest waterfalls in the world and the four deepest lakes in Europe (Hornindalsvatn 514 m, Salsvatn 464 m, Tinnsjø 460 m, and Mjøsa 449m).

At least 5000 species of plant and animal including more than 100 red list species are associated with freshwater habitats in Norway. The rich river ecosystems have made it possible for a wide range of bird species to establish thriving populations. Approximately 70 of Norway's 250 breeding species of birds are dependent on inland waters and wetlands. Of these, 25 species are considered endangered or declining. Some of these bird species are particularly vulnerable to shoreline development including transport infrastructure.

Norway has 41 species of freshwater fish although most are restricted to the south east of the country and are prevented from spreading westward by high mountain ranges dividing the major river catchment systems. Stocks of migratory salmonid fishes have been registered in 1222 rivers in Norway, of these, 669 are salmon (*Salmo salar*) rivers. Sea trout (*Salmo trutta*) is the most widespread of salmonid species and is found in 1185 rivers. The sea char (*Selvelinus alpinus*) occurs in 147 rivers.

Norway is the only country in the world where Atlantic salmon, sea char and sea trout occur in the same river system. Norway and Iceland have the largest remaining stocks of wild salmon in Europe, but many of these are in a precarious state. The ranges of many fish species, especially trout (*Salmo trutta*) have been expanded by deliberate introductions for sport interest. In contrast, stocks of trout and salmon have been drastically reduced in the south west due to acidification by long-range transport of pollutants. Acidification has had serious negative impacts on biological diversity in inland waters, with approximately 2500 fish stocks lost in southern Norway. Current rates of sulphur and nitrogen deposition exceed critical loads for ca. 25% of Norway. Since 1988, the sulphur content of precipitation has been declining with the result that the pollution reaching rivers and lakes in southern Norway has dropped by about 35%. There are clear signs of recovery of the flora and fauna in lakes and rivers because of this improvement. However, deposition levels of nitrogen have not been reduced.

River valleys have been important for transport for thousands of years and remain the major transport arteries from east-west and north-south. This results in a significant pressure on land use along valleys from the competing interests of housing, agriculture, industry, and infrastructure. Road development often has a negative impact on rivers both directly or through disturbance and fragmenting of riparian habitats.

4.2.6. Mires and wetlands

Mires account for a large proportion of Norwegian wetlands, and 10% of the total land area. Compared with most other countries, Norway has a very wide range of mire types, from extremely nutrient-poor to extremely nutrient-rich.

River deltas are an example of a heavily exploited habitat along the coast. They have for instance been used for industry, housing, roads and agriculture. In Western and Central Norway, 86 % of the total area of land formerly covered by 15 river deltas has been used for infrastructure development or agriculture. The remaining areas are highly vulnerable to further development and fragmentation. Therefore, most river deltas and mud flats qualify as high priority habitats for nature conservation.

Mires, forested mires and swamp forests account for 16.4 % of forested areas under the coniferous timber line. The major threat to mires has been drainage that alters the habitat conditions necessary for rare plants, juvenile and adult fish, amphibians, reptiles, and the breeding and staging areas for many bird species. Vulnerable bird species that breed on mires include the common crane (*Grus grus*), broad-billed sandpiper (*Limicola falcinellus*) and great snipe (*Gallinago media*).

4.2.7. Mountains

Mountains cover about half the mainland area of Norway. Together with the Norwegian Arctic and the northern parts of Sweden, Finland and Russia, they are the last remaining large areas of wilderness in Europe. The Dovre mountains in Oppland and Sør-Trøndelag counties are the only intact mountain ecosystem in Europe west of the Urals where indigenous populations of wild reindeer (*Rangifer tarandus*), Arctic fox (*Alopex lagopus*) and wolverine (*Gulo gulo*) still occur together. In addition, the Musk Ox (*Ovibos moschatus*) has been successfully re-introduced. All these species are all vulnerable to disturbance and habitat fragmentation, especially reindeer.

4.2.8. Marine and coastal ecosystems

Marine areas under Norwegian jurisdiction include both coastal waters and shallow and deep areas of open sea. The North Sea and the Barents Sea are shallow seas which are highly productive as a result of circulation patterns and their nutrient content. They are important nursery areas for a number of commercially-important fish stocks, and also very important feeding grounds for marine mammals and seabirds.

Norway's coastal waters with their naturally productive marine areas provide unique opportunities for harvesting seafood. Fish and fish processing have, therefore, been of fundamental importance for the historical development of settlement patterns and human activity along the Norwegian coast. In recent years, aquaculture (mainly salmon and rainbow trout) has emerged as a new industry with a strong impact on settlement patterns and commercial activity in the coastal zone, including new transport infrastructure to service these industries.

Infrastructure development poses major fragmentation threats to coastal areas since major trunk roads follow coastal routes and access roads for housing, industry and to popular tourist areas are increasing.

4.2.9. Threats to habitats and species

Land use change

The extent of land use change in Norway ranges from major physical alterations that eliminate all biological production, to relatively minor changes in environmental conditions which cause the loss of some species or the establishment of others. The fragmentation of large, almost untouched areas clearly affects animals that range over large areas, such as wild reindeer and large predators, but also alters conditions for other species. Many specialist species are associated with long-established ecosystems such as virgin forest or traditional semi-natural ecosystems (e.g. hay meadows, coastal heaths and pasture) and vulnerable to even small changes in habitat conditions.

Agricultural and forestry practices influence both the structure of landscapes and their biological diversity through altering habitat qualities and spatial patterns, and introducing alien species.

Transport and communications installations occupy significant areas of important biotopes in coastal areas and along river valleys. In addition, they can result in the fragmentation and impoverishment of large areas of natural habitat in upland areas.

Pollution
Pollution is another serious threat to biological diversity in Norway. Acidification caused by long-range transport of pollutants is the factor that has had the greatest adverse impact. Other important factors with a negative effect on biological diversity are discharges of environmentally hazardous chemicals and inputs of nitrogen and phosphorus to river systems and the sea from domestic waste, sewerage and agriculture.

Over-exploitation
Harvesting of wild species and stocks of large and small game and fresh-water fish is important in both commercial and recreational terms. In general, game stocks are currently large enough to provide a sustainable yield at levels to satisfy recreational needs. However, wild populations of Atlantic salmon are declining markedly because of several pressures including the parasite Gyrodactylus. Fisheries and other harvesting of marine resources exert pressure on natural resources. Overexploitation of such resources can have major direct or indirect effects on marine biological diversity.

Hunting of the four species of large carnivores (wolf, wolverine, bear and lynx) is subject to detailed regulation to ensure that sustainable populations are maintained in the long term and mainly related to conflicts with livestock and reindeer husbandry. All species of raptors and owls are protected, although these were earlier hunted and persecuted leading to decimation of populations of most species.

Introduction of alien species
The deliberate and accidental introduction of alien organisms has been increasing during the past hundred years. Plant and animal species deliberately introduced to Norway include the Canada goose, musk ox and various trees and other plants; others, such as mink and pineapple mayweed (*Chamomilla suaveolens*), have spread from farms and botanical gardens. Other species have been accidentally introduced through trade, tourism, in ships' ballast, etc. These include Canadian pondweed (*Elodea canadensis*) and the salmon parasite *Gyrodactylus salaris*. Measures to combat Gyrodactylus have so far cost Norway more than NOK 70 million.

Introduced tree species in modern forestry and the planting of decorative shrubs such as Rhododendron (*Rhododendron ponticum*) along roads are modern threats for which we need detailed impact assessments. The natural regeneration of such species is likely to constitute a major threat to forest ecosystems.

New transport routes can act as dispersal corridors and spread alien plant and animal species. Bridges can lead to the spread of pest species, such as mink, fox, badger and stoat to coastal islands with their vulnerable seabird colonies.

4.3. Overview of fragmentation due to different land uses
Land use has intensified greatly over the past 50 years, particularly associated with urban development, agricultural intensification and forest management. Urban areas, both as housing and industrial areas, have expanded to cope with the influx of people migrating from outlying countryside areas, changes in life style and the industrial base of Norway. More than

75% of the Norwegian population now live in urban areas compared with only 35% in 1900. The infrastructure needed to support this rapid expansion has been a major threat to natural and cultural landscapes close to urban centres. Urban expansion has taken valuable agricultural land and other cultural landscapes and been a pressure on green spaces within built-up areas. It is estimated that about 75,000 ha of agricultural land has been lost in this way since 1945, of which about 40,000 ha has been lost since 1970. Only 20-30 % of the green spaces that existed in urban areas in the 1950s remain today. Infilling of old, established housing areas, to increase housing density, has been a major cause of losses of important urban green structure and habitats (orchards, herbaceous gardens, trees and shrubs, etc.) and led to a significant fragmentation of the remaining resources.

Arable agricultural land covers only 3% of the land surface of Norway, but it is unevenly distributed with municipalities in the Southeast with 30-40% cover of arable crops. Losses of linear biotopes as important habitat refuges or as movement corridors, as well as the increasingly large fields of cereal monoculture have been major factors responsible for the decline of farmland wildlife. Other factors affecting farmland wildlife have been increased use of farm chemicals, particularly pesticides and fertilisers, and changes in farming system resulting in increased areas of monoculture and autumn-sown crops.

Industrialisation of the forest industry in the 1900s has resulted in the fragmentation of areas of old forest. These losses of habitat have drastically reduced the amount of old forest habitat with its special habitats for lichens and insects. Remaining areas are a conservation concern but are mostly small and isolated remnants of once much larger patches. Forest roads have been a major factor in the fragmentation and disturbance of large areas of undisturbed nature.

Some of the most serious disruption of natural environments in Norway is caused by hydropower developments. These cause permanent disruption to wildlife habitats and can act as barriers to movement and migration through the establishment of dams and reservoirs, the regulation or reduction of water flow in streams and rivers, inundation of land and construction of installations.

The most used indicator of fragmentation in Norway is the mapping of areas of undisturbed land. This is achieved by mapping areas of the countryside more than a set distance from any man-made installation such as buildings, roads, power lines etc. The important aspect here is that the indicator is based on standard methods that enable a comparison between years and between geographic regions (Figure 4.4.). Although, the method can be improved to cope with the area requirements of different species, different terrain and vegetation etc., in its current form it provides an objective quantitative measure of fragmentation at the national level. The method has exposed losses of undisturbed areas (> 1 km^2 from significant disturbance) by 4,550 km^2 in the period 1988-1998, and wilderness-like areas (> 5 km^2 from disturbance) reduced by 1621 km^2. The mapping and indices will be monitored regularly (4 years) to identify pressures and trends.

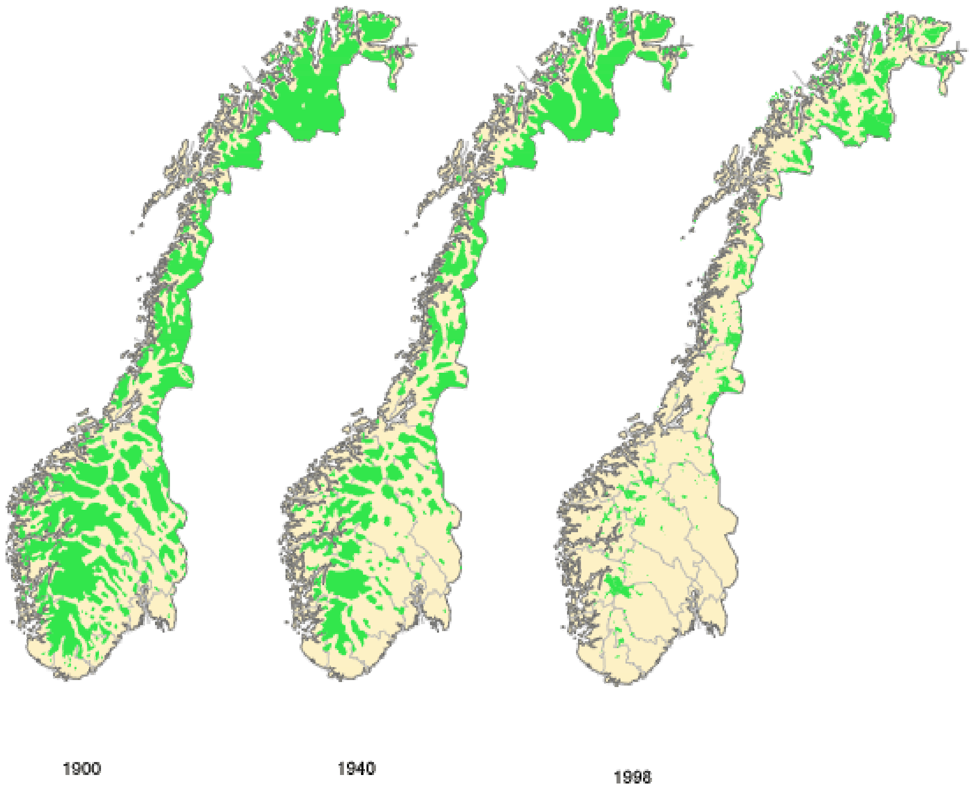

Figure 4.4. - Changes in the area of undisturbed land between 1988 and 1998 (Source: Statens kartverk/DN).

4.4. Administrative and legislative framework

The Ministry of Environment has overall responsibility for environmental and planning policy. Execution of this policy in relation to habitat and species protection is through the Directorate for Nature Conservation and the sector responsibilities of all those Ministries and Directorates whose activities affect habitats or species. At a practical level, responsibility has increasingly been given to county environmental authorities. The Department of Environmental Affairs of the County Governors are the representatives of the Ministry of the Environment at the county level.

4.4.1. Local Authorities

The administrative framework in Norway is based on the principle of municipal self-government. The Norwegian administrative system features an extensive public sector, which uses around 50% of the country's gross national product (GNP). Increasingly, local authorities have been given a larger role in the execution of environmental policies. The County Governors are responsible for the practical management of areas protected under the Nature Conservation Act and in some cases this has been delegated to the municipality level that also have the responsibility for mapping biotopes important for nature conservation. These are in turn incorporated into local land use plans. Local Authorities possess considerable independence from central government, which allows for a certain flexibility to vary the way national policies are carried out.

Norway is divided into 435 Local Authorities and 19 counties. The Local Authorities vary in size from under 1,000 to nearly half a million inhabitants. More than half of Norwegian Local Authorities have fewer than 5,000 inhabitants, while only 10 Local Authorities have a population of more than 50,000. There are substantial differences among Norwegian Local Authorities with respect to area, topography, settlement patterns, industrial base and budgets. Their geographic fragmentation and great diversity make it extremely difficult to introduce simple and standardised solutions to environmental issues.

4.4.2. Norwegian legislation Relevant to habitat fragmentation

The Planning and Building Act (1985)

The act aims to ensure the planning of public works shall be co-ordinated and form a basis for the development of resolutions concerning the development, use and conservation of resources such that development takes place for the benefit of both individuals and the society at large.

The Public Roads Act (1963)

Defines the different types and standards for roads and who is responsible for them. All road planning, construction and budgeting must take account of the interests of local communities. The road planning process is steered by the Planning and Building Act.

The Nature Conservation Act (1970)

The act covers the conservation of outstanding areas of nature, landscape and the protection of flora and fauna. This includes the establishment and management of national parks, nature reserves, landscape conservation areas and natural monuments.

The Pollution Control Act (1981)

The Act aims at protecting the environment from pollution and to reduce pollution to secure environmental quality at a level where nature can maintain the potential for production and self-renewal.

The Land Act (1955)

Conservation of the land, supporting agriculture as an industry and ensuring the land is used in the most beneficial way for society.

The Land Reallocation Act (1979)

The act aims to improve land use efficiency by reallocation of land areas where property and rights boundaries are inappropriate. If a voluntary agreement cannot be made then the land may be placed under reallocation under the terms of the Reallocation Act. The act is mainly used to control land in agriculture. For road construction the act may be used to promote nature conservation or other environmental protection measures as well as to reduce the negative impacts of new roads on agriculture.

The Outdoor Recreation Act

Protection and regulation of the common rights of access to cultivated and unfenced areas. Common law allows everyone to wander freely in the countryside and to harvest the wild fruits and mushrooms.

Act Relating to Salmonids and Freshwater Fish

Aims to ensure natural stocks of fish, their habitats and other freshwater organisms are managed in such a way that the diversity and productivity of Nature are preserved.

Act Relating to Motorised Traffic on marginal Land and Watercourses (1977)

The aim of this act is to regulate motorised traffic in unfenced areas and on rivers and lakes to protect the natural environment and promote people's enjoyment of it.

Act Relating to Forestry (1965)

This act aims to encourage timber production, establishment of forests and protection of the forest resource. Emphasis is given to the significance of forests for timber production while considering forest resources for recreation, forests as important landscape features and as habitats for plants and animals.

Act Relating to Watercourses (1940)

This act provides general legislation concerning rivers and lakes, laying down the framework for handling various forms of encroachment and stipulating limits for activities on rivers and lakes.

Wildlife Act (1981)

Aims to manage wildlife and the areas in which it lives in such a way that the productivity of Nature and its diversity are preserved. Within this framework, the harvesting of wildlife for the benefit of agriculture and outdoor recreation is regulated.

4.4.3. International Conventions

Norway has signed the following conventions and international agreements relevant to habitat fragmentation by transport infrastructure.

- Convention on wetlands of international importance especially as waterfowl habitat (Ramsar)
- Convention on the conservation of flora fauna and natural habitats (Bern)
- Convention on the conservation of migratory species of wild animals (Bonn)
- Convention concerning the protection of the World Cultural and Natural Heritage (UNESCO)
- Convention on Biological Diversity (Rio de Janeiro)
- ECE Convention on environmental impact in a trans-boundary context (Espoo)

4.5. Land-use planning in relation to nature and landscape conservation and transport infrastructure

The Norwegian Planning and Building Act is one of the most important tools in land use planning and thus an important instrument of environmental policy.

4.5.1. Regional planning and land-use policy

One of the main tasks in regional planning is to ensure sustainable land use management, particularly in areas where natural resources predominate. National and regional protection plans following the Nature Conservation Act are important, but they are not sufficient on their own to achieve Norway's environmental policy goals of maintaining viable ecosystems and biological production and diversity. It is therefore essential that planning at county and local authority levels includes goals and work programmes for environmental issues.

To resolve conflicts between protection and management interests in large continuous areas of natural habitat is a task of particular national importance. This implies especially to large continuous mountainous areas, areas near major river systems and the coastal zone. Strengthening co-operation between different actors and levels of organisation is a major aim of the Ministry of Environment. This will be of crucial importance in making county planning a more effective tool in precautionary, long-term strategic environmental management. Local authorities are sometimes unsuitable planning units for the conservation of natural or cultural resources, e.g. where transport planning issues concern large continuous areas of natural habitat and where administrative boundaries often have little or no relationship to the boundaries of the resource being managed. It is, therefore, essential to develop co-ordinated plans for such areas in their entirety, where county-level planning is a more appropriate tool than planning at the local level. Local authorities have designated an average of ca. 80% of their administrative area as priority for agriculture, recreation or nature conservation in strategic plans (LNF-areas).

4.5.2. Environmental impact assessment

Environmental impact assessments (EIAs) are an important tool of environmental policy intended to prevent environmental degradation. Since 1990, the Planning and Building Act has included provisions relating to EIAs for development projects that may have significant effects on the environment, natural resources and the community. The procedures are intended to ensure that the impact of such projects is properly assessed and that their effects are taken into account both during planning and during the authorities' decision-making process. The directorate for Public Roads is responsible for organising and setting the framework for EIAs for road projects. Local authorities and counties contribute to the screening and scoping process carried out to produce a programme for the contents of the EIA study.

Although Norway is not part of the EU, it is a signatory to the EEA Agreement on environmental impact assessments, and obliged to harmonise its provisions relating to EIA with EU Directive 85/337 on the assessment of the effects of projects on the environment. Both the amendments and the regulations entered force on 1 January 1997 and require EIAs for a wider range of projects.

4.5.3. The role of the Norwegian Public Roads Administration

The Norwegian Public Roads Administration has the responsibility for planning, constructing and maintaining the national and county road networks. It is answerable to the Ministry of Transport and Communications for work related to the national road network and to the county councils for work related to county roads. The planning process for roads is based on a 10 year “National Transport Plan” (NTP) which is reviewed every 4 years. This government document defines the major elements of the national transport policy including road, rail, air and coastal transport and includes a planning budget for the period.

The County Roads Offices are responsible for the planning of road projects. Plans for new roads, re-alignment and upgrading are increasingly subject to full environmental impact assessments. Quality control of the impact assessment process has its own guidelines (Statens

Vegvesen 1999). Contributions to the planning of individual road projects come from many sources within the local authorities and county planning authorities. The County Roads Office takes all the comments into account in the planning process. The municipal council is however responsible for making the actual decision. If regional government agencies disagree with the local planning authorities, the decision has to be taken at the Ministerial level.

The transport sector currently follows guidelines and aims for the NTP-period 1998-2007 developed as part of the Ministry of Transport and Communications environmental action plan (1998). It includes both major policy directions for the various consequences of its activities mainly on biodiversity, recreation, cultural heritage, air pollution and noise.

Land-use planning regarding road building is tightly controlled in Norway for public roads although less so for private and forest roads.

Railway development and upgrading are also subject to detailed impact assessment and environmental standards, which include the development of environmental standards for the development and construction phases. In addition, contingency plans for environmental damage and accidents are to be built in to development projects.

Results of environmental measures and mitigation are sometimes evaluated so that experiences and new knowledge can be used for planning new developments and projects. Environmental mitigation is included in the tender documents for new infrastructure developments.

4.6. Summary

The low population and rugged terrain in Norway have allowed large continuous areas of natural and cultural landscape to survive as some of the most intact and unspoilt in Europe. The environmental gradients found in Norway have resulted in a wide range of biotopes including various wetlands, mires, heaths, forests, and mountain environments. Changes in agriculture and forestry have been major factors causing the fragmentation of natural and cultural landscapes. Compared with such changes, the negative effects of fragmentation caused by the official transport system in Norway are probably lower than in most countries in Europe. Nevertheless, problems do exist and these are shown most clearly in the declining areas of coherent undisturbed nature and the concentrations of development along the coast, fjords and river valleys. The planning and maintenance of the network of private roads, particularly forest roads, is not as tightly controlled as public roads, and yet is the fastest growing sector of infrastructure development with more than 1000 km of new forest & tractor roads per year. This may represent a major fragmentation threat since these roads are often in otherwise undisturbed areas of nature.

Norway has a well-developed land-use planning legislation that includes impact assessments of new infrastructure developments. The rate of building of new road networks outside urban areas has slowed in recent years and is concentrated mainly on the improvement and upgrading of existing roads. Norway is not a full member of the European Union but abides by some of its environmental policies and directives through the European Economical Agreement, as well as being signatory to most International conventions on environmental protection.

Chapter 5. Habitat fragmentation due to existing transportation infrastructure

5.1. Introduction

Because of the relatively low density of roads and railways in Norway (Tables 5.1 and 5.2), habitat fragmentation resulting from transport infrastructure is lower in Norway than in most European countries. The national road and rail nets have been in place for some decades and major new routes are not planned for the immediate future. Plans for new road building projects are often the most controversial as they involve significant habitat fragmentation and habitat loss. Problems are also caused by upgrading of existing major trunk routes to cope with increased traffic volumes or to avoid small towns (by-passes) or traffic bottlenecks in or near urban areas, since these all increase the length of the road network often in areas where road density is already high. The rapid increase in traffic density in recent years has increased functional fragmentation and isolation effects of roads. Increased traffic has increased fauna casualties and created a physical or behavioural barrier that decreases the likelihood of many animal species approaching the busiest roads. Wildlife fences are necessary along certain roads with heavy traffic to prevent accidents involving moose and deer. These fences can intensify the barrier effect.

Table 5.1. - Main Road Network in Europe 1999 (Source: European Review).

Country	**Motorways (M)**		**Highways (H)**		**Average traffic**	**Passenger Transport**	**Goods Transport**	**MRN Density**
	Length (km)	**Speed Limit (km/h)**	**Length (km)**	**Speed Limit (km/h)**	**(10^3 vehicles /day)**	**(10^6 pkm)**	**(10^6 tkm)**	**(M+H) (km/km^2)**
E	9649	120	16419	100	100-175	205,3	134,9	0,05
F	9346	130	27223	80-110	30,3(M) 10,1(H)	708,4	245,4	0,07
UK	3358	n.a.	16088	n.a.	200 (bM)	630,0	159,5	0,08
NL	2207	100-120	936	80-100	15-200(M)	150,6	46,5	0,09
B	1682	n.a.	12500	n.a.	n.a.	95,7	35,0	0,47
CH	1638	80-120	-	-	5-93 (M) 51(bM)	n.a.	n.a.	0,04
S	1428	90-110	14615	90-110	n.a.	95,0	32,7	0,04
P	1252	120	11408	90	135(bM)	75,6	14,2	0,14
DK	861	90-110	3700	80-90	84,9 (bM)	58,5	15,3	0,11
H	505	110-130	6495	90	26,5 (M) 7,3 (H)	44,3	17,0	0,07
CZ	499	130	-	-	15	70,9	37,0	0,01
CY	280	100	n.a.	80	36 (bH)	n.a.	n.a.	n.a.
N	144	90	445	80	5-100(M)	53,2	12,8	0,09
RO	114	120	14810	90	5	23,2	16,5	0,06
EE	87	90	3810	90	3	185,4	12,2	0,09

n.a.= not available, bM= busy Motorway

Table 5.2. - Secondary Road Network in some European countries 1999. (Source: European Review).

	Total Roads (km)	**State Roads (S) (km)**	**Municipal Roads (mR) (km)**	**Average traffic (#10^3 vehicles /day)**	**SRN Density (S+mR) (km/km$_2$)**
F	605100	360100	569000	1,3 - 0.5	1,7
E	463258	68910	394348	n.a.	0,9
UK	138531	25425	113106	15 – 0,7	0,6
B	130700	1300	129400	n.a.	4,3
CZ	127732	55432	72300	n.a.	1,6
NL	126720	6360	114000	n.a.	3,4
S	121868	83368	38500	n.a.	0,3
P	108600	46100	62500	n.a.	1,1
N	90246	53224	37022	< 10	0,3
H	74465	23268	105233	1.38	1,38
CH	69435	18238	51197	3.6-8.9	1,7
DK	67100	7100	60000	n.a.	1,6
RO	58131	36009	22122	n.a.	0,3
EE	46539	12533	34006	n.a.	1,0
CY	4250	1500	2750	n.a,	n.a.

n.a.= not available

5.2. Transportation networks in Norway

The road network in Norway has been developed from the earliest farm roads, to national, county and municipal roads (Table 5.3.). The national roads are the responsibility of the government, the county roads of the county and the municipal roads by the local authorities.

Table 5.3. – The development of the road network in Norway. Classifications changed in 1930. (Source: Vegdirektoratet and NOS Samferdselsstatistikk)

Year	National and county roads		Municipal roads
1850	6 181		9 910
1900	10 671		17 920
1925	14 080		21 462
	National roads	**County roads**	**Municipal roads**
1930	9 303	6 116	22 024
1935	13 629	4 125	21 843
1940	14 695	5 135	22 768
1945	15 866	5 243	22 871
1950	15 929	5 875	22 869
1955	16 109	6 825	24 454
1960	16 378	8 321	26 534
1965	23 213	27 744	14 780
1970	24 321	29 572	18 369
1975	24 897	30 681	21 523
1980	25 282	31 598	24 837
1985	25 599	29 735	30 548
1990	26 221	26 974	35 727
1995	26 452	27 133	36 677
1999	26 705	27 213	36 962

5.2.1. Highways and motorways

The total length of public roads (national, county and municipal roads) in Norway in 1999 was about 90,000 km.

National Roads: 26,705 km in 1999

Specifications vary according to volume of traffic and whether the area is built-up. 7,604 km of the national network are considered as trunk roads. Trunk roads are important for communications between different parts of the country and abroad. They carry half the traffic on the national road network. The Ministry of Transport and Communication and the Norwegian Public Roads Administration are responsible for national roads.

Figure 5.1. - The trunk road system in Norway (National roads)(Source: Vegdatabanken)

County Roads: 27,213 km in 1999

The County roads can be of a lower standard than national roads. The county roads are the responsibility of the County Councils and the County offices of the Norwegian Public Roads Administration.

Figure 5.2. – The National and county roads of Norway (Source: Vegdatabanken)

5.2.2. Secondary road infrastructure

Municipal Roads: 36,962 km in 1999

Local authorities can draw up their own standards. The Executive Committee of the local authority is responsible for planning.

Figure 5.3 – Public roads in Norway (national, county and municipal roads) (Source: Vegdatabanken)

Private Roads: 97,800 km in 1997 (forestry and tractor roads only)

In addition to public roads there are private roads of differing standard and levels of maintenance belonging to the military, to telecommunications companies, industrial parks, industry, housing, holiday homes and summer farms. There are no standard requirements, although to obtain grant aid, forestry roads need to be approved by the local forestry officer of the local authority.

5.2.3. Railways

The rail network in Norway has been relatively stable over the past 50 years. New railway developments are mainly to improve the current infrastructure through upgrading to 2 lines or to accommodate high speed trains. In addition, there are plans for increasing the number of train passing places on single line sections of the rail network. In 1998 there were 4,000 km of railway line in Norway (Figure 5.4.) of which 2,471 km were electrified (overhead power lines). There are ca 5000 level crossings in Norway and long term plans to upgrade many of them. The rugged terrain in Norway has required the construction of 693 tunnels (ca 255 km) and 2,660 bridges (ca 40 km) along the 4,000 km of track.

Line improvements to cope with high-speed trains represent a major part of the development of the rail net. The current stretches of high speed rail are links between Oslo and the new national airport, Oslo and Trondheim and Oslo and Stavanger. The high-speed trains make higher demands of the rail track and its alignment as well as greater safety regarding wildlife accidents.

Figure 5.4. - The national railway network in Norway. The densest rail net is in the southeast around Oslofjord as with the road network. The other major rail routes are the coastal route to Stavanger, the east-west route between Oslo and Bergen skirting the Hardangervidda plateau, and the two north-south routes via Dombås and Røros. (Source: Jernbaneverket)

5.2.4. Waterways

There is no extensive canal system in Norway although several of the major river systems and large lakes were essential parts of the transport system in historical times and some are still used for transporting timber and tourists. Most rivers are too steep to be suitable for transport and the terrain too rugged and rocky to be suitable for the construction of canals. Two systems which linked natural waterways are now of historical and tourist importance, the Telemark Canal and Halden watershed. Both operated as inland waterways and involved systems of locks to allow boats to navigate steep gradients between natural watercourses.

5.3. Effects of the existing transportation network on nature

5.3.1. Habitat loss

The area of habitat loss through direct construction and permanent physical disturbance by infrastructure is relatively small in Norway. Loss of habitat continuity through fragmentation, however, is likely to have had a significant impact on biodiversity. One area where the loss of valuable habitat has been very acute is in coastal areas and along the floor of steep glacial valleys where both road and rail links are concentrated. One of the greatest pressure areas for infrastructure development has been the shingle beach, salt marsh, mud flats, coastal meadows and other special habitats associated with gently sloping shorelines. These are areas under great demand for their agricultural potential, industrial development, housing and infrastructure and are productive areas with a high biological diversity and/or threatened biotopes. For the 15 river delta areas in western Norway, 86% of the total area has been developed or transformed to intensive agriculture. In recent years, most remaining areas have been afforded some form of protection or incorporated into strategic planning measures. Nevertheless, pressures increase in a zone where the often steep coastal terrain restricts options for the placing of new or upgrading of existing roads along the coastal strip. The loss of breeding and staging posts for water birds are of great concern and the losses continue to be significant. At one recent road development (E6 at Sandfærhus), the impact on breeding and over-wintering birds was clearly related to the proportion of habitat lost (Husby 1996). The road project involved both infill and a take of about 40% of coastal meadow and saltmarsh plus lesser areas of inter-tidal mud flats. The water flow and drainage around the river delta were also altered. The total impact on bird numbers was greater than could be expected from the percentage of land lost for those bird species nesting on the marshes and meadows with a lesser impact for species such ducks and waders using adjacent habitats.

Power lines are often pass through otherwise undisturbed areas and often demand the removal of tree and bush vegetation altering the ecological characteristics of a much wider belt than just the area where trees are removed.

It must be remembered that habitat loss involves more than the take necessary for the road itself. During construction, a wider area is so heavily disturbed by grading, surfacing, drainage works and access that it is often beyond repair to its natural state. Such activity naturally increases the width of permanent road disturbance and adds to the fragmentation effect.

5.3.2. Corridor function

Although wildlife corridors are a major issue in nature conservation, we remain unsure of the conditions required before different species will use them. In this discussion, we use corridors as functional features that increase the movement of individuals between patches of suitable habitat in the landscape. In recent studies of roadside verges in Norway, the spread of some species of plants has been observed. Roadside verges have also been found to increase the movement of butterflies across agricultural landscapes.

Not all corridor effects are considered positive. The spread of diseases, pests, predators and weeds are all potentially damaging to nature conservation interests. The spread of mayweed and garden escapes may threaten some semi-natural vegetation types. The example of the spread of rhododendron in the UK is a clear example of roads acting as corridor for a very invasive plant. Recent road verge planting of rhododendron in western Norway should take note of this experience.

5.3.3. Disturbance

Although only about 1% of Norway is urban and a further 3% is intensive agricultural land, the proportion of wilderness-like areas (more than 5 km from major infrastructure development) has decreased from 48 % of Norway's total area in 1900 to 12 % in 1994. In southern Norway, undisturbed habitats account for only 5 % of the total area, and they have been disappearing considerably faster during the past 15 years than earlier this century. Recent pressures have been from developments such as forestry roads, power lines, hydropower development, building of holiday cabins, etc.

Effects of the disturbance of the existing road net in Norway are little understood. There are few studies directly linking population declines with disturbance from roads, but caution is required since we have insufficient data to assess the impact for most species. Reindeer are an exception; we have quantitative data for this shy species clearly demonstrating a negative effect of infrastructure development (Figure 5.5.).

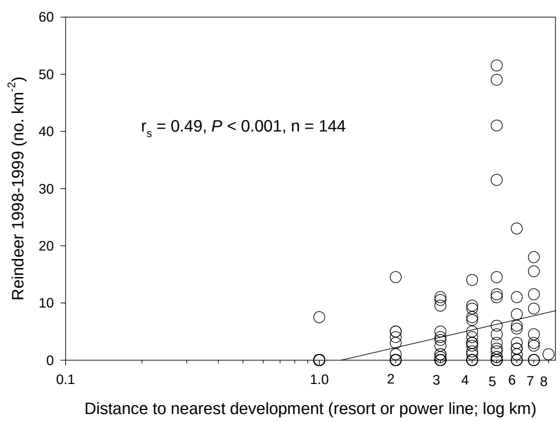

Figure 5.5. - Reindeer density pressure at different distances from disturbance (Source: Nellemann 2001).

The effect is one of avoidance; such that reindeer under-use valuable resources near roads and other installations such as power lines and holiday huts (Figure 5.6.).

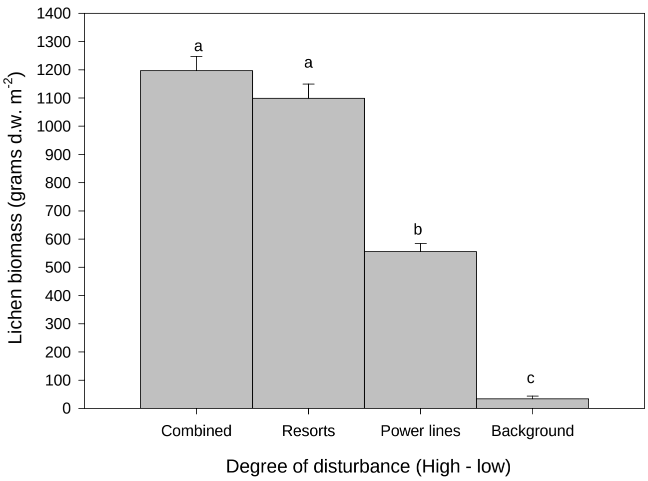

Fig. 5.6. - Lichen biomass at distance from disturbance in Nordfjella, Norway, including combined development, tourist resorts, power lines and background areas >5 km from infrastructure. (Source: Nellemann 2001).

Results of this avoidance are a reduction the “available” grazing resources (lichen grazing) in wide zones parallel to roads and an equivalent increase in grazing pressure in a zone at some distance from roads leading to an over exploitation in this zone.

Traffic noise and vibration as well as car headlights and street lights can all affect changes in the ecology of species. Although little quantitative data exists, there is a common belief among sport fishermen that several aspects of road and rail disturbance affect fish behaviour and possibly migratory patterns especially of sea trout. Streetlights also reduce the opportunities for night fishing for sea trout, which is a highly valued sport.

5.3.4. Fauna casualties

Road casualties involving wildlife are not seen as a national conservation problem. Nevertheless, there can be local problems in restricted areas related to a few species such as birds of prey (Eagle owl (*Bubo bubo*)) and the hedgehog. Road casualties of deer and moose are of little consequence for biological diversity even with over 2000 moose killed each year on the roads and railways in 1996/7. The respective numbers for red deer and roe deer casualties are ca. 500 and 3,500 (Table 5.4.). Road or rail casualties for wild reindeer are also not a problem. At a national level, the populations of all these species seem unaffected by the losses sustained through infrastructure casualties. Patterns of casualties follow the distributions of the species and traffic densities. Between-year variations in fauna casualties for road and rail are highly correlated for red deer and moose although the cause is not known.

<u>Moose (Alces alces)</u>

According to official Norwegian statistics, there are in average killed approximately 1300 moose on Norwegian roads each year (Table 5.5.) The actual numbers may be twice as high.

There is a clear conflict between moose and infrastructure in Norway. The moose is a forest animal requiring browse of bushes and trees. Moose find their way onto roads for a number of reasons. Roads may dissect the home range of moose, cross traditional migration routes between summer and winter grazing, or moose may be attracted to rich foraging along roads. The density of younger deciduous trees near roads is often higher than in the forest because of disturbance and edge effect. The time of year of accidents varies considerably from place to place. The shorter days of winter coincide with snow and more difficult browsing causing movement to lower altitudes including valley bottoms where road and rail lines are concentrated. Moose are of special concern because of their large size (300-500 kg and up to 2m high at the shoulder) which means that traffic accidents often result in tragic injuries and occasionally death to people and suffering and death for the animals.

Table 5.4. - Large game species killed on Norwegian roads 1979-1998

Species	Yearly quotas for hunting	Hunting results	Animals killed on the road	People killed	Accidents with severe personal injuries	Accidents with light personal injuries
Moose	**30 - 35.000**	**approx. 85%**	**approx. 1.200**	**0 - 5**	**4 - 14**	**76 - 117**
Roe deer	**40 - 45.000**	**?**	**approx. 2.700**	**0**	**0 - 1**	**4**
Red deer	**15 - 20.000**	**approx. 65%**	**approx. 280**	**0**	**0**	**3**
Reindeer	**8 - 9.000**	**approx. 45%**	**3 - 5**	**0**	**0 - 1**	**1**

All figures are estimated average pr. year over the last 10 years.

Table 5.5. – Number of moose killed by road traffic in Norway (Source: SSB)

Hunting season	Total no. of moose killed
90/91	884
91/92	977
92/93	1417
93/94	1464
94/95	1111
95/96	1142
96/97	1394
97/98	1085
98/99	1286
99/00	1334
00/01	1321
01/02	1304

Red deer (Cervus elaphus)
Red deer are also a large game species that can cause serious traffic casualties. The number of animals killed each year on the road has approximately doubled since 1980 and is more than 400 animals each year. The pattern of accidents involving red deer correlates to 2 peak activity periods in the year; the late summer/ autumn rut which also includes the hunting season, and the dispersal of yearling calves in the spring. Rail deaths of red deer are few since red deer are not abundant along the main rail net. Red deer road casualties are mainly confined to the counties of the west and central Norway.

Roe deer (Capreolus capreolus)
Roe deer are a common and numerous species in Norway. They are the deer species most involved in road casualties, with more than 3000 deaths annually. Roe deer can reach high population densities on farmland near large population centres, making them vulnerable to traffic accidents. Roe deer are an important game species with more than 40,000 shot each year. Roe deer appear more vulnerable to road accidents than to train accidents. This may be a result of their habitat preferences and the fact that stretches of railway line are fenced against domestic stock which may prevent roe deer but not moose from access. Several mild winters with relatively little snow have helped roe deer build up large populations in eastern and central Norway.

For game species, there are often daily peaks in accident frequency around sunset and sunrise. At the peak periods of activity in the autumn, this coincides with the morning and evening peaks in rush traffic, which intensifies the problem.

Wild reindeer
Wild reindeer are more sensitive to disturbance than the other large deer species and tend to be shy of human activities. Their habitat preferences favour mountain plateaux, which along with their avoidance of disturbance mean that they are little impacted by road or rail accidents. Domesticated reindeer may be driven into more populated areas and thus are more likely to become road casualties.

Differences between road and rail game casualties
The impact of train collisions on moose and other large game (roe deer, red deer and reindeer) is well recorded and reflects the much smaller transport net. However, certain stretches of railway have a high frequency of accidents involving game species and on-going research projects are examining measures to reduce this. Train drivers register ca. 1,000 large game killed by trains each year. The figure for rail accidents is difficult to compare with road accidents, as the recording methods are not the same. A larger proportion of accidents on roads go unrecorded than on rail. Nevertheless, the casualty rate on railways with their lower traffic frequency and much shorter length compared with the road network suggests that game are vulnerable to rail casualties (ca. 1 game animal death per 4 km of railway track compared with ca. 1 death per 18 km of state roads). This may in part be because of the higher speed of trains plus the extensive use of fencing that can trap animals once they wander into fenced stretches of the rail net. Animals may thus cross roads but wander along railway lines. To assess the importance of this difference in the vulnerability of game species to accidents on roads versus rail requires greater standardisation of the accident data.

Badgers (*Melees melees*) in Norway are mostly confined to areas with agricultural landscapes and deciduous forest. Badgers are nocturnal and their ecology is generally considered to render them vulnerable to traffic accidents. They have fixed foraging routes that may cross roads and, in addition, single males roam widely spring. The population structure of badgers can be in the form of a meta-population requiring sufficient dispersal between sub-populations to maintain long-term stability. These dispersing individuals are vulnerable to traffic accidents although the degree to which this represents a threat to the species in Norway has yet to be fully assessed. Preliminary results in several counties suggest the badger is such a frequent road casualty that roads are a major mortality factor limiting local population size.

Hedgehogs (*Erinaceus europaeus*) are often quoted in European literature as suffering population declines related to road casualties. This species has a Middle European distribution. In Norway, hedgehogs are found at their highest densities in the warmer, richer farming and sub-urban areas along the coast where the road net is most dense. Consequently, hedgehog road casualties are common, even on relatively quite stretches of road. As the hedgehog reaches its Northern limit in southern Scandinavia, it has been estimated that 60% of the Norwegian population die from the cold each winter. The hedgehog is on the Norwegian red list because of its uncertain status and further studies on the impact of roads on local and regional abundance are required.

Other mammals interacting with transport networks

Other mammals commonly found as road casualties include the red squirrel (S*ciurus vulgaris)*, pine marten (*Martes martes*), red fox (*Vulpes vulpes*), hare (*Lepus timidus*), and otter (*Lutra lutra*). However, the regional or national significance of this mortality for the status of these species is unknown.

Amphibians

There are few amphibians in Norway and their status is declining such that several species have red list conservation status. Amphibians are vulnerable to the negative impacts of fragmentation and road kills. The crested newt (*Triturus cristatus*), smooth newt (*Triturus vulgaris*), and moor frog (*Rana arvalis*) are all considered to be threatened by landscape changes reducing suitable habitat. Many amphibian species migrate to their mating places each year. When roads separate the hibernation areas and spawning sites, large numbers of individuals may be run over. Similarly, in the late summer or autumn the mortality of juvenile frogs and toads crossing roads during dispersal from breeding sites can locally be very high. There are few data but there many reports of high numbers of frogs killed on roads near to ponds. The peak time is in late summer as young adult frogs disperse from ponds to seek over-wintering sites. Local death rates appear very high (greater than hundreds per day for short stretches of road) but the impact on population levels is not recorded.

Birds

Birds are also well represented in road casualties observed by drivers. Passerine birds often nest in roadside vegetation and their flight behaviour can make them highly vulnerable to collisions with cars and goods vehicles. The blackbird is an example of this, as it sits on posts near roads and flies by swooping low over roads and often colliding with vehicles. Other birds such as crows are attracted to roads because of road casualties or grit, and often become casualties themselves.

Fences along roads, railways and power line cables can also be hazards for birds either through collision or electrocution. Such collisions are well documented with quantitative data in Norway. The work of Bevanger (1994, 1995) and Bevanger and Henrikson (1995) has clearly demonstrated the scale of the problem. Aerial power lines, often running parallel with transport systems, are an important mortality factor for some bird species. The rare eagle owl (*Bubo bubo*) is one such species. Fences, especially deer fences, because of their height (2.5m), can locally reduce populations of larger birds such as willow ptarmigan. Surveys of casualties at fence lines in Northern Norway found that 20 species of bird killed by reindeer fences including the rare snowy owl (*Nyctea scandiaca*).

Collecting the data required to fully assess the threat of fauna casualties caused by infrastructure development will not be easy. Many animals hit by cars are not killed outright and move away from roads before dying, smaller animals may be thrown by the impact or dragged away from roads by scavengers. After a short time, road casualties are difficult to identify either because they have been eaten or run over several times.

To gain some overview of the scale of road casualties on a wider range of species, the Norwegian Public Roads Administration have initiated a pilot survey to estimate of the wildlife toll for birds and mammals.

5.3.5. Barrier effect of infrastructure

Roads are well-documented barriers to the movement of wildlife. The best known case study of infrastructure barriers in Norway is the fragmentation of the wild reindeer (*Rangifer tarandus*) population on Dovrefjell. The problem is a classic example of functional fragmentation caused by disturbance. Before both road and rail links were built across the mountain plateau, the reindeer population was an open population divided into 7 sub-populations. After the infrastructure development, some reindeer were partially cut off from the others in an area known as Snøhetta that was previously used only as a summer grazing area. This has had significant impacts on the isolated sub-population as winter grazing areas that are decisive for the condition and survival of individuals. The winter grazing in the Snøhetta area is not adequate and the individuals of the Snøhetta sub-population weigh significantly less (ca. 15%) than the main population. The lower weight has negative implications for life-time breeding success. During winters with much snow a percentage of the Snøhetta population cross the road and rail barrier, which may help maintain the sub-population.

Another case study of fragmentation that is well documented is the infrastructure development associated with the building of the new national airport at Gardermoen where new access roads and a high-speed rail link present a significant barrier for wildlife. In this area, a population of ca. 600 moose had traditionally crossed this area between lowland winter and higher elevation summer grazing area.

Despite the use of fauna passages and crossing points along the infrastructure routes, the moose are effectively trapped in part of their annual range, the winter grazing area. The main road system E6 has been extensively fenced in recent years leaving only 3 crossing points of 60m wide. The net results have been a drastic reduction of moose movements between summer and winter grazing areas such that there is no longer a net movement between them. Very few animals have been recorded crossing the 7 fauna passages built to compensate for the increased development of transport infrastructure, including a single large fauna passage (cost NOK 15M) over both road and rail routes close to the national airport (see Figure 5.5). The problem appears to be difficult to solve since the airport transport links are not the only fragmenting factors and land use in a much larger area would need to be incorporated in a moose management plan to reduce the barrier effect. Land use change and development associated a general industrial and housing growth in the area add to the problems facing this moose population. Although there are clear signs of over browsing in the areas close to roads and reports of moose in poor condition, we do not yet know the long-term consequences of the fragmentation of their range. Signs are that the current restriction of the population will lead to overgrazing in the winter area. To avoid this would require further measures to increase the use of current fauna passages by e.g. guiding fences and increasing the forest cover in the vicinity of fauna passages (Kastdalen 1999).

Figure 5.5. - The overpass over highway 174 and the high speed rail south of Gardermoen, Norway. (Photo: S. Guldseth).

A further barrier effect of roads can arise as a consequence of winter road maintenance. Snow ploughing to keep roads open in the winter can result in high banks of snow each side of a road. These may be so high as to be barriers to the movement of game species or trap them on the road. The most serious threat to wildlife from snow ploughing in Norway is possibly the fragmentation of wild reindeer populations on the Hardangervidda mountain plateau. Here there is increasing evidence that reindeer are stressed by increasing levels of disturbance and loss of access between grazing areas. Reindeer cross the east-west highway 7 more frequently when the road is closed in poor weather (Danielsen & Strand pers.com.). Increased traffic and snow accumulations from ploughing are reducing contact between two important areas north and south of the main road.

Figure 5.5. - Snow wall created by snow ploughing which can act as barrier to reindeer movement (Photo: B. Iuell)

Traditional migration routes and home ranges crossed by new roads are a problem for large game species and increase traffic accidents. The long term effects of road building programmes have to be seen in conjunction with the development that follows road building. Increases in associated development lead to higher traffic densities and higher rates of fauna casualties. Increased road casualties lead to increased fencing and this in turn further increase the barrier effect of infrastructure. This can be seen along stretches of the main routes into the major urban areas where road, rail and ribbon development combined with fencing comprise absolute barriers to many species.

Wolf (*Canis lupus*) and bear (*Ursus arctos*) populations are spreading into Norway from expanding populations in Sweden. Their movements are being carefully researched and monitored and it is believed that the major north-south oriented transport routes are restricting their dispersion eastwards.

5.3.6. Effects on populations

Although there are hard data for game species killed on roads and railways, on birds and mammals colliding with fences and on effects on reindeer, much of the remaining information on fauna casualties and barrier effects is qualitative or anecdotal. Relating even the best data available to population processes and the long-term consequences for species distribution and survival is difficult without further research. Fauna casualties and infrastructure barriers are relatively new and dynamic phenomena. It may, therefore, take some time before the impacts of current mortality rates and range restriction become apparent. There may well be a time lag between cause and effect. In addition, other population pressures occurring at the same time may intensify negative consequences on population viability.

5.3.7. Overview of environmental bottlenecks

The most significant environmental bottlenecks related to Norwegian infrastructure are the stretches of road and rail network which cross important migration routes of the large game animals especially moose and wild reindeer. Other environmental bottlenecks occur at points where infrastructure development has little choice but to fragment or destroy important habitat such as coastal flats, riparian corridors, or the base of steep valleys.

5.4. Secondary effects of transport infrastructure

Two of the main secondary effects of transport infrastructure in Norway are the effects of salting roads and snow clearance in winter. The winter is long in Norway and some mountain areas need snow clearance for 5-6 months each year. The snow cleared from roads by snowploughs accumulates as vertical banks at the side of the road; often reaching more than 3m high. The effect of a wall of snow each side of a road in winter can be an absolute barrier to the movement of animals especially large game (see Section 5.4.5). The steep banks of snow increase the risk that animals venturing onto roads become trapped and road casualties.

Salting roads during weather conditions produce temperatures between 0 and –8° C reduces road accidents by 20%. The cost of salting is high; ca. 100,000 tonnes of salt were spread on public roads in Norway during the winter of 1998/9 causing both rusting of cars and wear to road surfaces. The environmental effects of salt include the contamination of water quality in surface and ground waters as well as altering soil conditions and vegetation. Several coastal plant species are now found along roadsides because of salting. Many stretches of busy roads have vegetation clearly affected by pollutants from roads. Salt has a direct effect on many plant species including many of the native trees and bushes that grow close to roads. Necrosis and leaf loss are common damages caused of road salt (Fostad 1997). Salt attracts game species to roads and may increase road casualties.

Further secondary effects of roads may be mediated through road lighting, changes in microclimate or contamination with dust, and heavy metals. Where roadworks follow shorelines or where bridges are constructed over rivers and estuaries, permanent changes in water flows may occur which effectively fragment aquatic habitats. Changes in the water flow though aquatic systems rapidly changes ecosystem structure. In Norway, examples of such effects have been recorded in flows between 3 sections of Herstrømsbukta in Drammenselva and around Tautra in Tronheims fjord. The Herstrømsbukta case is interesting as it demonstrates the long-term effects of road alignment and grading. Road improvements in the 1970s led to the fragmentation of Herstrømsbukta a tidal-influenced pool into 3 functional pools with reduced flow between them. Eutrophication of the pools has occurred consequently. A recent study by the Norwegian Institute of Water Research recommends, among other measures, to increase water flows between the fragmented pools to levels that existed before road building to avoid further eutrophication.

The development of roads leads to secondary effects though attracting associated developments. These may be the provision of services directly related to the new road such as service stations or restaurants or it may be new industry or housing attracted to the area by the greater accessibility. Other effects can arise from the building of forest and farm roads as compensation to farmers affected by motorway construction and through the increased felling of forest areas near to new roads. Only careful planning can help to limit the undesirable side effects of road construction. Similarly, the consequences of associated development need to be taken into account when assessing the impact of forest roads. Although often narrow and used infrequently by motorised transport, forest roads increase access by foot and by car and will include a wide disturbance zone when used for harvesting and timber removal.

5.5. On-going research and review of relevant studies

Many research areas are relevant to the problem of fragmentation caused by transport infrastructure. It is difficult to gain a full overview of the work in hand as much of it either deals with the detailed ecology of specific species without references to infrastructure or examine aspects of road ecology without considering fragmentation. There are also a growing number of studies completed or in progress which examines fragmentation problems and many of these are relevant to roads.

5.5.1. Projects financed by the Norwegian Public Roads Administration

1. Development of guidelines for the design and placing of fauna passages and other mediation measures. The project includes assessment of all forms of current mitigation measures, assessment of the role of regional green structure and the way animals disperse in a landscape. In addition, ways of preventing unwanted species from spreading will be examined, e.g. preventing predators from reaching the nests of seabirds on islands.

2. Assessing the success of existing measures in 5 counties:

- Summarising experience with the use of wildlife barriers to prevent wildlife crossing at accident-prone areas.
- Experiments with the use of winter forage to reduce the local movement of moose into the Østerdalen valley in search of food where they are vulnerable to road and rail accidents. Use of GPS to record fauna casualties on the E6.
- Continued surveillance of wildlife using the fauna passage over the E6 and high-speed rail link near Oslo airport.
- Monitoring fauna passages on the E18.

5.6 Summary

The situation in Norway is somewhat different from most of the Western Europe. A combination of a low population density, rugged terrain and some of the wildest areas in Europe give the country a profile that is, on the one hand, less impacted by transport infrastructure, yet because of this position is highly vulnerable to further fragmentation. This can be seen clearly by the rapid erosion of the area of undisturbed countryside during the last 40-50 years. The major wildlife problems associated with transport infrastructure development in Norway are undoubtedly the negative effects on reindeer populations, both the direct barrier effects of roads fragmenting of populations and the indirect impacts caused by disturbance. These disturbance effects can influence reindeer use of resources for large distances either side of roads.

Norway has several natural features that fragment populations of plants and animals such as the mountain plateaux dissected by steep glacial valleys and fjords. This also makes some species even more susceptible to fragmentation by transport infrastructure. The road system is highly aggregated along the coast, fjords and major valley systems placing high pressure on the animals living in these areas. This effect is intensified by the fact that these areas are already the most developed and house the vast majority of the Norwegian population. The use of the major valley systems requires both road and rail routes to fit into narrow valley floors with resultant threats to river systems. Coastal beaches, mud flats and river deltas are highly vulnerable to fragmentation by roads and internationally important for breeding or staging birds and their flora. The coastal shorelines as well as those of rivers and lakes are, therefore, a priority theme for mitigation measures. Although the density of the public road network is low compared with the European average, there is increasing concern over the development of the private road network that often intrudes in remote areas which would otherwise be without vehicular access.

Fauna casualties are tragic in terms of human and animal suffering. This is especially so when very large animals such as the moose are involved. Yet, for most species the losses do not seem to be a problem at the population level except for certain local populations. Further research is needed to assess long term threats to specific species such as hedgehog but all the large game species continue to increase nationally despite the large losses.

Although fragmentation effects are increasingly identified and quantified for a wide range of species, there are few data on the long-term population consequences of the effects of transport infrastructure.

Chapter 6. Traffic safety in relation to fauna collisions

Traffic safety in relation to fauna collisions is an important consideration in Norway on the roads although much less so for railways. The particular problem in Norway has been with deer species and especially moose because of the high number of road accidents involving moose that result in serious injuries to people. Although approximately three times as many roe deer as moose are involved in collisions with cars, the moose is a very large and heavy animal causing much more damage (more than 10 times the injury rate caused by all other deer species together). The large size of moose with its high centre of gravity (height at shoulder up to 2m, and weighing up to 500kg) results in collisions where moose are over the bonnet height of private cars such that the front windscreen and passenger area of the car take the full impact.

Tables 6.1. and 6.2. show the numbers of accidents with wildlife causing human injuries in Norway. Some of the accidents causing fatal injuries include heavy motorcycles and moose.

Table 6.1. – Road accidents involving moose resulting in injury to people 1993-99
Number of accidents (acc) with number of people killed or injured and degree of injury (d=death, vs=very serious injury, s=serious injury, l=light injury)

Year	acc	d	vs	s	l	total
1993	77	1	2	8	86	97
1994	69	0	2	2	87	91
1995	61	1	0	5	79	85
1996	91	0	0	9	117	126
1997	65	4	2	11	76	93
1998	72	6	5	8	86	105
1999	58	0	2	10	53	65
Total	**493**	**12**	**13**	**53**	**584**	**588**

Table 6.2. – Road accidents involving reindeer, red deer and roe deer resulting in injury to people 1993-99
Number of accidents (acc) with number of people killed or injured and degree of injury (d=death, vs=very serious injury, s=serious injury, l=light injury)

Year	acc	d	vs	s	l	total
1993	14	0	1	0	16	17
1994	3	0	0	1	2	3
1995	6	0	0	0	7	7
1996	6	0	0	0	7	7
1997	5	0	0	3	3	6
1998	4	0	0	0	6	7
1999	14	1	0	0	16	17
Total	**52**	**1**	**1**	**4**	**71**	**64**

Where accidents involve personal injury, there are no data for road accidents arising from car drivers acting to avoid colliding animals. Additional information exists in insurance company files and could be used to give a more comprehensive picture of the material damage resulting from animals wandering onto roads.

See also chapter 5.

Chapter 7. Avoidance, mitigation, compensation and maintenance

7.1. Introduction

Avoiding fragmentation effects is a major consideration during the planning of new road schemes. For major new transport infrastructure developments and upgrading of existing routes, fauna passages are usually an integral part of the planning and design process. The aim of this section is to discuss the concrete measures to reduce the fragmentation effects of road construction including measures to reduce the use of wildlife fences used to reduce fauna collisions.

7.2. Avoidance of habitat fragmentation

New roads are planned to avoid habitat fragmentation by using the topography and local knowledge concerning valuable wildlife habitats and species. Where new roads or the upgrading the existing net cannot avoid habitat fragmentation, mitigation measures are used to reduce the barrier effects. Sets of guidelines for the placing of transport infrastructure in the landscape have been developed (Øverlid 1994).

- avoid severing or disturbing extensive, uninterrupted areas of nature
- if disturbance to such areas is unavoidable, the road should be sited as far as possible away from core areas and other areas highly vulnerable or of major significance
- involve specialists to evaluate assets of areas to guide what must be taken into consideration and what measures could be used to alleviate conflicts
- take account of animal crossing points for wildlife in the planning phase of road construction
- avoid crossing or influencing wetlands when placing roads in the landscape
- reduce the number and extent of additional services in the countryside to avoid further development pressures
- limit snow clearance in areas where animals are vulnerable to this threat

If habitat or important movement corridors are destroyed, compensatory measures or habitat restoration are undertaken to reduce impact.

7.3. Overview of mitigation measures

In Norway, the major measures to minimise fragmentation by roads are:

1. *fauna passages* – main mitigation measure for roads with traffic over ADT (average daily traffic through the year) 10,000 or where distinct seasonal migration routes or where roads bisect foraging areas
2. *placing roads in tunnels* creates large ecoducts above ground or building viaducts over steep valleys to create natural underpasses
3. *methods to reduce the need for fencing* - deer fencing is used to reduce road accidents with >10,000 ADT rates. These fences can act as serious barriers to movement, but may also be used to guide animals to safe crossing places or fauna passages.
    - clearing vegetation – can reduce forage and give better line of site to traffic
    - warning signs – to warn people of the danger at collision hot spots
    - additional methods to avoid fauna casualties

- population regulation-reducing some game populations to lower traffic accidents

7.3.1. Fauna passages

Fauna passages are increasingly used on new road and rail links and in connection with major upgrading and realignment. In 1997, all the county road offices of the Norwegian Public Roads administration were asked to complete a questionnaire providing details of fauna passages in each county. The survey revealed 30 passages although many other crossing points exist (mostly underpasses) that were constructed primarily for agriculture but are likely to function as fauna passages. The largest of these are where bridges carry the road over valleys instead of using large amounts of in-fill (see figure 7.1.). Costs vary from NOK 530K to NOK 15M with an average cost of NOK 4.4M. The success of fauna passages varies and there is a clear need for improved monitoring to establish which designs function best for which species.

Figure 7.1. – A bridge is built instead of a road on an embankment, taking care of the both the natural migration routes for wildlife and the microclimate along the small stream. Highway 23 Akershus, Norway. (Photos: B. Iuell

Conclusions from work with fauna passages in Norway are:

Advice regarding establishment:

- the natural terrain should be used as much as possible to maintain natural crossing places and reduce construction costs
- vital to perform detailed investigations both ecological and within local planning to avoid wasting the investment in fauna passages
- local and regional conditions vary greatly in Norway, it will thus be difficult to make general recommendations and case by case assessments will be necessary
- fauna passages must be placed on the natural migration routes of animals and be integrated as part of the regional green-structure

Advice regarding design:

- which type of passage to choose and size will depend on the type of animal it is intended for and which function it is meant to maintain
- size alone is no guarantee for a fauna passage to be effective

- most species are sensitive to human disturbance - noise, smell and light can all disturb wildlife, therefore, passages and their surroundings should been screened by vegetation belts and noise barriers
- openings to passages should be as attractive to wildlife as possible and be at the same level as the surroundings
- fauna passages should have a natural base of soil or vegetation.
- fauna passages in combination with water should be designed to include a dry bank alongside the water.
- the most attractive game passages are broad and give animals views to natural vegetation on the other side.
- for red deer overpasses are more successful than culverts

Advice regarding the type of animal to benefit from fauna passages:

- are vulnerable to high mortality as a result of road kills
- have strong migratory behaviour
- have dispersal restricted by transport infrastructure
- require large home ranges
- require several different biotopes
- avoid open areas without shelter

The major conclusions from the work so far are that authorities need a better understanding of the needs of animal species for which fauna passages are designed. The context of the passage including its location, surrounding land use and relationship to movement corridors are all crucial aspects of successful design and maintenance. Monitoring of existing facilities and careful documentation of successes are required to increase the cost effectiveness of fauna passages.

7.3.2. Placing roads in tunnels or construction of bridges in steep terrain

Placing roads in tunnels creates large ecoducts/overpasses above road/rail routes. This has the advantage of making use of natural habitat for movement corridors or of saving sensitive or otherwise important habitats. The option is expensive but may offer the best opportunity to avoid habitat fragmentation in steep of terrain. The savings in length of journey sometimes offset the cost of constructing tunnels.

Similarly, the use of bridges over minor valleys or gorges instead of in-fill creates a natural underpass greatly reducing the fragmentation effects of new road schemes.

7.3.3. Measures to replace wildlife fencing

Fencing as a measure to reduce traffic accidents is controversial. Fencing with high fences to prevent large game species (especially moose) from accessing roads can also act as a serious barrier and thus increase the fragmentation effect of roads and railways. Fencing can also be used to guide animals to safe crossing places e.g. on straight sections of roads with clear overviews by motorists as well as to guide animals to purpose designed fauna passages. Wildlife fencing is commonly used to reduce accidents on roads with traffic densities greater than 10,000 ADT although less trafficated roads down to 5000 ADT are considered for fencing. If fences are used with crossing places, up to a 60% reduction in accidents has been recorded. When used with animal passages 85%+ reductions in road accidents can be achieved (Stikbakke 1997).

Clearing vegetation

The purpose of clearing vegetation (Figure 7.2.) is to reduce the attractiveness of road or railway line vegetation as forage and give better line-of-site to traffic (Andersen et al. 1991). A study of the effect of vegetation clearance (Jaren et al. 1991) was able to quantify the positive effect of removing all bush and tree vegetation along a 20m corridor and understory vegetation from a further 10m zone each side of a railway line where accidents were common. During a 4-year period, a reduction of 56% train kills was recorded. The work also performed a cost-benefit analysis on applying the technique to other stretches of railway. In cases where the annual kill was greater than 0.3 moose per year, the scheme seems profitable to society such that extending the measure to the most accident prone 500km of railway would provide an economic surplus of NOK 31M. To generalise from the study the authors recommend further studies to find the circumstances where vegetation removal was an effective mitigation technique. Vegetation clearance has also been applied successfully to stretches of road with high accident rates. As a mitigation measure, vegetation clearance may be a way of reducing the need for fences along vulnerable roads.

Clearing vegetation may have negative side effects in some settings, e.g. by increasing the effects of fragmentation by roads, by removing a wider area of important habitat, and increasing edge effects. Further studies are required on the total impact of this measure before it can be widely recommended. Until then, it should be used experimentally as an alternative to fencing and to solve specific traffic accident problems.

Figure 7.2. - Vegetation clearance along E18 Akershus, Norway, to reduce collisions with moose. (Photo: B. Iuell)

Warning signs

In Norway, the sign displaying moose crossing roads has become a tourist icon (see Figure 7.3.) The purpose of these signs is, however, more serious; to warn people of the risk of colliding with moose on stretches of road where accidents are common. The signs may also be accompanied by a small text sign displaying for how long the danger lasts e.g. 1-3 km.

however, studies have shown that driver behaviour does not alter significantly after a short time of exposure to such signs.

Figure 7.3. - The moose warning sign. This has become a popular tourist icon and postcards and imitation signs sell well. Unfortunately, drivers do not pay much attention to the real signs if permanent. And neither do the moose, but it happens. (Photos: (right) B. Iuell, (left) S. Persson, Østlandets Blad)

Alternatives to fixed warning signs have been tried in Norway. One of the reasons for warning signs failing to affect driver behaviour is that many of them are set up permanently - even if the danger of animal collisions is seasonal. The Norwegian Public Roads Administration has undertaken a survey of alternative measures including temporary signs, signs with flashing lights during periods of high danger and heat sensitive warning lights combined with warning signs (Stikbakke 1997). The method has a high potential to reduce traffic accidents but requires further studies of its overall cost and impacts (some require vegetation clearance and regular maintenance). Sensor technology is developing rapidly resulting in increases in the range of sensors; current models are effective over 250m. The method may also be valuable on high traffic density roads at places where game are led to narrow crossing points by guide fences as an alternative to continuous fences acting as a barrier to movement.

Additional measures to reduce road casualties

Several measures to prevent animals wandering onto roads that have fragmented their home range have been tried in Norway. Most of these have been targeted at moose and include winter feeding to prevent moose being killed when migrating to richer grazing at lower altitudes and the use of reflectors and mirrors which divert the beam of car headlights into flashes of light penetrating into forest. Speed limits reduce the speed of vehicles on stretches of road vulnerable to accidents involving game species. Slower vehicles have time to avoid collision or give time for game to disperse.

These and other measures such as the use of chemical and natural odours are all of interest in reducing road casualties. Some of them are undergoing systematic tests to quantify their effectiveness.

7.4. Overview of compensation measures

Compensatory measures are the replacement of damaged or destroyed habitats by the construction of alternative areas. In many cases this is not a viable alternative as the site is important in its context e.g. wetlands important for migratory birds or wetlands dependant on special hydrological conditions. There are few Norwegian examples of compensatory measures, but the approach has been used to safeguard freshwater systems during the construction phase (e.g. use of settlement ponds or other barriers to pollution). An example of compensation measures for the long-term protection of a habitat from fragmentation is the case of a stream draining the Årungen lake in south-eastern Norway. Planned road upgrading and re-alignment parallel to the stream involved a culvert for 200m of the stream as it ran under the road. This was considered a barrier to the movement of salmon and sea trout and likely to reduce production in the system An alternative plan which involved the compensatory building of a completely new river bed designed to provide good habitat for fish was agreed. The new plan resulted in only a short length of stream being placed in a culvert under the road (Figure 7.4.).

Figure 7.4. Photograph of the new river bed and culvert of constructed for Årungselva as it ran close to a stretch of the E6 Akershus, Norway, being upgraded to dual carriageway. Under construction and after. (Photos: B. Iuell)

7.5. Existing quality standards for measures; justification, minimum requirements.

Norway is currently reviewing measures to reduce fragmentation effects of transport infrastructure through monitoring and assessment of on-going projects. Currently there are no specific engineering specifications for fauna passages and other measures although the Public Roads administration has developed guidelines for fauna passages and for measures to reduce animal casualties (see section 7.3.1.) A Norwegian handbook on these issues is planned to be produced, built upon the results of the COST 341 Action.

7.6. Maintenance aspects

The fragmentation of areas where there were previously no roads or railways are the most important fragmentation problem caused by transport infrastructure. The way roads and railways are maintained may either mitigate or worsen this effect. The management of verges, clearing of snow, de-icing chemicals etc. can all have a negative impact on nature.

7.6.1. Verge management

The establishment and management of roadside verges and embankments is an increasingly important aspect of road planning. Road verges play a major role in the visual impact of roads, the driver experience, screening against visual and noise disturbance, the incidence of animal casualties.

Vegetation establishment along roads involves many variables and functions. Some of these functions conflict with each other and demand priorities to be decided in relationship to specific local conditions and needs. Techniques of establishing vegetation along roads are well developed internationally and there have been several local and more general studies in Norway (Håbjørg 1992, Pedersen and Håbjørg 1995). Several research projects have focussed on the practical problems concerning the establishment of vegetation in relation to topsoil removal, pollution, water and nutrient availability and wind. Several projects have examined the possibility of using native plant seed mixes to establish meadow-like roadside vegetation. Emphasis of these studies has been to answer questions related to the establishment problems and maintenance requirements associated with meadow-like vegetation.

The verges of both major and minor roads can be very rich habitats for plants and insects. Although there have been few systematic biological surveys of roadside verges in Norway, the results support findings in other European countries. For example, in the county of Akershus in southeast Norway more than 20% of the national flora was recorded in a small sample of roadside verges (Framstad and Lid 1998). The factors most affecting plant diversity are timing of cutting, chemical treatment and width. Of special interest in roadside verges are species that are otherwise associated with dry grassland communities such as hay meadows. These species are declining rapidly on farmland because of intensification in arable farming areas or through the abandonment of meadows in marginal farming areas.

A study in the county of Sogn and Fjordane (Auestad et al 2000) set out to investigate the importance of roadside verges for the conservation of biodiversity in Norway. The work involved a county-wide botanical survey of roadside verges as well as their ecological and management characteristics. As the county has a wide biogeographical range, the results may be applied to several other areas of Norway. The results permitted roadside verges to be classified into 9 major types reflecting geography, climate, nutrient status, soil moisture, adjacent land use and stability. Some plant species were widespread and found in most types of roadside verge (e.g. *Agrostis capillaris* and *Festuca rubra*). Some species were associated with disturbed habitats including the tall herbs (*Digitalia purpurea* and *Verbascum thaspsus*) which thrive in gravel-dominated verges. Small plants capable of surviving dry, unstable habitats such as infilling and embankments were *Linarea vulgaris* and *Viola tricolor*. Several common meadow species are also common in roadside verges (*Potentilla erecta*, *Acillea millefolium, Plantago lanceolata*). Where roadside verges are adjacent to forest edges or heathland, they typically contain several species typical of these habitats.

Roadside verges have their own zonation with a dry, disturbed zone closest to the road, a mid zone more typical of grassland plant communities and an inner zone which reflects adjacent vegetation communities. Stability related to age, history and management were important factors in determining vegetation richness. The richest verges were those with stable meadow-like grassland communities. In these verges were found several typical meadow species such as *Campanula rotundifolia, Anthoxanthum odoratum, Silene vulgaris, Knautia arvensis* and *Lathyrus pratensis*. Verges also contain some declining grassland species including the orchid *Platanthera chlorantha*, as well as other rare species such as *Androsace septentrionalis* and *Logfia arvensis*. The future of these meadow-like verges is dependent on suitable management especially the date and frequency of cutting to maintain an open habitat cut after seed setting. Removing the cut vegetation helps to prevent nutrient enrichment and invasion by quick growing species. For some meadow species, roadside verges can be an integral part of their management strategy in a time where their natural habitat is threatened by abandonment.

The Public Roads Administration has included the need for timing of cutting to take into account the seed setting of verge plants in its guidelines verge management. Work is also underway to find locally appropriate seed mixes that reduce the need for maintenance. This is also required to improve larger areas of seeded soils associated with road construction work that will receive little or no maintenance.

Guidelines for verge management have to balance several verge functions including drainage, road visibility, protection of the road surface, access to drains and culverts, snow clearance, game accidents, mechanical cutting procedures, power and telephone line utilities, and public access in the form of footpaths, cycle-ways and pavements.

7.6.2. Management of other surfaces

Rail track management includes the use of chemicals for vegetation control and the removal of vegetation for safety reasons and to reduce animal casualties (see section 7.3.1.).

7.6.3. Co-ordinating land use in adjacent areas

The management of the land adjacent to the fauna passages and other measures is an important issue. It is clear that greater co-operation is required with those who own and manage land adjacent to mitigation measures - this may be a considerable area in the case of large game species such as moose. Without such co-operation, large sums of money may be wasted on elaborate animal passages to no significant effect. The road and rail infrastructure associated with the new Oslo airport highlights these problems where planned land use changes from forest to open habitat or to housing and industry will alter the permeability of the landscape for moose. The changes are likely to negate the large investment in a large overpass and alter the need for and placing for moose crossing places (Kastdalen 1999).

7.7. Evaluation and monitoring of the effectiveness of measures

The evaluation of existing measures to assess their effect on animal movement and road casualties is considered a priority by the Norwegian Public Roads Administration. Several projects are underway and the results will be used in the formulation of guidelines for the design of fauna passages, fencing and animal crossings (see section 5.6.)

7.8. Summary

Avoidance of fragmentation remains the preferred method of avoiding wildlife impacts of transport infrastructure development. Placing roads or railway lines in the landscape such that they avoid sensitive habitats is the best option but not always practical. For wetland and shoreline development, avoidance is the only effective measure. In cases where fragmentation cannot be avoided, then minimising the effect by safeguarding as much as possible of interior habitat conditions is important. Where habitat is unavoidably fragmented fauna passages become necessary. Natural over and underpasses using the natural terrain and bridges and tunnels seem to be the best alternative.

Fences used to reduce fauna casualties can seriously worsen fragmentation effects and many other devices have been used to reduce accidents yet avoiding the need for fences. Guide fences have also been used to direct animals to safe crossing places. Because of the number of accidents involving moose and other large game species, this problem is currently a high political priority because of the social and emotional cost of such accidents. The moose is the most serious problem since many local populations are increasing and accidents often involve serious injury or even death to car passengers. Much of the annual budget for measures to mitigate fragmentation problems is therefore channelled towards efforts to reduce road accidents involving large game, e.g. through use of fauna passages. Whereas from a nature conservation perspective, other aspects of infrastructure are of a higher priority since there is no evidence that game species are threatened by habitat fragmentation or road casualties – even though some local populations may not be viable at current elevated levels. Populations of wild reindeer are the exception; here there is evidence that both on Dovre and Hardangervidda populations are stressed by current levels of infrastructure-related fragmentation. Mitigation of fragmentation in the case of wild reindeer is difficult, as they are extremely shy of human disturbance and unlikely to use fauna passages.

For most species of animal, we lack clear evidence of the seriousness of the threat or knowledge of how best to tackle the problem. This is in part because each species and situation needs careful analysis to formulate effective mitigation strategies. With limited resources, the approach is to accumulate information from case studies to provide general guidelines (Norwegian Public Roads Administration 1998) and supplement this with research on areas where new data is required.

The maintenance of roads and railways also affects their barrier function. Fragmentation effects and road casualties can be significantly affected by maintenance practices. Snow clearance, use of chemicals and verge maintenance are all important issues. Roadside verges are biologically rich habitats and become increasingly important as semi-natural grasslands decline. Several types of roadside verge with long stability possess floral communities normally associated with traditionally managed hay meadows and pastures. Survey of the resource and adoption of management procedures to mimic meadow management are important priorities.

To avoid expensive mitigation measures transport policy favours the placing of transport networks in the landscape to minimise impacts on nature. Methods to aid the assessment of impacts of alternative routes for new road and rail development at the planning stage e.g. using GIS analysis to analyse for vulnerability to fragmentation of species populations and natural areas are under development.

Chapter 8. Habitat fragmentation and future infrastructure development

8.1. Introduction

Norway has produced National Guidelines for Co-ordinated Areal and Transport Planning which were adopted in 1993 and set out the needs and aims of transport planning.

These guidelines provide the basis for planning in relation to the Plan and Building Act. They aim to achieve a better co-ordination of planning across administrative boundaries and across sectoral interests.

The guidelines specifically treat the following themes:

- to make clear national goals in relevant to land use and transport planning
- to clarify important principles that should be given weight in planning decisions
- to emphasise the need for co-ordination and responsibility in applying these principles.

Goals for a co-ordinated land use and transport planning in Norway (abstract of points of relevance to fragmentation)

1. Land use and transport systems will be developed to promote socio-economic effective use of resources with environmentally sound solutions, safe local communities and housing environments, good road safety, and effective traffic. These should be achieved through a long-term sustainable perspective in planning. Emphasis should be on achieving good regional solutions across municipal boundaries.

2. Planning of the transport net should aim to integrate the most effective, safe and environmental transport such that the need for transport can be limited by reducing needs to travel and co-ordination between different transport forms.

3. 3 A clear boundary between urban and rural area used for nature, agriculture and outdoor recreation. Impacts of development should be concentrated as much as possible. Along existing road and rail networks the conservation of a differentiated transport system should be safeguarded along with future expansion needs of road and rail networks.

   Emphasis should be on better and more concentrated use of existing development areas including in-filling and increased density in built areas. Design of built areas should include plans to protect green structure, biological diversity and the aesthetic qualities of built areas.

   The needs of an effective transport net must be weighed against the protection of agricultural and natural areas. Decisions concerning development patterns and transport systems must be based on broad evaluations of their consequences including socio-economic aspects long-term aims of agriculture, and protection of natural and cultural environments.

   Damage to valuable natural habitats, cultural landscapes, coastal and river shores, outdoor recreation areas and valuable cultural environments and cultural heritage sites should be avoided.

4. When planning new housing or transport developments solutions should be found such that locating and design protects environmental quality thus avoiding mitigation measures in the future.

5. Environmental and health risks should be taken into account in the locating of development along new transport routes.

6. Adherence to these guidelines should form the basis for payment of state subsidies and loans for large development and transport projects.

8.2. Policies and strategies/trends

The environmental aim of the transport sector in Norway is to avoid disturbance to natural habitats, large coherent areas of undisturbed nature, vulnerable biotopes and other areas of importance for biological diversity when developing and maintaining transport networks.

Fragmentation is seen as a major policy issue by the Ministry of Environment and by all sector interests that can affect habitat fragmentation including the transport sector.

8.3. Indicators/indices of fragmentation

There are no officially adopted indices of fragmentation by transport infrastructure in Norway. The best-known fragmentation index in Norway is the one developed by the Directorate for Nature Management. This index defines disturbance-free natural areas and is based on the distance to nearest heavy technical installations such as roads, railways, tunnels, forest roads, farm roads, routes that can be used by tractors or terrain vehicles, power lines over 33kV, regulated rivers and lakes, and technical installations related to hydro power and other river engineering works. The resultant maps are divided into three zones based on the distance to nearest disturbance, 1-3km (zone 2), 3-5km (zone 1) and over 5km (wilderness areas) from technical installations (Figure 8.1.). These maps offer a comparative index of fragmentation over time and clearly identify the remaining areas of unfragmented habitat. The need now is to develop more detailed indices for specific animal species, since the degree to which animals are disturbed by specific technical installations varies greatly between species. The fragmentation effect of a narrow forest road with only few vehicles per year is unlikely to be the same as a major highway with 10,000 vehicles per day, but the small roads cannot be ignored as they intrude into otherwise undisturbed areas. Ecological studies and full use of existing studies reported in the international literature are required before such maps can be used to make more predictive indices for species. In the meantime, the index offers a barometer of the fragmentation of natural areas due to technical installations and its temporal dynamics in Norway.

Figure 8.1 – Map of Telemark county, Norway, showing areas 1-3 km (zone 2, light green), 3-5 km (zone 1, green) and further than 5 km from nearest technical installations (wilderness areas, dark green) in 1998. Red areas are wilderness areas lost since 1988. (Source: DN, INON)

8.4. Models to predict fragmentation by new infrastructures

Several university and research institutes are working on aspects of habitat fragmentation that are useful to road planning.

8.5. Data on transportation networks development

The current road building plan covers the period from 1998 to 2007. Several the road development plans for his period are considered potentially damaging to biodiversity interests. Most of these include intrusion into sensitive areas or fragmenting beach or riverside habitats. Plans for these areas will be improved to minimise impacts on existing important habitats.

8.6. Summary

Planning roads will continue to present challenges to nature conservation. The further fragmentation of habitats will be extremely difficult to avoid although mitigation measures will be extensively used. Preventing fragmentation is difficult since the terrain in Norway forces roads to follow narrow river valleys and coastal plains. Placing of new roads in the landscape to avoid fragmenting valuable habitats will face strong competition from agriculture and forestry. New road schemes will, therefore, often be controversial and require careful planning of mitigation measures to reduce the severity of habitat loss and fragmentation.

Chapter 9. Economical aspects

Road and rail projects are financed by the Ministry of Transport and Communications. The respective authorities for roads and railways are responsible for both infrastructure development and for EIAs associated with new developments and upgrading. The current EIA process separates priced and non-monetary consequences of infrastructure development. This is a political acceptance that not all values can be priced. Aspects of road development that can be priced include journey time costs, vehicle costs, benefits of new traffic forms, accident costs, environmental damage, maintenance costs, and costs of public transport. Values that are not prised include transport quality, ease of cycle use, recreation, nature, cultural heritage, aesthetics, agriculture and fish, geology and water resources. Special methods have been developed to evaluate non-priced goods in road development based on an evaluation of the availability of the resource and its quality. Fragmentation effects are increasingly used in the assessment of effects on nature.

Chapter 10. General conclusions and recommendations

10.1. Conclusions

- In a European context, transport infrastructure is relatively little developed in Norway, and the roads carry relatively little traffic.

- Transport infrastructure in itself does not constitute a major threat to nature, but the special topographic conditions (which can produce natural barriers) and the special problems associated with moose road casualties which leads to extensive use of wildlife fences can significantly increase the fragmentation effects of infrastructure.

- In Norway, fragmentation by transport infrastructure development (especially private and forest roads) threatens the few remaining large, undisturbed areas of nature.

- Of the habitats most threatened by transport infrastructure, steep river valleys and coastal strips are especially vulnerable as areas where roads and railways are forced into very narrow corridors of land also under pressure from agriculture, industry and housing; mountain plateaux which represent the largest areas of undisturbed nature; wetlands which are especially sensitive to alterations in hydrology; forests and productive habitats near settlements (meadows and pastures) important for their special plant and animal communities and already highly fragmented.

- Few species are directly threatened by infrastructure fragmentation but of these, populations of reindeer are the most impacted with several other species locally impacted including the hedgehog, badger and moose.

- The special climatic and landscape characteristics of Norway give rise to special problems such as barriers caused by high snow banks alongside mountain roads kept open by snowploughs in winter; the extensive network of forest roads in remote areas; and the dissection of mountain plateaux by road, rail and power lines.

- Current mitigation measures include:
    - avoidance of habitat fragmentation during planning of new road & railway links
    - construction of fauna passages
    - protection of surface waters

- EIA procedures for road building projects should include accumulative effects of developing the road network and including other sources of fragmentation

- Research is needed to assess the severity of threat of fragmentation due to transport infrastructure especially on which species and habitats are vulnerable and why.

- Experiments are required to test the benefits of different mitigation measures including when they are appropriate, where to place them in the landscape and detailed design considerations related to specific objectives.

10.2. Recommendations

- Use bridges to act as underpasses as an alternative to in-fill in steep terrain and tunnels as an alternative to deep cuttings in hills and ridges.

- Modify existing engineering structures to function better as fauna passages.

- Avoid all known areas of sensitive habitat including protected areas and species.
- Support development of an integrated approach to infrastructure planning that selects routes and combines mitigation measures to safeguard against habitat fragmentation effects on nature, cultural interests, recreation and landscape.
- Keep the width of the disturbance zone to a minimum during construction (e.g. grading, drainage, width of shoulder etc.) to prevent permanent loss of habitat in the road corridor and increased fragmentation effects.
- Develop methods to incorporate the full costs (both monetary and non-monetary) of fragmentation into road planning.
- Initiate monitoring and evaluation of new and existing measures.
- Develop techniques to identify and map conflict points on existing transport networks.

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