European Co-operation in the Field of Scientific and Technical Research

COST 341

Habitat Fragmentation due to Transportation Infrastructure

The European Review

European Commission
Directorate General for Research

A great deal of additional information on COST Transport is available on the World Wide Web. It can be accessed through the CORDIS server at the following address:
http://www.cordis.lu/cost-transport/home.html
Cataloguing data can be found at the end of this publication.
Luxembourg: Office for Official Publications of the European Communities, 2002
ISBN xx-xxx-xxxx-x

Printed in Belgium

Foreword

"Land is under continuous pressure for new transport infrastructure: between 1990 and 1998 some 33,000 ha, about 10 ha of land every day, were taken for motorway construction in the EU. … Most areas in the EU are highly fragmented by transport infrastructure. The average size of contiguous land units that are not cut through by major transport infrastructure ranges from about 20 km^2 in Begium to nearly 600 km^2 in Finland, with an EU average of about 130 km^2." (EEA, 2001)

One of the most radical changes to the landscape of Europe over the past centuries has been the creation and subsequent extension of infrastructure networks. Towards the end of the 20^{th} century, expansion of the major railway and road networks slowed, but did not cease. At the same time, an ever denser network of minor roads (*e.g.* for forestry), tracks and trails has extended into the last areas of wilderness of Europe. Canals, pipelines, electricity and telephone networks have added to the exponential fragmentation of natural areas, while urbanisation has rapidly increased the built-up area.

Researchers, nature organisations and authorities have expressed their concern over the impacts of fragmentation. Studies have highlighted the risks associated with reducing the size of remnant patches of habitat and, as a consequence, increasing the edge and barrier effects. Only during the past decade has there been sustained, international collaboration to review knowledge about the wider impacts of transportation infrastructure in terms of fragmentation and especially about the means to avoid and mitigate it.

COST 341, which started in 1998, is one aspect of this effort. We now have before us the first result of this project, the European Review of 'Habitat Fragmentation due to Transportation Infrastructure'. This Review presents a growing body of information about fragmentation. A lack of knowledge can no longer be seen as a valid motive for not taking the necessary action to avoid or mitigate against the fragmentation problem. On the other hand, the review also underlines the need for continued, targeted expert study and co-operation.

When the need to mitigate against fragmentation effects leads to the construction of ecoducts and other wildlife passages, the investment required can be quite substantial. If these solutions are also required on existing roads, project execution may not be simple and many agencies have found it very difficult to mobilise the resources needed. This underlines the importance of avoiding fragmentation in the first place, leaving existing habitats intact as far as possible, or contributing to their restoration. Infrastructure authorities and agencies need to maintain close contact with the local authorities and each other to ensure that purposely preserved habitats are kept intact and that the efficacy of wildlife passages is not diminished by other structures or landuse developments.

The participants in COST 341 and the members of the Infra-Eco Network Europe expert group have made an important contribution both to knowledge and responsible practice. I am convinced that their work will proceed successfully and that it will significantly improve our manner of dealing with habitat integrity, and avoiding and mitigating against further fragmentation.

"Umstøđunar skapa alt" (The conditions of life shape everything) (Gaffin, 1996)

Anders HH Jansson
Chairman,
World Road Association (PIARC) Committee on Sustainable Development and Road Transport

List of Contributors

CHIEF EDITOR	CO-EDITORS
Marguerite TROCMÉ	Sean CAHILL; Hans (J.G.) DE VRIES; Helena FARRALL; Lennart FOLKESON; Gary FRY; Claire HICKS; Johan PEYMEN

CHAPTER	MAIN AUTHOR	CO-AUTHORS
Executive Summary	Hans (J.G.) DE VRIES	Tatsiana DAMARAD
Chapter 1	Gerardus J. BEKKER	
Chapter 2	Andreas SEILER	
Chapter 3	Andreas SEILER	
Chapter 4	Helena FARRALL	Irene M. BOUWMA; Gary FRY
Chapter 5	Claire HICKS	Johan PEYMEN
Chapter 6	Annette PIEPERS	Georgina ALVAREZ; Irene M. BOUWMA; Hans (J.G.) DE VRIES; Andreas SEILER
Chapter 7	Verena KELLER	Gerardus J. BEKKER; Ruud CUPERUS; Lennart FOLKESON; Carme ROSELL; Marguerite TROCMÉ
Chapter 8	Franziska BORER	Gary FRY
Chapter 9	Tatsiana DAMARAD	Dick VAN STRAATEN
Chapter 10	Marguerite TROCMÉ	

Table of Contents

Executive Summary

Minimising the Impact of Infrastructure on Nature: A challenge!

Habitat fragmentation has been recognised as one of the most significant factors which contributes towards the decline of biodiversity in Europe, and should thus be a major concern for society. Transportation infrastructure is often considered to be a principal cause of fragmentation. This report provides an overview of the scale and significance of the problem of fragmentation of natural habitats by roads, railways and waterways in Europe and examines solutions that are currently applied. It is one of the products of COST 341 'Habitat Fragmentation due to Transportation Infrastructure', a European Commission (EC) funded research project involving sixteen European countries.

Between 1970 and 1996, the length of the Trans-European Transport Network (TEN-T) almost doubled, to cover 1.2% of the total available land area. Today, the network is made up of *ca*. 75,000 km of roads (*ca*. 20,500 km of which are being planned) and *ca*. 79,000 km of conventional and high-speed railway lines (*ca*. 23,000 km of which are being planned). This significant increase in the length of transportation infrastructure will inevitably create a greater risk of intensifying existing habitat fragmentation. The challenge for European practitioners is to adapt the existing and future transportation infrastructure to ensure it can become an ecologically sustainable transportation system. The critical question thus remains: how can the European transportation infrastructure be upgraded and extended without significantly increasing the fragmentation effect, and how can the problems associated with the existing network be addressed?

Habitat Fragmentation: The problem

Habitat fragmentation involves the splitting of natural habitats and ecosystems into smaller and more isolated patches. This process leads to conditions whereby individual animal and plant species, as well as their wider populations, are endangered by local, then more widespread extinction. Fragmentation is a complex process, in which the loss and isolation of natural habitats are the most important factors. Habitat fragmentation also reduces the availability and the suitability of adjacent areas for wildlife.

Transportation infrastructure contributes towards fragmentation directly by causing habitat loss and disturbance (*e.g.* from noise, visual and chemical pollution) in the surrounding environment. Another direct effect is that the infrastructure often forms a barrier to the movement and dispersal of many species. Furthermore, traffic associated with the infrastructure causes an increase in the mortality risk for fauna, which adds to the fragmentation effect.

De Vries, H. (J.G.) and Damarad, T. (2002) Executive Summary. 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. 11-14. Office for Official Publications of the European Communities, Luxembourg.

The overall consequences of habitat fragmentation for wildlife are difficult to assess because different species respond differently - spatially and temporally - to the loss and isolation of habitat. In general, however, species with large area requirements or strong dependence on a specific type of habitat will be most vulnerable to habitat fragmentation. Unfortunately, these are quite often the species that are of greatest conservation concern *e.g.* wild reindeer (*Rangifer tarandus*) in Norway, badgers (*Meles meles*) in the Netherlands, or the Iberian lynx (*Lynx pardinus*) in Spain.

What are the solutions?

Measures to counteract the problems of habitat fragmentation caused by transportation infrastructure can be classed as:

- Avoidance - abandoning the project altogether or choosing the most appropriate route and design;
- Mitigation - minimising any residual impacts of the project; and
- Compensatory measures - creating, restoring or enhancing habitats to compensate for any outstanding losses.

The three approaches should be applied in the order stated above. Best practice dictates that project planning and design should aim to avoid ecological damage first and foremost, especially for protected or sensitive habitats and/or species, before employing mitigation techniques. Compensatory measures should only be employed as a last resort where avoidance is impractical, and the mitigation measures are considered insufficient.

The principles of avoidance, mitigation and compensation are embedded in European and national administrative policies and legal frameworks. Currently, the most important instruments in this respect are: the EC Directives on Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA), the Habitats and Birds Directives (which together designate the Natura 2000 ecological network), the Convention on Environmental Impact Assessment in a Transboundary Context and the Pan-European Biological and Landscape Diversity Strategy (PEBLDS). Together these promote the establishment and protection of an ecologically sustainable European transportation system. The concept of ‘ecological networks’ (*i.e.* connections between habitats via ecological corridors) has been specifically identified as an effective strategy for addressing habitat fragmentation as it promotes the integration of biodiversity conservation into landuse planning procedures. Referring to these ‘ecological networks’ in the planning of roads, railways and waterways may help to avoid critical bottlenecks in habitat connectivity and identify where mitigation measures are required.

What further action is required?

The information presented in this report clearly emphasises the differences in experiences of dealing with habitat fragmentation between different countries and organisations. Common to all, however, is an acceptance of the importance of the issue. In general, efforts to tackle the negative effects of fragmentation have already led to a marked improvement in the situation. Nevertheless, it is obvious that throughout Europe the science of addressing the impact of habitat fragmentation due to transportation infrastructure is still in its infancy and will require more concentrated effort in the near future. In summarising the experiences of the COST 341 countries, the following principles and recommendations should act as guidelines for dealing with the issue of fragmentation of natural habitats by transportation infrastructure in the future:

- Habitat connectivity is a vital property of landscapes, especially important for sustaining animal movement across the landscape. It should be a strategic goal in the environmental policy of the transport sector and infrastructure planning should be focused on the landscape scale.

- European and national nature protection legislation needs to be integrated in the planning process at the earliest possible stage. Only an interdisciplinary approach involving planners, economists, engineers, ecologists, landscape architects etc., can provide all the necessary tools for addressing fragmentation successfully. The approaches need to be integrated at all levels of the transportation network.

- Because of the complexity and widespread nature of the problem, an ongoing exchange of knowledge through Europe is vital. A systematic and uniform approach to collecting information on mitigation techniques and measures is necessary if statistics are to be compared between countries.

- The disturbance effect created by infrastructure needs to be more widely studied and mitigated for so as to minimise habitat degradation adjacent to infrastructure.

- Mitigation measures such as fauna underpasses and overpasses have a proven record of success. However, mitigation should not only focus on the more prestigious passages for large animals. Much can also be done, at relatively low cost, to increase the permeability of the existing and future transportation infrastructure by adapting the design of engineering structures to wildlife. Many existing wildlife traps could be addressed by adapting local road overpasses and underpasses to allow for at least infrequent use by animals. Engineering structure design processes and standards should be reviewed to assess these possibilities by ecologists.

- Monitoring programmes to establish the effectiveness of mitigation measures are essential and need to be standardised. The cost of monitoring programmes should be included in the overall budget for new infrastructure schemes.

- The fragmentation of natural habitats by transportation infrastructure is a problem which cannot be solved without an acceptance of the issue at a policy level, and without interdisciplinary co-ordination and co-operation at scientific and technical levels. Public involvement is also essential, to ensure the success of the chosen solutions.

Throughout Europe the process of addressing the impact of habitat fragmentation due to transportation infrastructure is still in its infancy, nevertheless, it is also clear that positive progress has been made in tackling the negative effects. Valuable experiences can be learned from densely populated and intensively developed countries like The Netherlands, where the problems of habitat fragmentation have long been recognised. Many other European countries have also developed national programmes of research into the effects of infrastructure on biodiversity, the findings from which must be used to inform the planning and design procedures for new infrastructure. There is still a long way to go before ecological tools are fully developed and implemented in transportation planning. It is hoped that the COST 341 European Handbook '*Wildlife and Traffic – A European Handbook for identifying conflicts and designing solutions*' which complements this Review, will assist in raising awareness of the problem and promote best practice within the planning and transport sectors. The key to success is the adoption of a holistic approach that allows the whole range of ecological factors operating across the landscape to be integrated within the planning process. The problem of fragmentation and its solutions are universal, therefore joint research and combined international efforts are required. To develop adequate tools for assessing, preventing and mitigating against the ecological impact of infrastructure requires interdisciplinary work. A significant challenge to ecologists, road-planners and civil engineers alike is the establishment of an ecologically adapted, safe and sustainable transportation infrastructure system.

Chapter 1. Introduction

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 are 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

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. Office for Official Publications of the European Communities, Luxembourg.

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. 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

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.

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. Office for Official Publications of the European Communities, Luxembourg.

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.

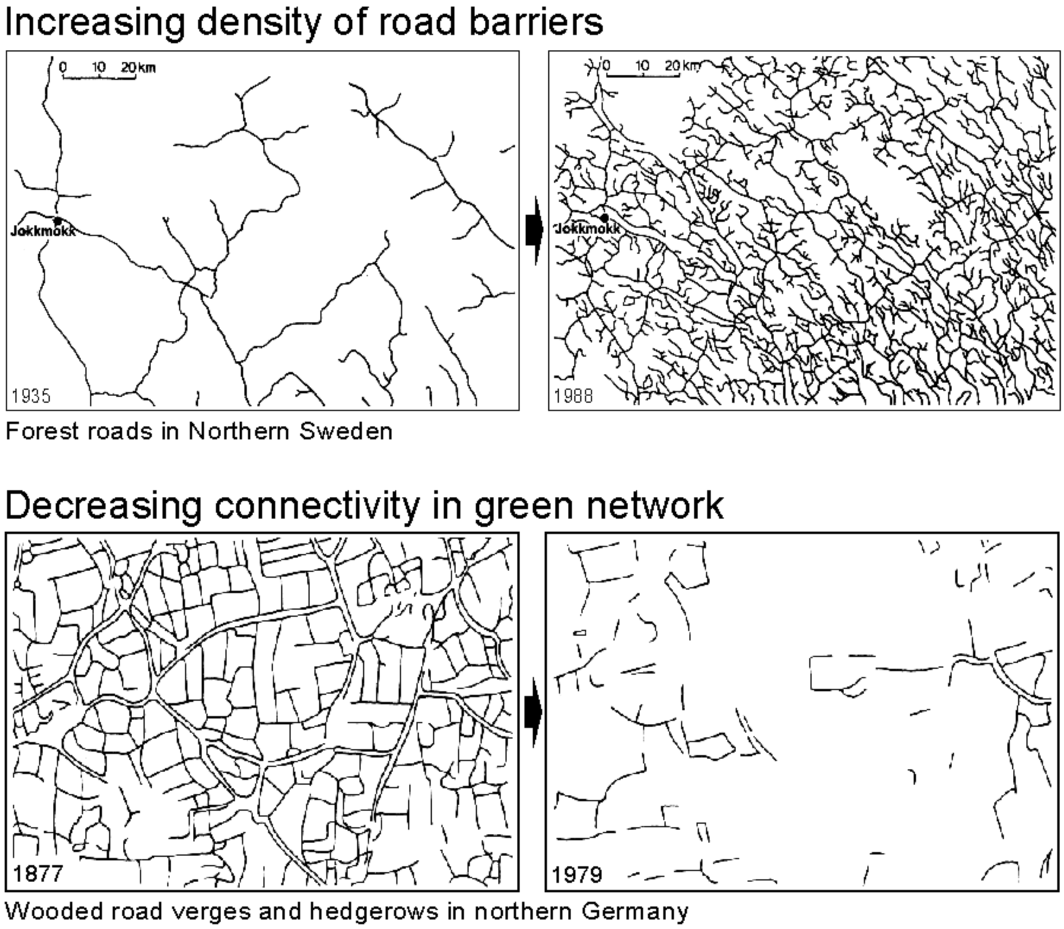

Figure 2.1 - Landscape change due to fragmentation and loss of connectivity. Top - Increase in forest road network in the Jokkmokk area in northern Sweden between 1935 and 1988 (after Bernes and Grundsten, 1992). Lower - Loss of vegetated corridors (tree rows, hedgerows, road verges) in the agricultural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

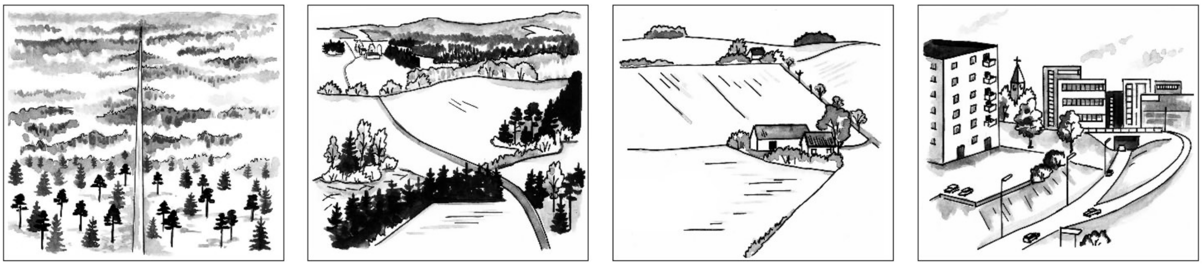

Figure 2.2 - Four types of landscapes that differ in the degree of human impact: A) A natural forested landscape containing a variety of natural ecosystems and habitats with little or no human influence; B) A mosaic, rural landscape where pastures, fields blend with forests that connect through hedgerows 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).

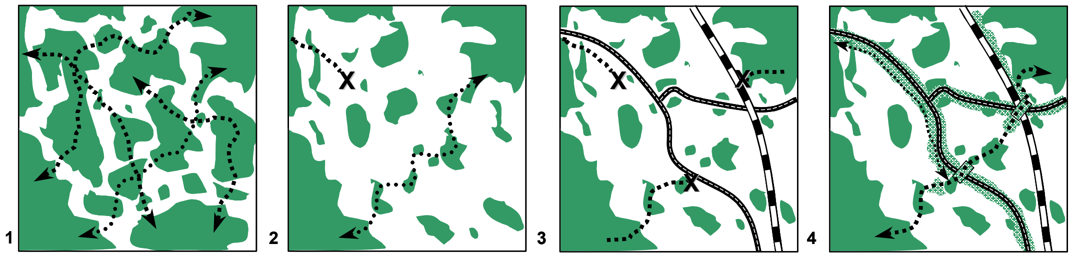

Figure 2.3 - (1) Fragmentation of an animals' habitat (shaded areas) reduces the ability of individuals to move across the landscape. (2) Some connectivity may be sustained through small habitat fragments or corridors. (3) Infrastructure imposes additional movement barriers and strengthens the isolation 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.

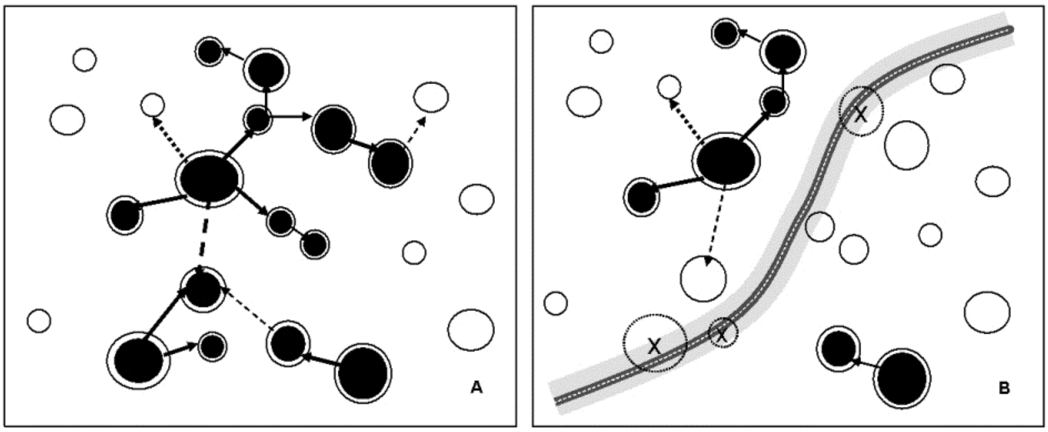

Figure 2.4 - Barrier effects on populations: (A) A metapopulation consists of a network of local populations that may vary in size and local dynamics, but are linked to each other through dispersal. Small local populations are more likely to go extinct than large populations, but the risks of this are 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).

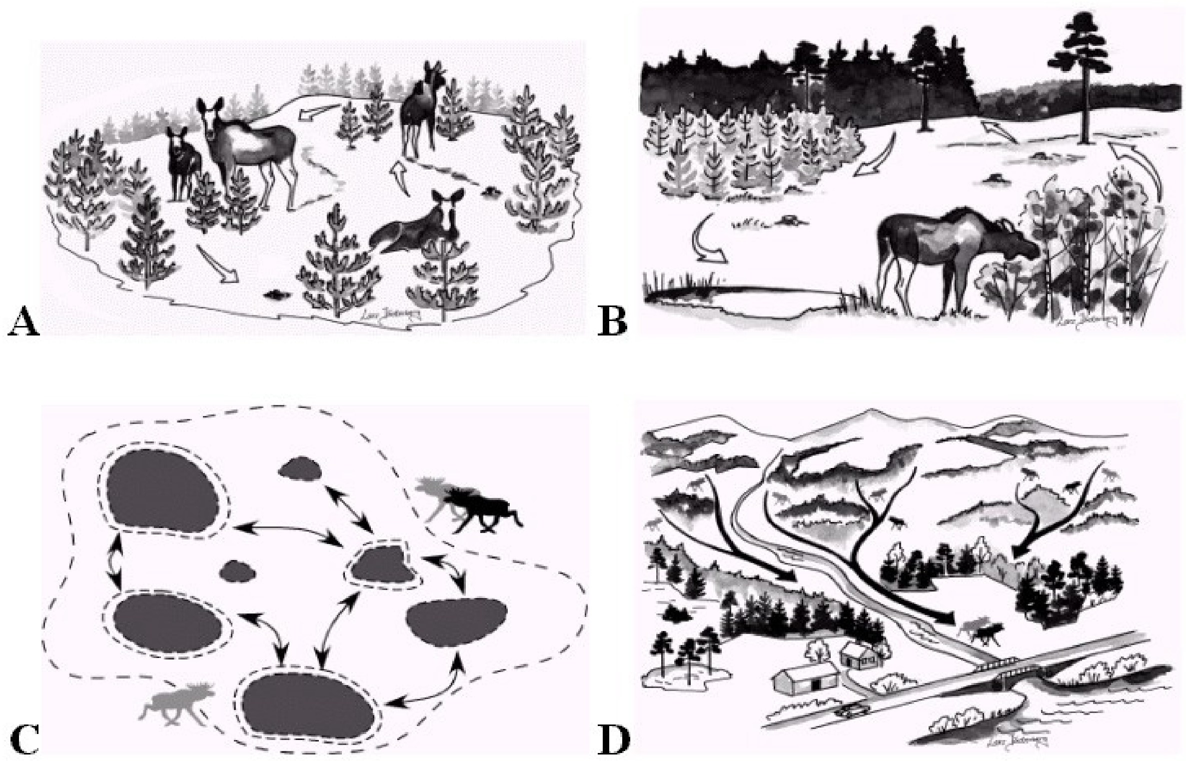

Figure 2.5 - Four basic types of animal movements: (A) Foraging movements of an individual within a forest stand; (B) diurnal or commuting movements between forest patches within the home range of an individual; (C) dispersal movements (emigration and immigration) between local populations; (D) migratory 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.

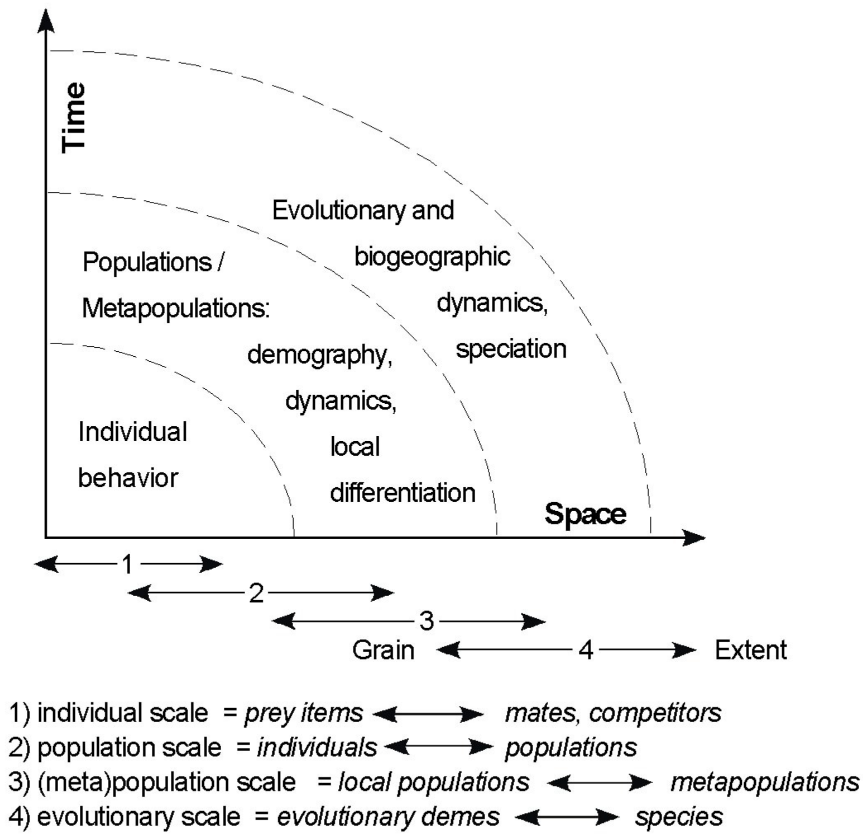

Figure 2.7 - Domains of scale in space and time. Enlarging the scale shifts the focus towards higher organisational levels that reveal new processes and dynamics. Nb. large spatial scales refer to small scales in map dimension. (Combined from Wiens, 1989 and Haila, 1990)

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).

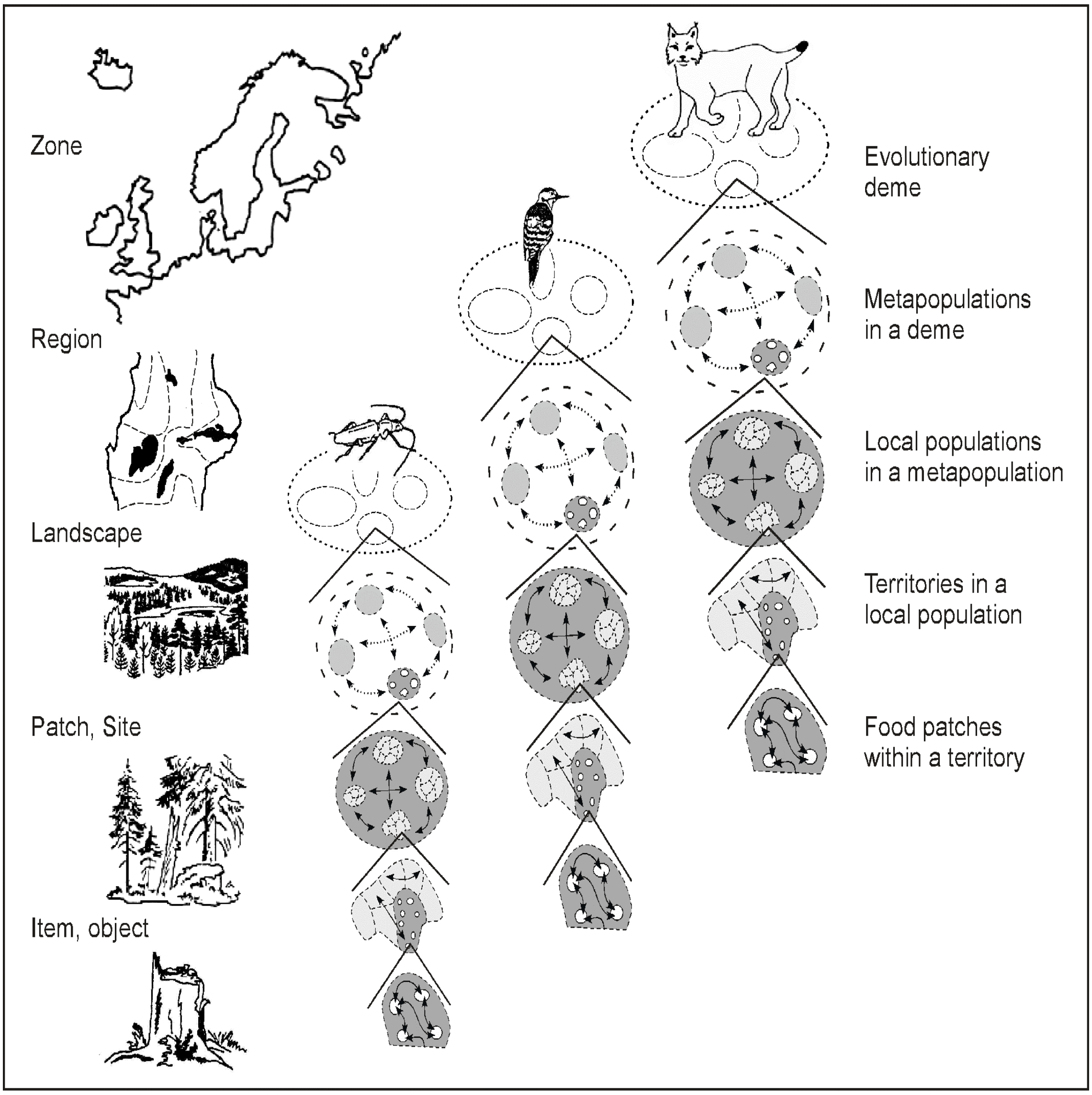

Figure 2.8 - Hierarchical layering in ecology. Food patches are nested in individuals' territories, which make up the habitat of a local population. In turn, these local populations make up metapopulations that together comprise the evolutionary deme of a species. At each hierarchical level (*i.e.* site, 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 are 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

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.

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. Office for Official Publications of the European Communities, Luxembourg.

- *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).

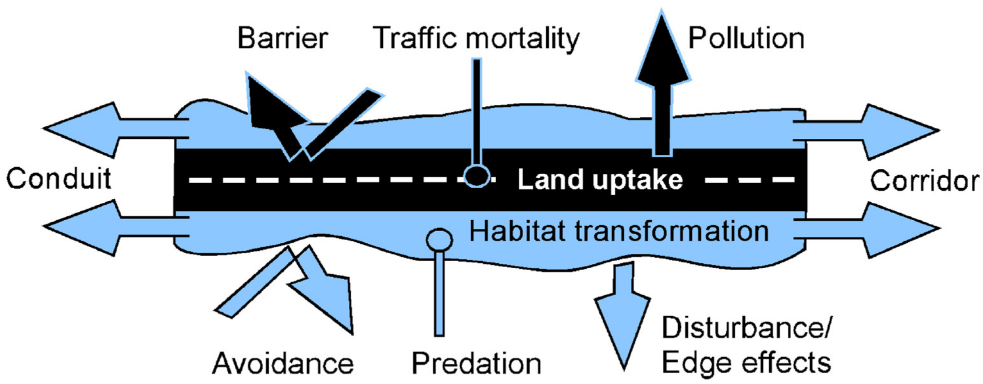

Figure 3.1 - Schematic representation of the five primary ecological effects of infrastructure which together lead to the fragmentation of habitat. (Modified from van der Zande *et al.*, 1980)

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.

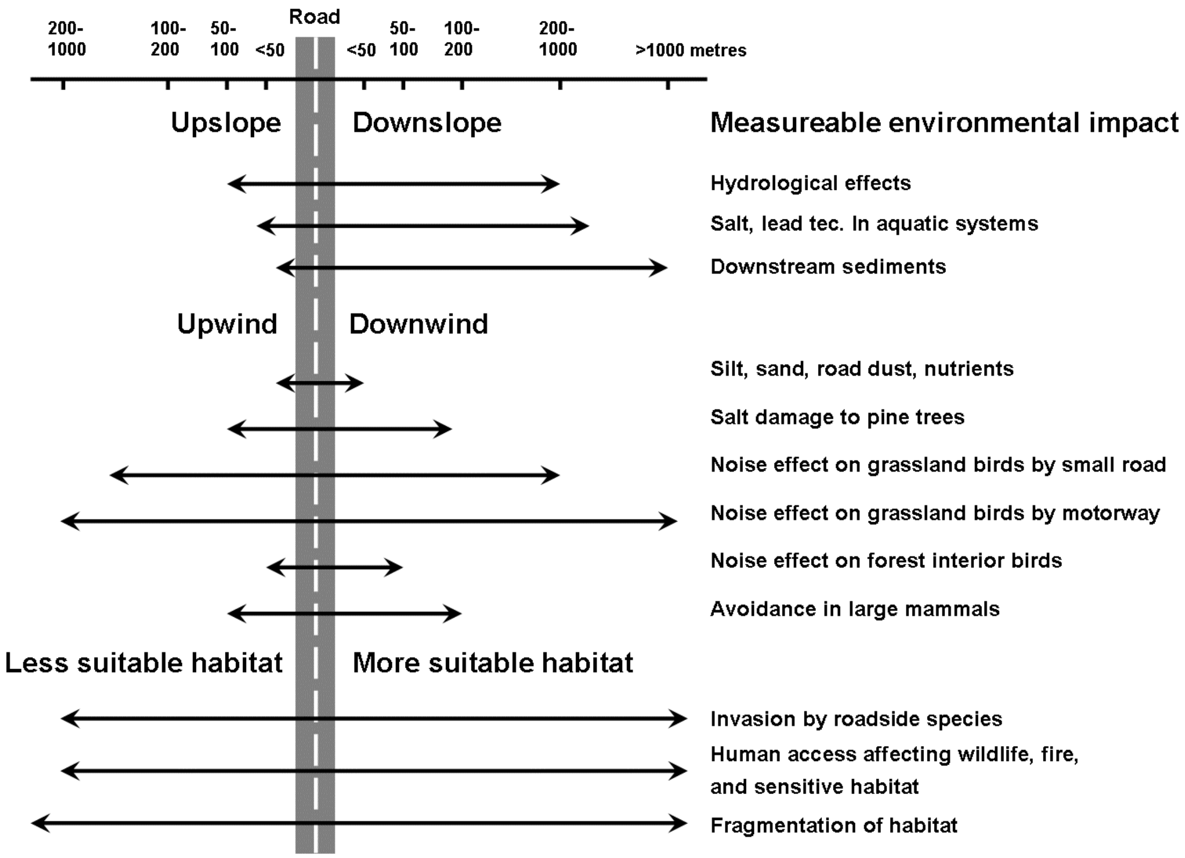

Figure 3.3 - Disturbance effects spreading from a road into the surrounding landscape. The distance over which disturbances affect nature depends on topography, wind direction, vegetation and the type of disturbance. The width of the affected zone is likely to be larger than some hundred meters on average.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

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).

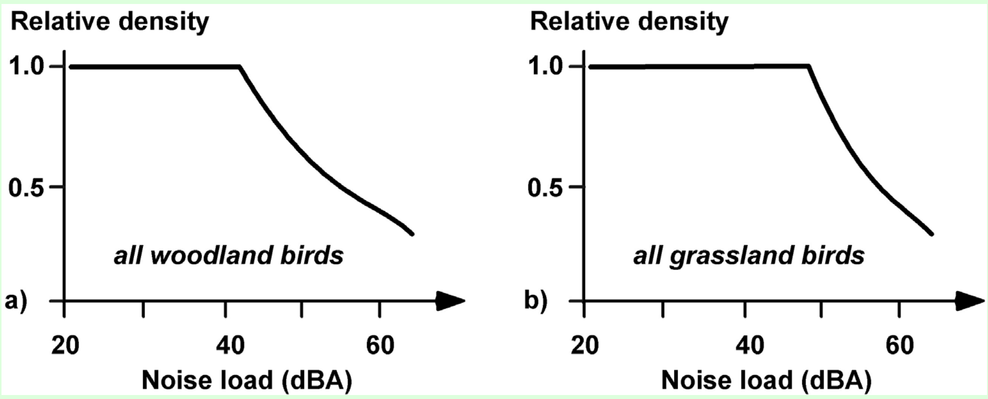

Figure 3.4 - Schematic representation of the impact of traffic noise on breeding bird populations in The Netherlands. When the noise load exceeds a threshold of between 40 and 50 dBA, bird densities may drop significantly. The sensitivity to noise and thus the threshold is different between species and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

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.

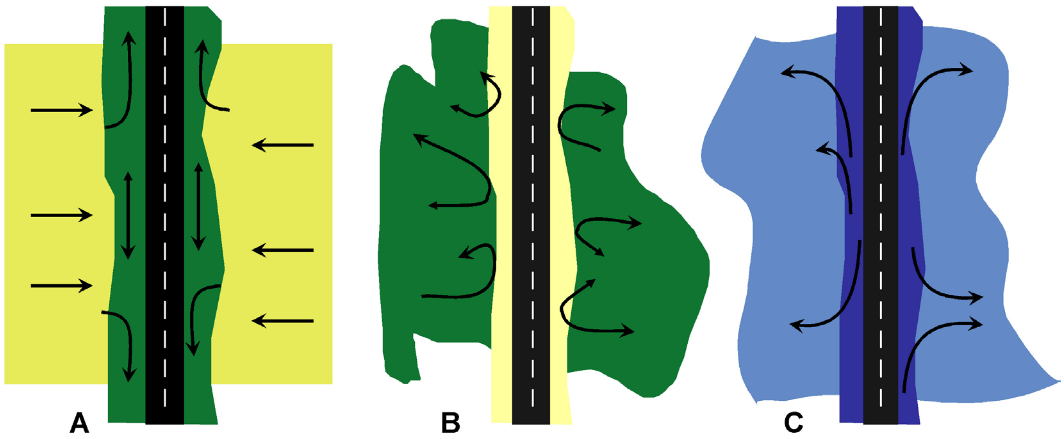

Figure 3.6 - The corridor function differs with respect to the surrounding landscape: A) Open, agricultural landscapes: richly vegetated verges can provide a valuable habitat for wildlife and facilitate movement. B) Forested landscapes: open and grassy verges introduce new edges and can increase the 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 (see Section 5.3 and Table 5.7).

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

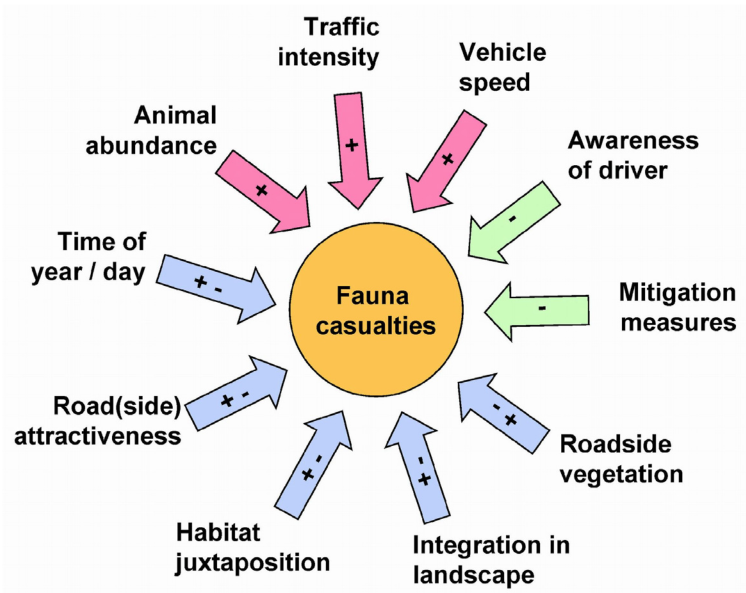

Figure 3.8 - Factors influencing the number of wildlife traffic accidents.

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 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?

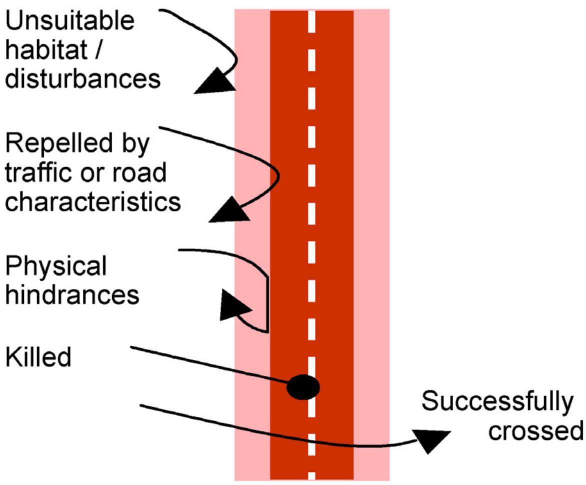

Figure 3.9 - The barrier effect of a road or railway results from a combination of disturbance/deterrent effects, mortality and physical hindrances. Depending on the species, the number of successful crossings is but a fraction of the number of attempted movements. Some species may not experience any 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.

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.

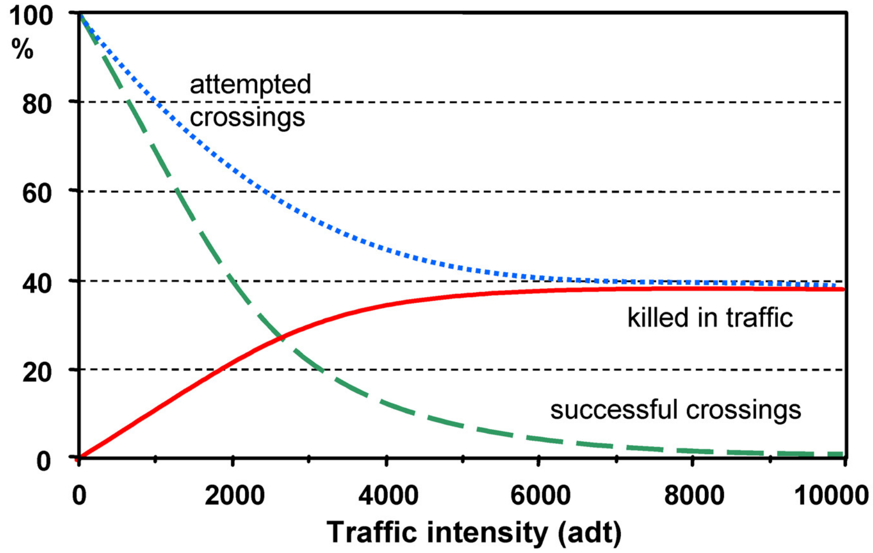

Figure 3.10 - Theoretical model illustrating the relationship between traffic intensity and the barrier effect: with increasing traffic, the number of roadkills increases in a linear fashion until noise and vehicle movements repel more animals from attempting to cross the road; at very high traffic volumes, 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.

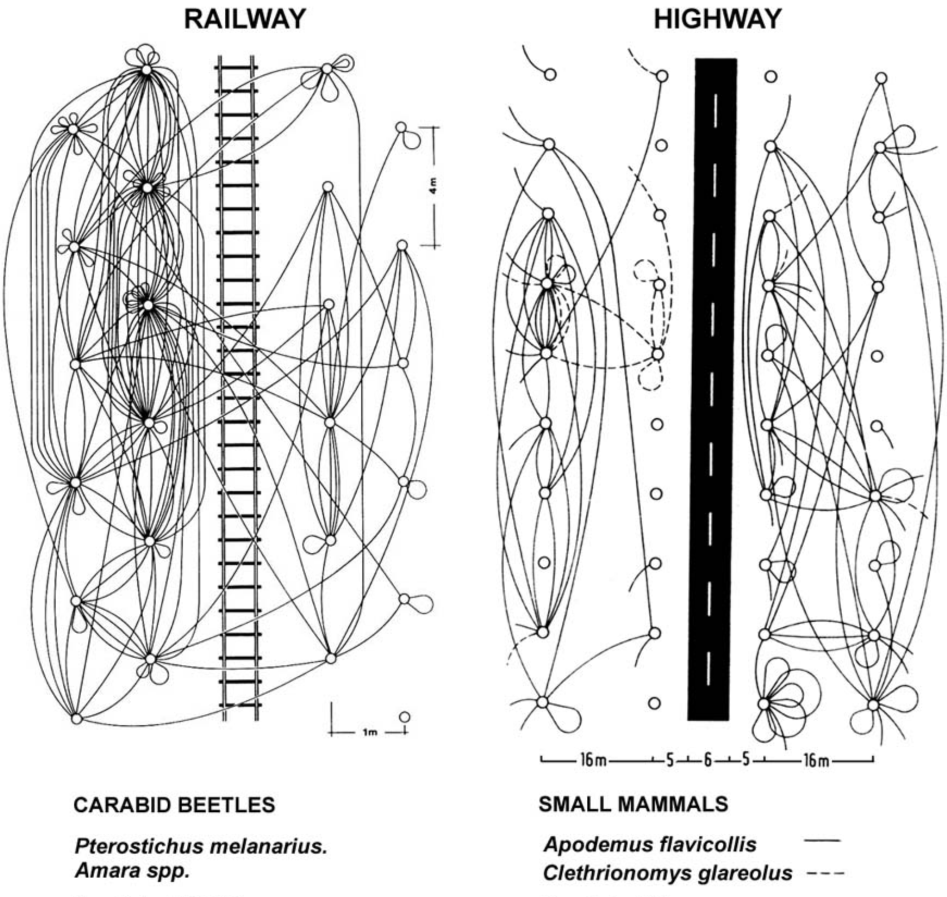

Figure 3.11 - Mobility diagram illustrating animal movements along and across a railway and road, based on capture-recapture data of: (left) carabid beetles (redrawn from Mader *et al.*, 1990); and (right) small mammals. (Redrawn from Mader, 1984)

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.

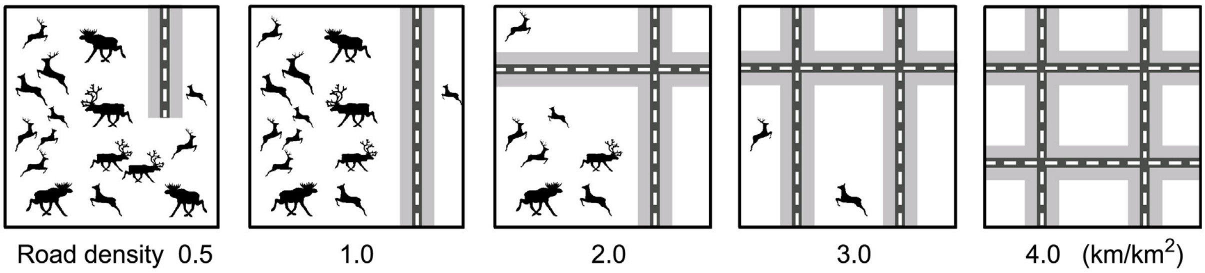

Figure 3.12 - Infrastructure causes a loss and degradation of habitat due to disturbance effects (grey corridors) and isolation. With increasing infrastructure density, areas of undisturbed habitat (white) are reduced in size and become inaccessible. Remnant fragments of suitable habitat may eventually 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. European Nature and Transportation Infrastructure

Habitat fragmentation in Europe is a result of human-induced change in the natural landscape *e.g.* industrial development, urban expansion and agricultural intensification. Over time, innovation and technology have resulted in an increased rate of change in the natural environment. By the second half of the 20th century, the fragmentation of natural and semi-natural habitats was acknowledged as one of the main causes for the decline in biodiversity in Europe. Infrastructure development has been identified as one of the most important fragmentation processes affecting habitats and species. With a focus on the role of transportation infrastructure, this chapter examines the main European habitat types threatened by fragmentation, the causes of that fragmentation and describes current policy responses to it.

4.1. EUROPEAN NATURE

Agriculture, forestry, water management and urbanisation have profoundly changed the natural vegetation in Europe thus influencing the distribution of species and habitats. According to Bohn (2000), without intervention the natural vegetation of Europe would consist mainly of different types of forests, whereas the actual vegetation is currently characterised by a broad range of cultural landscapes (Stanners and Bourdeau, 1995). At present, the land cover across Europe is dominated by arable land (34%) and coniferous and deciduous forests (17% and 9%, respectively) - see Figure 4.1. The difference between the natural vegetation of Europe and the actual land cover provides an insight into the habitats that are most threatened by fragmentation processes. The cover of woodland in countries such as The Netherlands and Denmark represent mere remnants of once extensive woodland cover. In other countries *e.g.* Scotland, afforestation over the past 50 years has increased the woodland cover but the plantations of predominantly alien tree species do not suport many of the native woodland flora and fauna. Other highly fragmented habitats include heathland and wetlands.

Some of the important cultural landscapes shaped by humans but rich in species are also threatened by fragmentation. These include many of the remaining examples of species-rich habitats created by traditional farming practices *e.g.* hay meadows, extensive pastures and mountain summer farms. Many of these habitats have become increasingly vulnerable to fragmentation as these farming practices have become marginalised.

Farrall, H; Bouwma, I.M. and Fry, G. (2002) European Nature and Transportation Infrastructure. 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. 51-71. Office for Official Publications of the European Communities, Luxembourg.

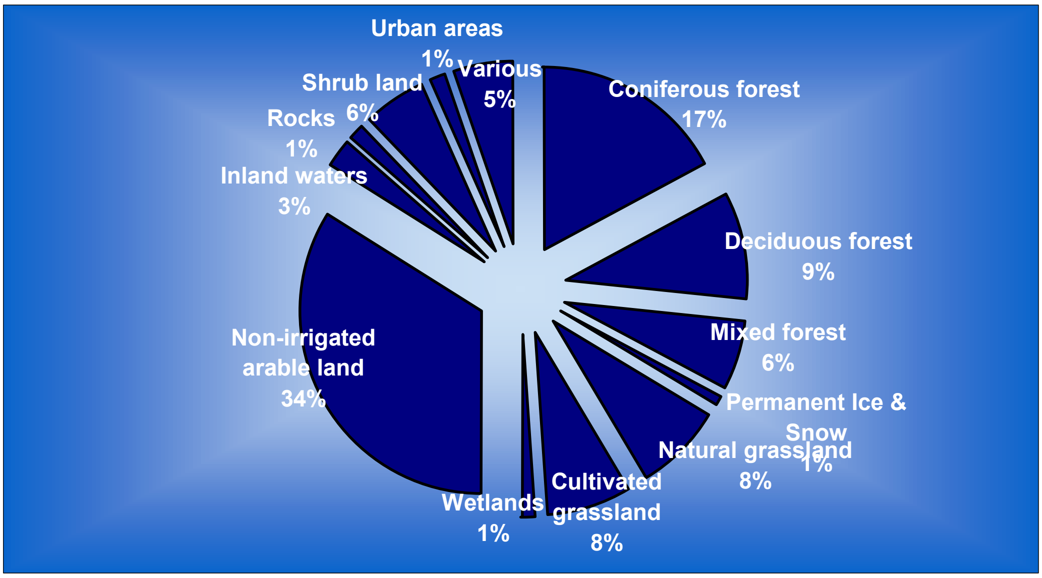

Figure 4.1 - Current distribution of landcover types in Europe, including European Russia. (After Mucher, 2000)

As yet, systematic information regarding the state of nature and landscapes in the different European regions is scarce; most of the available information relates to the abundance and distribution of species. In Europe, approximately 215,000 species are known to occur, of which 90% are invertebrates (Stanners and Bourdeau, 1995). In total, 172 vertebrate species and 2,851 of the higher plant species in Europe are globally threatened; 15 species (7 vertebrates, 7 invertebrates, and 1 plant) are known to have gone extinct in Europe (IUCN, 2000).

Analysis of data regarding the distribution of different species from the European atlases gives an indication of the species richness of the different European biogeograhical regions. It shows that the Mediterranean and Alpine regions are important because they support high species diversity in a relatively small area. Mammals and breeding bird species are evenly spread over the European regions, whilst amphibians and reptiles are concentrated in the Mediterranean and Continental regions (EEA, 1998a).

Figure 4.2 gives a more detailed picture of the variation in species richness throughout Europe. The analysis shows that the hotspots of richness (based on the distribution of mammals, breeding birds and plants) are concentrated in the Alps, Pyrenees and Central and Southern Europe. However, care should be taken in interpreting these figures as they are influenced by the recording effort undertaken in the different countries: low richness in Southern Europe is likely to reflect less intensive recording efforts.

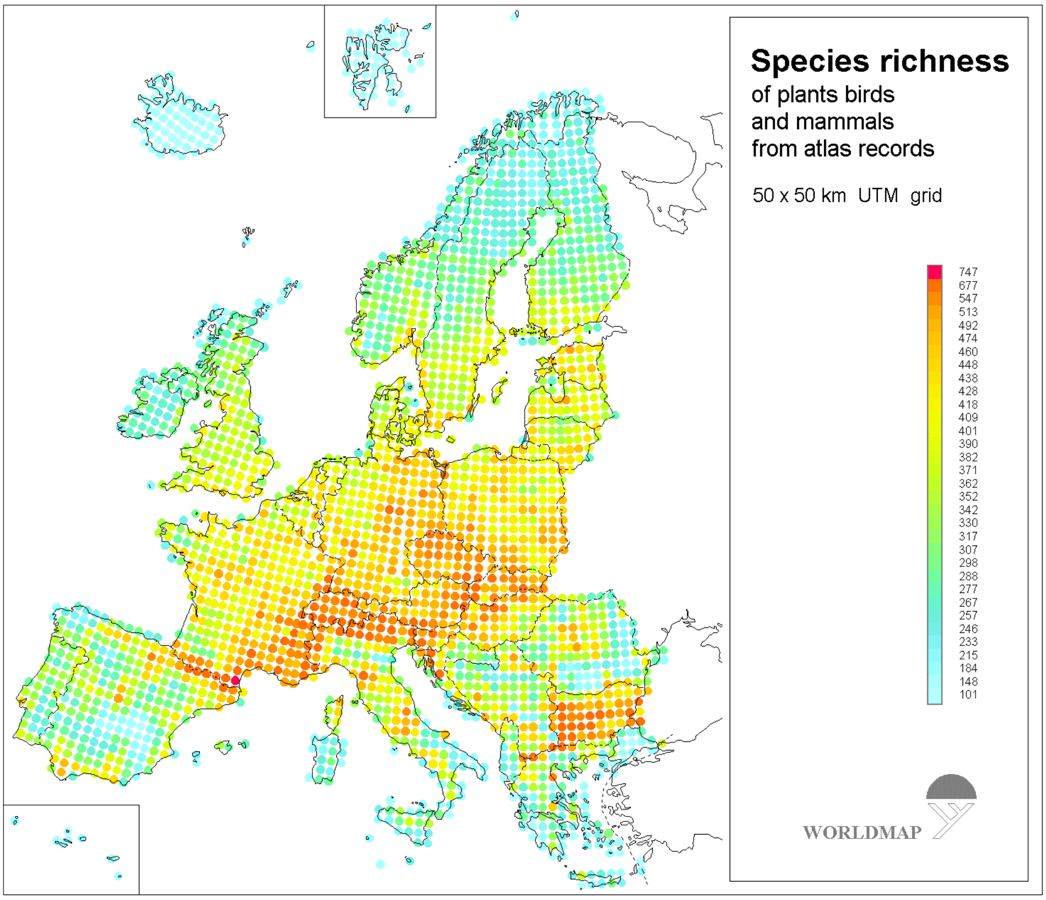

Figure 4.2 - Species richness across Europe. (From Williams *et al.*, 1998)

Data on species distribution is important for shaping conservation strategies but gives little insight into the important processes of migration and dispersal. Migration and dispersal are vital aspects of animal ecology, which form the key to survival in fragmented habitats. The potential for animals and plants to disperse is partly conditioned by natural features and partly by their own ecological characteristics. Mountain chains like the Alps, the Pyrenees and large rivers have acted as natural barriers to the dispersal and migration of terrestrial mammals. Where such natural barriers are present, special care should be taken to ensure human-induced barriers do not significantly increase the barrier effect. Yet, it must also be acknowledged that the major European river systems have provided the main dispersal corridors for some species. Although a substantial amount of information has been collected on the migration routes of birds and fish in Europe, very little data is available for other species groups.

4.2. THREATS TO EUROPEAN NATURE (OVERVIEW OF FRAGMENTATION)

4.2.1. Causes of fragmentation

Habitat fragmentation is the result of increasing human demands on the landscape associated with activities of various economic sectors *e.g.* agriculture, forestry, construction and transport. Case studies in various regions show that changes in agricultural practice since the 1950s are the most important cause of habitat fragmentation across Europe (Jongman, 1995; Mander *et al.*, 2001) particularly due to the process of intensification. Extensive farming systems including semi-natural grasslands, wetlands, hedgerows and small forest patches have been removed and remaining patches have become more isolated. For example, in England and Wales the total stock of managed hedges decreased by 186,000 km (33%) between 1984 and 1993 (UK-SoA); in The Netherlands the surface area of woodland and heathland almost halved between 1900 and 1990. In addition, marginalisation and land abandonment of land have led to the fragmentation of semi-natural grasslands. For example, in Estonia, a decrease in natural pastures and grasslands from 18,360 to 2,860 km^2 has occurred since 1900, partly due to natural forestation or commercial afforestation.

Within the forest industry, an increase in logging of old-growth forest and replacement of native species by introduced (coniferous) tree species have also contributed to the fragmentation of continuous areas of old growth and native forests (N-SoA). In densely populated areas in Europe, urbanisation and the development of transportation infrastructure are major causes of habitat fragmentation (N-SoA; F-SoA; EC, 1999).

Overall in Europe, the average size of continuous habitat patches is decreasing. The analysis of land partition by infrastructure in the European Union (EU) indicates that the average size of remaining non-fragmented land parcels is 130 km^2 (see Section 4.3). The reality of fragmentation may be much worse than indicated, since private and forest roads are not systematically mapped and hence may not be fully taken into account. By examining the proximity of protected areas to transportation infrastructure, it is evident that there is an increasing problem with road and railway infrastructure disturbing protected sites *e.g.* birds' designated Special Protection Areas (SPAs) and Ramsar wetlands: already a total of 1,650 SPAs and 430 Ramsar sites (66 and 63% respectively of the total number designated in 1997) are disturbed through having at least one major transportation infrastructure within 5 km. Most landtake for roads is from agricultural land (58%), with forest (14%) and wetlands (1%) being the major natural habitats impacted upon. However, although the area taken for infrastructure development is relatively small in itself, the barrier effects and the 'disturbed zone' impact upon a much wider area.

4.2.2. Sensitivity of ecosystems and species to fragmentation in Europe

The sensitivity of habitats and species to fragmentation is determined by several factors (see Chapter 2). Some habitats are more sensitive to disturbance than others *e.g.* those requiring large areas to fulfil their special light, hydrological or microclimate requirements. Habitats that are the home to species with a large area requirement and a medium to large dispersal capacity are considered to be sensitive to the large-scale fragmentation occurring in Europe, whether caused by linear infrastructure or other types of landuse (Foppen *et al.*, 2000). This is especially true for the last remaining areas of semi-natural vegetation such as wetlands and woodlands. Habitats supporting species with poor dispersal ability and/or narrow habitat requirements are also vulnerable. In this category there are both semi-natural habitats (*e.g.* ancient woodland) as well as several cultural habitat types (*e.g.* meadows and pastures). Many endemic species have a restricted range and a fragmented distribution, characteristics which render them vulnerable to extinction by additional fragmentation (Mitchell-Jones *et al.*, 1999).

Certain habitats are especially vulnerable to fragmentation by transportation infrastructure because they compete for space in areas with a relatively high transport network density. For example, steep alpine valleys and coastal strips are areas where several landuse and development pressures compete for the limited space available. The high density of infrastructure development near coastal ports is a disturbance threat to many coastal habitats, which are particularly valuable for birds. Holiday developments and their associated transportation infrastructure also fragment valuable coastal zone habitats. Few examples of undisturbed sandy and shingle beaches remain in Europe, yet these are the key habitats for several rare and protected plant species. Beaches are increasingly impacted upon by disturbance and those that remain are small and isolated. Infrastructure development in coastal zones needs to take special care not to significantly increase the threat to these valuable habitats.

Several groups of animals and plants are threatened by the ongoing fragmentation of their habitats. For example, migratory fish species throughout Europe are vulnerable to fragmentation when dams and other obstructions prohibit them from reaching their spawning grounds. As a result, the loss of migratory fish in the higher reaches of river systems alters the ecology of lakes and streams in areas that may otherwise remain remote from human disturbance.

Petit *et al.* (1998) used an expert model to identify ecosystems in Europe which are affected by fragmentation (Table 4-1). Fens, peatlands (valley bogs, raised and blanket bogs), dry grasslands, broad leafed deciduous and mixed forest and surface standing waters were amongst the ecosystems considered to be most strongly affected.

Table 4-1 - Overview of ecosystems for each European biogeographical region which are strongly affected by fragmentation. (After Petit *et al.*, 1998)

	Boreal mountains	Northern & Central Boreal	Continental hemi-boreal	North atlantic and sub-continental hemi-boreal	Central europe	North-sea atlantic & sub-atlantic	Atlantic plains	Sub-continental middle mountains	Alps	Pannonian ans southern european plains	Mediterranean and thermo-nemoral mountains	Mediterranean	Thermo-atlantic
Acid fens and valley bogs	L	L	L	L	L	l			l				
Artic and alpine dwarf-shrub habitats	l	l	l										
Alpine & subalpine grasslands	w	w			w				l		l		
Arable land & market gardens				l	l	l	l	l					
Broadleaved deciduous & mixed forests	w		l		l	L	L	L	l	l	L	L	L
Broadleaved evergreen forest												l	l
Coastal dunes & sand habitats				w		l	w					w	w
Coniferous woodland	w	w	w	l					w	l	w	w	
Dry grasslands	w	w		l	L	L	L	L	l				
Extensive species poor sedge and reed beds				w									
Intertidial habitats & estuaries							w					w	w
Inland sparsely or unvegetated	l	l											
Raised & blanket bogs	L	L	L		L	l			w				
Rich fens			L	L	L	l		w					
Mesotrophic and eutrophic graslands					l								
Non Sclerophyllous shrub habitats	l	l	l										
Saltmarshes and halophytic habitats			l										
Sclerophyllous shrub habitats													l
Seasonal wet and wet grasslands				l	l		l						
Standing saline & brackish waters		l											
Surface running waters					L	l						l	w
Surface standing waters	l	l	l	l		L	L	L	l			l	
Temperate heath habitats				L		l	w						L
Transition mires	L	L	L	L	l	l							
Tree-lines & sparsely vegetated land				L	L	W	W	L				W	L
Water fringing vegetation		w	w	w	l	w	l			w		l	w

L - Very strong impact-local; W - Very strong impact- wide spread; l - Strong impact-local; w - Strong impact wide spread

An overview of threatened terrestrial and fresh water mammal species considered to be sensitive to large-scale habitat fragmentation is given in Table 4-2. Two case studies, regarding the effects of habitat fragmentation by transportation infrastructure on specific large mammal populations, are then presented in Box 4.1 and Box 4.2.

Table 4-2 - Threatened mammal species in Europe sensitive to habitat fragmentation.

Scientific name	English name	Habitats Directive	Berne Convention Emerald Network	IUCN (2000)
Alopex lagopus	Arctic fox	X	X	VU
Bison bonasus	Bison		X	EN
Canis lupus	Wolf	X	X	VU (Italy) LR-cd
Capra pyrenaica pyrenaica	Pyrenean Ibex	Extinct since 2000 (García & Herrero, 1999)		
Castor fiber	Beaver	X	X	
Cervus elaphus corsicanus	(Corsican) Red deer	X	X	
Galemys pyrenaicus	Iberian desman	X	X	
Gulo gulo	Wolverine	X	X	VU
Lutra lutra	Otter	X	X	
Lynx lynx	Lynx	X	X	
Lynx pardinus	Iberian lynx	X	X	EN
Mustela lutreola	European mink			EN
Myopus schisticolor	Wood lemming			LR-nt
Ovis gmelini musimon	Mouflon	X	X	
Rangifer tarandus fennicus	Wild reindeer	X	X	
Rupicapra pyrenaica ornata	Southern chamois	X	X	EN
Rupicapra rupicapra balcanica	Alpine chamois	X	X	
Ursus arctos	Brown bear	X	X	

Sources: Mitchell-Jones *et al.*, 1999; Foppen *et al.*, 1999
VU= vulnerable, EN = endangered, LR/cd = Lower Risk/conservation dependent, LR-nt = Lower risk-near threatened.

Box 4.1 - Habitat fragmentation in the Carpathians (World Wide Fund for Nature (WWF) Large Herbivore Initiative)

The Carpathians is one of the last regions in Europe where relatively wild populations of the European bison (*Bison bonasus*) can still be found. The protected areas upon which this species depends are, however, not evenly distributed along the Carpathians. The highest number of natural parks and nature reserves are concentrated in the north-western part of the Carpathians. However, in that area the habitat fragmentation caused by major highways, railways and national borders is also much higher. This has a significant negative impact on the continuity of the home range, migration routes and behaviour of numerous animal species. The size of individual or group territories and home ranges is often confined because of habitat fragmentation, leading to isolation. This applies, in particular to species which tend to avoid human contact *e.g.* the European bison. In some situations, isolated local populations are threatened by a high degree of inbreeding. To restore and protect the spatial continuity of wildlife populations in the Carpathians, the mountain range should be managed strategically, combining efforts across national boundaries. Such a process could be initiated through a joint transboundary programme focusing on the conservation of selected key species, such as the European bison (Perzanowksi and Kozak, 1999*).*

Box 4.2 - Habitat fragmentation in the Dinara Mountains, Croatia (WWF Large Carnivore Initiative)

Brown bears (*Ursus arctos*), wolves (*Canis lupus*) and lynx (*Lynx lynx*) inhabiting the Dinara Mountains of Croatia belong to a large and stable population. Survival of the neighbouring Slovenian population depends on the Croatian one and together they form the source of re-colonisation for the Alps and much of Western Europe, either through natural dispersal or re-introductions of captured animals. Roads and railways cause habitat fragmentation, disturbance and direct mortality to all three carnivore species. As traffic is becoming faster, quieter and more intense and the network of transport routes becomes denser, road mortality increases. Between 1986 and 1994, 19% of brown bear mortality was caused by traffic accidents (compared with 11% before 1985); for the Eurasian lynx, traffic mortality was 6.6 % in the period 1978 to 1995; and traffic accidents have been responsible for 3.6 % of the grey wolf mortality since 1946. The main habitat corridor for all three large carnivore species in Croatia was found to be in the central part of Gorski Kotar, which is bisected by major road and railway routes. On a new highway under construction through the area, numerous under- and overpasses and several green bridges have been proposed in order to reduce the impact of traffic on wild animal populations (Zedrosser and Völk, 1999; Rauer and Gutleb, 1997).

The sensitivity of specific habitats to fragmentation effects depends on local circumstances, particularly the spatial context of a habitat patch and the total amount of that habitat in the region. It is, therefore, difficult to provide a complete list of species or habitats that should be considered when assessing the effects of a specific infrastructure development on an area. Specialist knowledge, particularly regarding the presence of locally, nationally or internationally protected species and designated sites is required to assess which special precautions should be taken to avoid further fragmentation.

4.3. EUROPEAN TRANSPORTATION NETWORKS

Between 1970 and 1996, the length of the road network has increased nearly two-fold in EU countries, while the length of railway and inland waterways has decreased by 8%. In 1996, EU transportation infrastructure covered 1.2% of the total available land area of the Member Countries; the EU15 total road network (motorway, state, provincial and municipal roads) was made up of 3.5 million km, occupying 93% of the total area of land used for transportation infrastructure. Rail was responsible for only 4% of landtake and the area corresponding to waterways (*i.e.* canals) was *ca.* 1% (EEA, 2000).

Land is under continuous development pressure in relation to new transportation infrastructure: as expressed in Figure 4.3, between 1990 and 1996, a total of 25,000 ha (*ca.*10 ha/day) were taken for motorway construction in the EU (EEA, 1998b). Estonia estimates that a total of 800 km^2 is taken up by transportation infrastructure (EE-SoA), while in Spain the area occupied by high-capacity roads is approximately 399 km^2 (E-SoA, 5.3). When compared to road transport, railways have the highest landtake efficiency (the ratio between land used and the traffic carrying capacity). Landtake per passenger-km of railway is about 3.5 times lower than for passenger cars (EEA, 1998b).

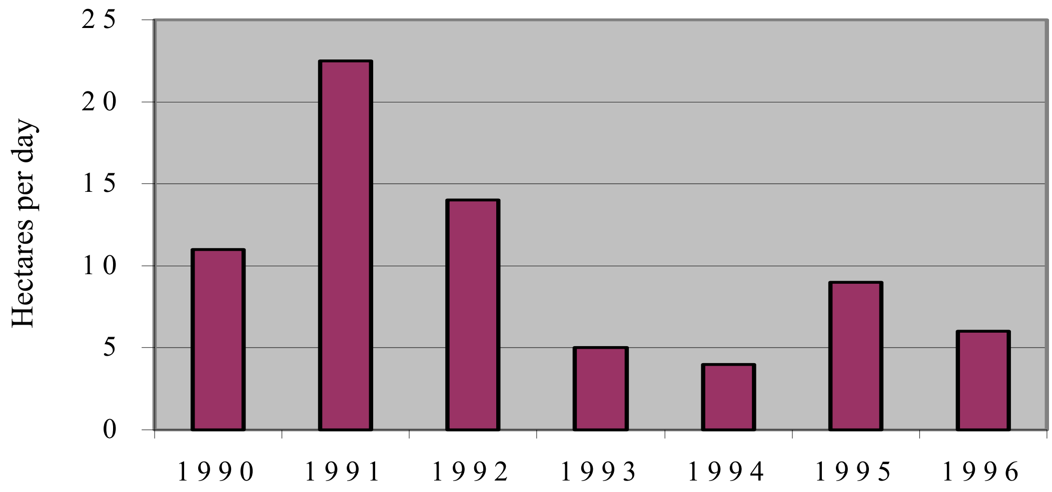

Figure 4.3 - Average daily land taken by new motorways in the EU. (From EEA, 1998b)

Most areas in the EU are highly fragmented by transportation infrastructure (EEA, 2000). The average size of contiguous land units that are not cut through by major transportation infrastructure is shown in Figure 4.4 by country. The size of non-fragmented land parcels varies from about 20 km^2 in Belgium to nearly 600 km^2 in Finland, with a EU average of 130 km^2.

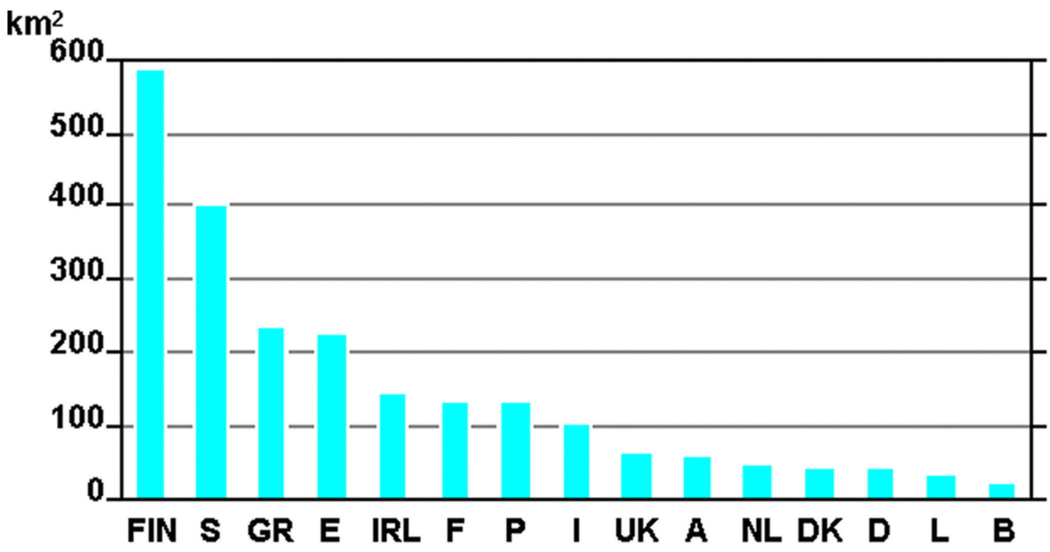

Figure 4.4 - Average size of non-fragmented land parcels. (Adapted from EEA, 2000)

In July 1996, the European Parliament and Council adopted, on the basis of Article 129c of the Treaty, a decision to develop guidelines for the development of the Trans-European Transport Network (TEN-T) (1692/96/EC). The main objective of the TEN-T is to 'develop a better integrated transport system in the EU and as a result contribute towards growth, competitiveness and employment in Europe, with the additional aim of improving economic and social cohesion through the linking of peripheral regions to EU networks'. The TEN-T plans cover major road, rail (both conventional and High Speed Rail (HSR/TGV)), and inland waterways, whether existing, new or to be adapted (Table 4-3). TEN-T also includes maritime ports, airports and combined networks.

In 1998, the EEA estimated the TEN-T consisted of *ca.* 49,600 km of roads and *ca.* 53,400 km of railways. These values, compared with the 1995 existing European transportation infrastructure are presented in Table 4-4. Figure 4.5 illustrates the spatial distribution of the TEN-T in the EU.

Table 4-3 - Trans-European Transport Network.

Network	Main elements	Role
Road	• Motorways • High quality roads	Long-distance traffic Link landlocked and peripheral regions to central regions of the Community and interconnect with other modes of transport
Rail	• Conventional rail • High Speed Rail (HSR/TGV)	Long-distance goods and passenger traffic Operation of long-distance combined transport interconnecting with: other types of transport network regional and local rail networks
Inland waterways	• Rivers • Canals • Interconnecting branches and links	Interconnecting industrial regions and major conurbations and linking them to ports

Source: CEC, 1996

Table 4-4 - Estimated length (in km) of Trans-European Transport Network.

Network		Existing TEN-T (1996)	Planned TEN-T (2010) new	Planned TEN-T (2010) upgraded	European Transportation Infrastructure (1995)
Road		49,598	[¤]12,363	[¤]14,512	*49,024
Rail	Conventional	48,477	1,372	-	155,836
	HSR	4,901	10,088	14,408	2,406
Inland waterways		12,239	1,412	n.a.	30,191

* motorways only

Sources: EEA, 1998b; [¤] EEA (2000)

Currently, according to the Commission of the European Communities (CEC, 2001c), the TEN-T network includes 75,185 km of roads and 79,440 km of conventional and high-speed railway lines (20,609 km and 23,005 km of which are still at the planning stage, respectively). The aim is that the TEN-T should be fully established by 2010.

Regulation 2236/95, amended Regulation 1655/99, defines the general rules for the granting of Community financial aid in the field of Trans-European Networks. The EU budget for 1995 to 1999 (inclusive) allocated a total of 1.830 billion Euros for the TEN-T. For 2000 to 2006, the share for transport networks is expected to be between 4 and 4.2 billion Euros (CEC, 2001a).

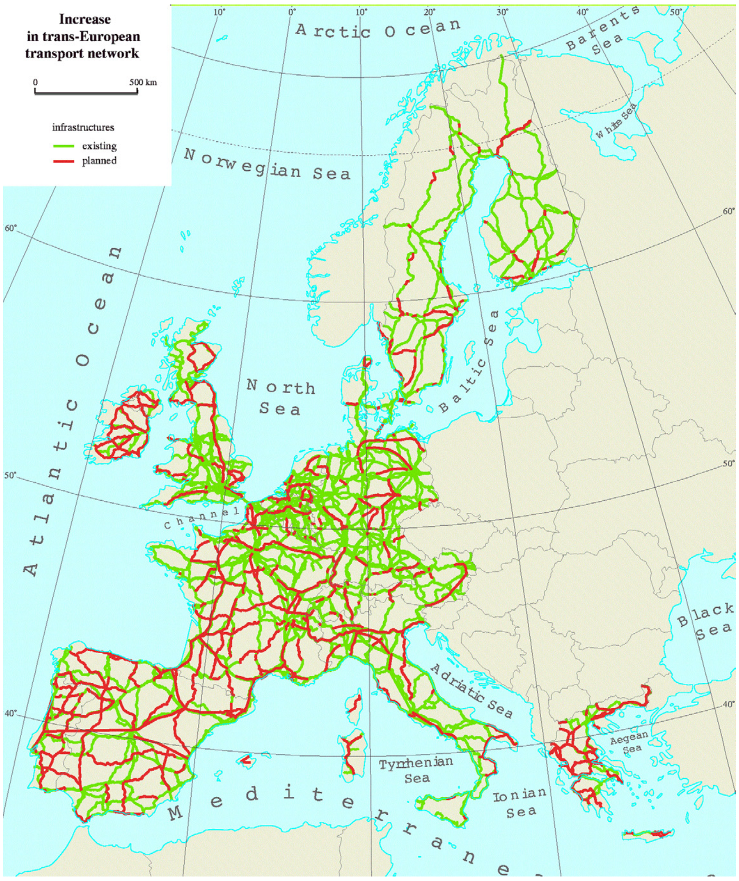

Figure 4.5 - Existing and planned Trans-European Transport Network. (From TINA Secretariat, 1999b)

According to a report prepared by the European Environment Agency (EEA, 2000), investment plans only partially reflect the Community aim of promoting rail and inland waterway transportation. TEN-T investment has focused on railways and roads, 39% and 38% respectively of total investment in 1996/1997. In the same period, 55% of total Community TEN-T funding was for road infrastructure, due to the intensity of its use and the potential for economic growth that it offers. Although the TEN-T road network accounts for only one quarter of the EU primary network, its use is proportionally much higher. For example in Germany and Denmark it carries about one third of road passenger traffic and in the UK, about half of the freight transported (tonne/km).

In 1996 the European Commission (EC) set up a process of Transport Infrastructure Needs Assessment (TINA) to oversee and co-ordinate the development of an integrated transport network in 11 applicant countries (Poland, the Czech Republic, Hungary, Slovenia, Estonia and Cyprus, plus Bulgaria, Latvia, Lithuania, Romania and Slovakia). The purpose was to co-ordinate infrastructure projects in these countries with those implemented and planned in the EU, with view to extending the TEN-T to these new Member States in future. The TINA network, summarised in Table 4-5 and illustrated in Figures 4.6 and 4.7, was approved by the TINA group in June 1999 (TINA Secretariat, 1999a). A report assessing the potential environmental impact of the TINA network on internationally Important Bird Areas (IBAs) in Central and Eastern European countries found that 85 of the 412 IBAs investigated are potentially affected by TINA developments, mainly through road and waterway expansion; these 85 sites support internationally important populations of 128 bird species, including 58 species listed in Annex I of the EU Birds Directive (Fisher & Waliczky, 2001).

Table 4-5 - Transport Infrastructure Needs Assessment (TINA) network.

Network	Extension* (km)	Cost** (million Euro)
Road	18,030	45,805
Rail	20,290	31,241
Inland waterways	n.a.	1,795

Sources: * CEC (2001b); ** TINA Secretariat (1999a)

In 2001, the EC prepared a White Paper on the European transport policy for 2010. This report indicates that the planned revision of the TEN-T guidelines must aim to reduce the bottlenecks in the planned or existing network without adding new infrastructure routes. The document is clear that by 2004 the guidelines will need to be redefined to take account of the enlargement of the EU and to provide a more accurate reflection of changes in traffic flows. The European Council, for its part, requested the Community institutions to adopt, by 2003, revised guidelines for the TEN-T, giving priority to infrastructure investment and in particular to railways, inland waterways, short sea shipping, intermodal operations and effective interconnections. (CEC, 2001c)

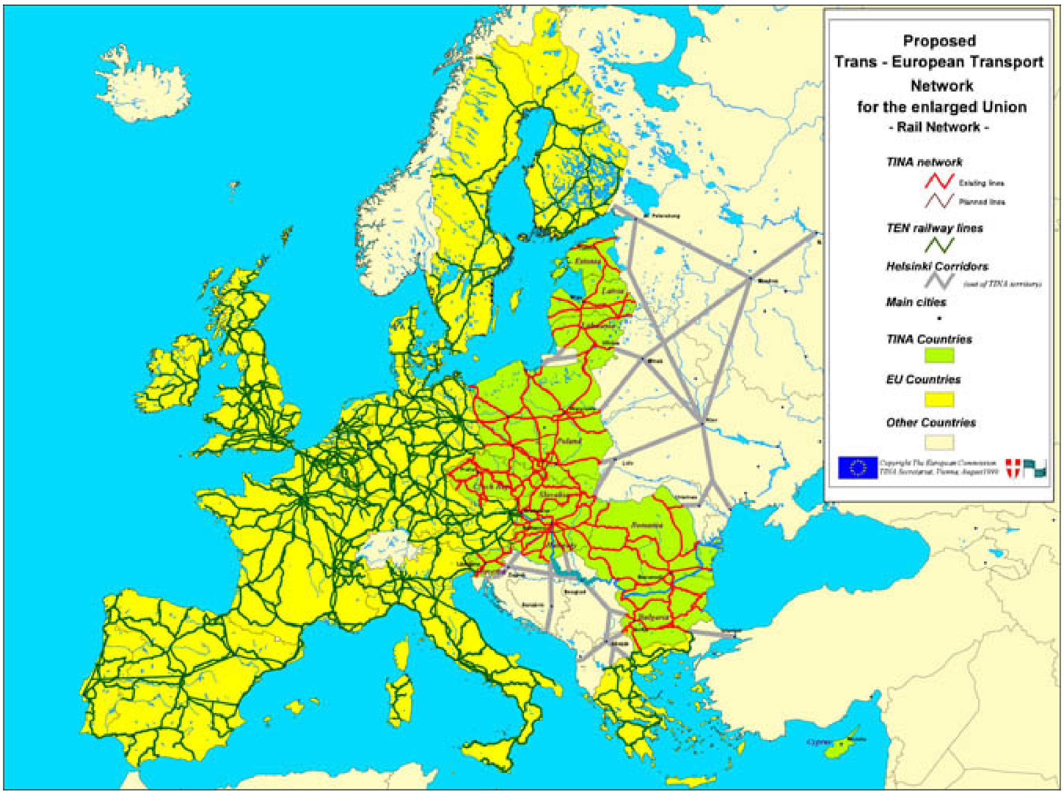

Figure 4.6 - Proposed Trans-European Transport Network for the enlarged Union – rail network. (From TINA Secretariat, 1999b)

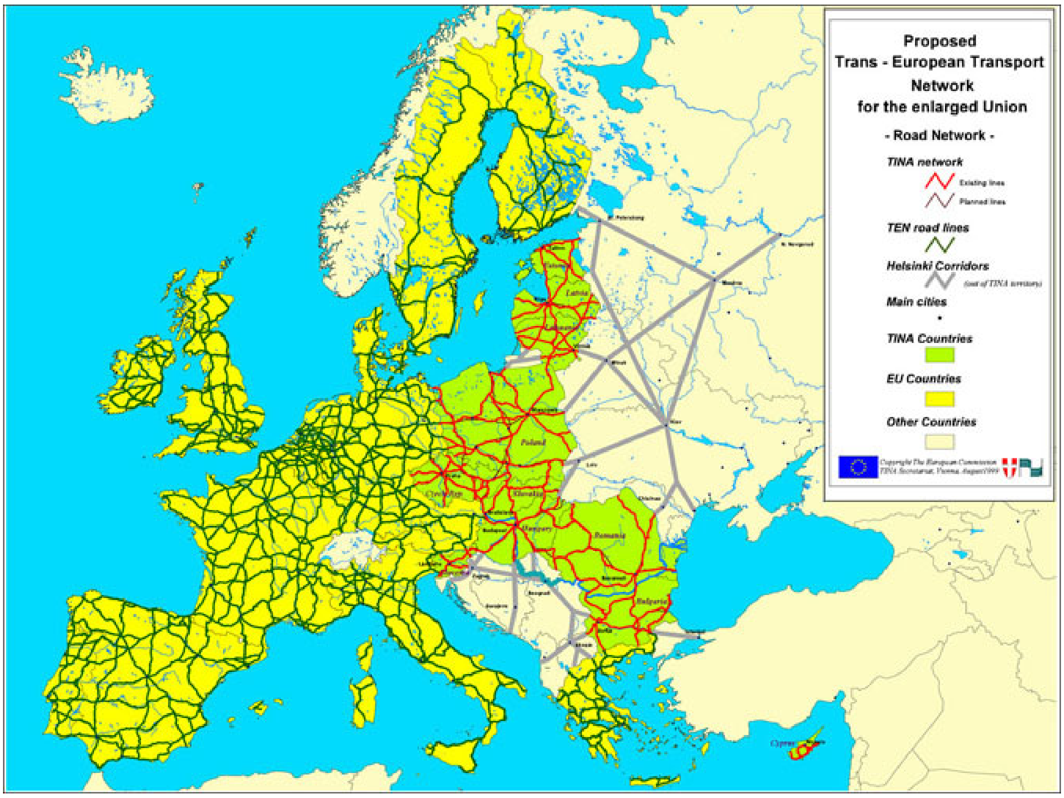

Figure 4.7 - Proposed Trans-European Transport Network for the enlarged Union – road network. (From TINA Secretariat, 1999b)

4.3.1. Road network

4.3.1.1. Main Road Network

The main road network (MRN) is characterised in Table 4-6, based on the Eurostat road classification system. Data refers to 1998 (CEC, 2000) or 1999 (DETR, 1999; A.Caramondani, *pers.comm*.), unless otherwise stated in the individual National State of the Art reports. For three countries - Switzerland, the Czech Republic and The Netherlands –the only roads included in the MRN are motorways.

Speed limits on the MRN vary between 80 and 130 km/h, while the annual average number of vehicles per day ranges from 3,000 to 200,000. Passenger and goods transport values refer both to the main and secondary road network (SRN). Data from the Russian Federation, referring to 1995, indicates a main road network of 519,000 km (Skvortsov, 1995). In this Federation, 80% of the commercial freight and 50% of passenger traffic circulates in the highway system only.

The MRN density is obtained by dividing the extension (total length in km) of motorways and highways by the total surface area of a country. The highest value is found in Belgium (0.47 km/km^2), reflecting high population densities and mobility levels, but the MRN density of the vast majority of the countries varies between 0.09 and 0.04 km/km^2.

Some European countries fence their main roads, generally for traffic security reasons. In Switzerland all motorways are fenced whilst in Portugal, The Netherlands and Spain 57 %, 48% and 37% respectively of the main road networks are fenced. In Flanders (Belgium), 55 km of roads are specifically fenced (42.5 km for amphibians; 5.3 km for roe deer and 6.8 km for badgers).

4.3.1.2. Secondary Road Network

The secondary road network (SRN), based on the Eurostat road classification system, is presented in Table 4-7. Statistics refers to 1998 (CEC, 2000) or 1999 (DETR, 1999; A.Caramondani, *pers.comm.*), unless otherwise acknowledged in the individual National State of the Art reports. Complementary to this information, in 1995 the Russian Federation had a secondary road network of 414,000 km (Skvortsov, 1995).

Average traffic statistics for secondary roads are not available for many European countries. The SRN density is obtained by dividing the extension (total length in km) of state and municipal roads by the total surface area of the country. Two countries have very high SRN density values - Belgium and The Netherlands – while four other countries possess high values, between 1.7 and 1.6 km/km^2; a third group of countries show medium SRN density values, between 1.1 and 0.9 km/km^2, with the lowest density values (0.6-0.3 km/km^2) found for the last group of four countries (see Table 4-7).

Table 4-6 - Main Road Network (MRN).

	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)
B**	1,682	n.a.	12,500	n.a.	n.a.	95.7	35.0	0.47
CH*	1,638	80-120	-	-	5-93 (M)	n.a.	n.a.	0.04
CY*[v]	280	100	n.a.	80	51(bM); 36(bH)	n.a.	n.a.	n.a.
CZ*	499	130	-	-	15	70.9	37.0	0.01
DK	**861	*90-110	**3,700	*80-90	*84.9 (bM)	**58.5	**15.3	0.11
E*	9,649	120	16,419	100	100-175	205.3	134.9	0.05
EE*	87	90	3,810	90	3	185.4	12.2	0.09
F	*9,346	*130	*27,223	*80-110	*30.3(M) *10.1(H)	**708.4	**245.4	0.07
H	*505	*110-130	*6,495	*90	*26.5 (M) *7.3 (H)	**44.3	**17.0	*0.07
N *	144	90	445	80	5-100(M)	53.2	12.8	0.09
NL	*2,207	*100-120	*936	*80-100	*15-200(M)	**150.6	**46.5	*0.09
P	*1,252	*120	*11,408	*90	*135(bM)	**75.6	**14.2	*0.14
RO*	*114	*120	*14,810	*90	*5	*23.2	*16.5	*0.06
S	*1,428	*90-110	*14,615	*90-110	n.a.	**95.0	**32.7	*0.04
UK	***3,358	n.a.	***16,088	n.a.	*200 (bM)	**630.0	**159.5	0.08

Sources: * National State of the Art Report; ** CEC (2000); *** DETR (1999); *[v]A.Caramondani (*pers.comm.*)
(bM) – busy motorway; (bH) – busy highway; n.a. – not available

Table 4-7 - Secondary Road Network (SRN).

	Length (km)		Average traffic ($\#10^3$ vehicles /day)	SRN Density (S+mR) (km/km^2)
	State Roads (S)	Municipal Roads (mR)		
B	**1,300	**129,400	n.a.	4.3
CH	*18,238	*51,197	*3.6-8.9	*1.7
CY	*v 1,500	*v 2,750	n.a,	n.a.
CZ	*55,432	*72,300	n.a.	1.6
DK	**7,100	**60,000	n.a.	1.6
E	*68,910	*394,348	n.a.	*0.9
EE	*12,533	*34,006	n.a.	*1.0
F	**360,100	**569,000	*1.3 - 0.5	1.7
H	*23,268	*105,233	*1.38	*1.38
N	*53,224	*37,022	*< 10	*0.3
NL	*6,360	**114,000	n.a.	3.4
P	*46,100	*62,500	n.a.	*1.1
RO	*36,009	*22,122	n.a.	*0.3
S	*83,368	*38,500	n.a.	0.3
UK	***25,425	***113,106	*15 - 0.7	0.6

Sources: * National State of the Art Report; ** CEC (2000); *** DETR (1999); *v A.Caramondani (*pers.comm.*)
n.a. – not available

4.3.1.3. Country Road Network

The country road network (cRN) is a heterogeneous group of roads that complements the SRN. Although it does not normally feature in National or European transport statistics, the cRN is nevertheless quite extensive (Table 4-8.). In some countries *e.g.* Sweden, the United Kingdom, Romania and Norway, the cRN covers more than double the length of the SRN.

Table 4-8 - Country Road Network (cRN).

	Country Roads (cR)		Average traffic	cRN Density
	Length (km)	Class	($\#10^3$ veh./day)	(km/km^2)
B	n.a.		n.a.	n.a.
CH	*69,000	Private and forest roads	n.a.	*1.7
CY	*v 4,450		n.a.	n.a.
CZ	n.a.		n.a.	n.a.
DK	n.a.		n.a.	n.a.
E	*175,000	Country and forest roads		*0.3
EE	n.a.		n.a.	n.a.
F	*600,000	Country roads	n.a.	1.1
H	*52,919	Country and forest roads	*0.6	*0.57
N	*97,800	Forest and private roads	*0-10	0.3
NL	*10,012	Unpaved rural roads	n.a.	*0.3
P	*61,883	Municipal ways, forest roads	n.a.	*0.7
RO	*78,421	Country roads	n.a.	*0.3
S	*284,198	Paved and unpaved private roads	n.a.	0.7
UK	*207,255	Unclassified roads	n.a.	1.2

Sources: * National State of the Art Report; ** CEC (2000); *** DETR (1999); *v A.Caramondani (*pers.comm.*)
n.a. – not available

An overview of the road network density in Europe is given in Table 4-9, which considers the main (MRN), secondary (SRN) and country (cRN) classes together. In most countries, the cRN serves mainly agricultural and forest areas, many of which include landscapes of great importance from a European biodiversity conservation policy context. From the data presented it is obvious that the cRN contributes significantly to habitat fragmentation but at least for some countries, the greatest impact of the cRN comes from the increase in accessibility to less disturbed areas it provides. This last aspect is easily overlooked when considering only main and secondary road networks.

Table 4-9 - Road Network density in Europe.

Road Network Density (km/km^2)	B	CH	CZ	DK	E	EE	F	H	N	NL	P	RO	S	UK
MNR+SRN	4.8	1.7	1.6	1.7	1.0	1.1	1.8	1.5	0.3	3.5	1.2	0.3	0.3	0.7
MRN+SRN+cRN	n.a	3.4	n.a	n.a	1.3	n.a.	2.9	2.0	0.6	3.8	1.9	0.6	1.0	1.5

n.a. – not available

4.3.2. Railway network

The principal characteristics of the railway network are summarised in Table 4-10. Unless otherwise stated in the individual National State of the Art reports, data refers to 1998.

Table 4-10 - Railways.

	Length of Lines (km)	Length of HSR Lines (km)	% of Line Electrified	Passenger Transport (10^6 pkm)	Goods Transport (10^6 tkm)	Density (m/km^2)
B	**3,410	**88	**74	**7.1	**7.6	n.a.
CH	*5,000	0	*99	*0.5	*1.0	n.a.
CZ	*9,444	*0	*30	*7.0	*16.7	*120
DK	**2,232	**15	**28	**5.6	**2.1	n.a.
E	*14,817	*471	*53	**18.9	**11.8	*28
EE	*968	0	*14	*6.8	*37.4	*20
F	*31,868	*1,281	*44	**64.5	**54.0	n.a.
H	**7,715	n.a.	**30	**8.9	**8.2	**83
N	*4,179	*139	*62	*2.8	*1.8	*13
NL	*2,805	**0	*73	**14.8	**3.8	*79
P	*2,794	*0	*31	*4.6	*2.0	*30
S	*15,236	**31	*50	*7.1	**19.1	*40
RO	*11,010	*0	*36	*29.0	*57.2	*16.5
UK	**16,847	**52	**30	**35.4	**17.4	n.a.

Sources: * National State of the Art Report; ** CEC (2000)
n.a. – not available

In the EU, according to published statistics (CEC, 2000), the length of the railway network (km) has decreased by 10% in the last 30 years. The effect that this decrease has had on capacity is difficult to estimate. In 1998, the rail network was *ca.* 152,600 km long, of which 51% formed part of the TEN-T and 49% was electrified. Growth in the sector since 1990 has focussed on the construction of high-speed railway (HSR/TGV) track and by 2006, an extra 1,650 km of HSR will complement the *ca.* 2,700 km already in operation in the EU. HSR lines are all fenced and constructed to allow trains to travel at speeds of over 220 km/hr (the older, traditional networks, trains travel at a maximum speed of 160 km/hr). Due to its characteristics therefore, HSR might produce a greater barrier effect than other types of railway.

In the EU, railway passenger transport increased by 34% between 1970 and 1998, while goods transport decreased by 15% during the same period (CEC, 2000). In Denmark and

Switzerland, the traffic frequency on major rail stretches is *ca.* 600 trains/day. In 1997, an average of 11,120 trains traversed the French railway network daily, but about half of the passenger journeys made in France involve HSR.

The density of the railway network (expressed as linear metres per km^2), varies between countries by a factor of 10. The Nordic countries and the Iberian Peninsula have the lowest railway densities. The area occupied by the rail network is estimated as being 104 km^2 in Spain, 102 km^2 in Sweden and 29 km^2 in Portugal. In contrast with the expansion of roads (motorways in particular), railway densities fell in most countries between 1990 and 1996: in Belgium by about 3% whilst in the Netherlands density increased by a modest 0.5%. In The Netherlands, over 14 km of railway line is fenced for wildlife, whilst in Spain the extension of fenced railway line is more than 955 km.

In Spain, *ca.* 407 km of state-run railway lines affect 48 Protected Natural Areas and another 1,200 km of railway cross 129 areas listed as of natural potential interest.

4.3.3. Waterways

Table 4-11 summarises the information regarding regularly used inland waterways of the COST 341 countries. These waterways represent, respectively, 71 % of the French, 33 % of the Swedish and 49 % of the United Kingdom's navigable waterway networks. The Netherlands has the second most extensive waterway transport network in Europe and has been recognised as being of international importance.

Statistical data, obtained from CEC (2000), refers to 1996 (Central and Eastern European countries) and 1997 (EU countries). Between 1970 and 1997, an 8% decrease in the length of the waterways regularly used for transport in EU countries was registered. Nevertheless, the transport of goods through these waterways increased by 17% in the same period.

Table 4-11 - Inland waterways regularly used for transport.

	Length (km)			Length by carrying capacity of vessels (km)		Locks (#)	Goods Transport
	Canals	**River/ Lakes**	**Total**	**<= 1000 t**	**> 1000 t**		**(10^6 tkm)**
B	**880	**660	**1,540	**300	**1,240	**211	**6.3
CH	n.a.	n.a.	*1,200	*1,179	*21	n.a.	n.a.
CZ	n.a.	n.a.	*664	n.a.	n.a.	n.a.	*0.9
E	**0	**70	**70	**0	**70	n.a.	n.a.
EE	0	*520	*520	n.a.	n.a.	n.a.	*1.1
F	n.a.	n.a.	*8,500	*6,475	*2,025	**1,836	**6.2
H	n.a.	n.a.	**1,373	n.a.	n.a.	n.a.	**1.6
NL	**3,745	**1,301	**5,046	**2,648	**2,398	**132	**40.7
P	*0	*124	*124	*0	*124	n.a.	n.a.
S	**70	**320	**390	**90	**300	**6	n.a.
RO	*86	*1,075	*1,161	300	801	*0	*20.9
UK	**191	**962	**1,153	**406	**747	**100	**0.2

Nb: Rivers/lakes: includes free flowing rivers, canalised rivers, lakes and coastal waterways.
Locks: data for France include locks at navigable waterways not regularly used for transport; the total number of locks in the UK is 1555 of which *ca.* 100 are located on waterways used for freight.
Waterways <= 1000 t (waterway classes 0-III) are of regional importance; waterways >1000t (waterway classes IV-VII) are of international importance and can carry pushed convoys.
Sources: * National State of the Art Report; ** CEC (2000); n.a. – not available

In France, traffic intensity on the different classes of waterway varies; it can range from 5 to 100 boats per day. Traffic on the smallest waterways is most frequent during the summer period, consisting mainly of private sailing craft. In Belgium (Flanders), the average width of the canals varies between 40 m (Class 0) and 160 m (Class VI) and the estimated surface area occupied by navigable inland waterways is 105.7 km^2.

Other canal structures associated with power stations and hydro-electric dams are often constructed as concrete-sided channels, which can pose an important physical barrier to fauna, as documented in the Swiss National Report (CH-SoA, 5.1.1.5.). In Portugal and Spain, there are numerous canal structures which are used for irrigation or for transporting water between river basins or from reservoirs to towns; some of these structures are quite large, almost as wide as a typical navigable canal. The design of these types of canal increases the barrier effect: the majority of such channels are concrete with steep sides that impede animal access and exit; in addition, the more recent structures are covered with a layer of very low roughness coefficient material, which significantly increases the barrier effect. In urbanised areas of several countries (*e.g.* Portugal, Spain, Switzerland), streams are commonly stabilised by enclosing them within concrete walls, which make it difficult for many animal species to disperse.

4.4. ADMINISTRATIVE AND LEGISLATIVE FRAMEWORK

Habitat fragmentation can be avoided through the development of targeted policies and legislative proposals. Internationally, policies and legislation have been developed that explicitly or implicitly promote the avoidance of habitat fragmentation. However, participation in international conventions and policies is voluntary and the means to enforce implementation by signatory countries are limited. This problem does not apply within the EU. The Member States are bound to implement EC law and policies. Non-compliance can result in severe fines being imposed by the European Court. The EU therefore has a heavy influence on the policy and legislation of its Member States.

Within Europe, three main political administrative legislative units can be distinguished: the EU (15 Member States), the Council of Europe Member States Countries (40) and the member states of the United Nations Economic Commission for Europe (55). Each of these is discussed in turn below.

European Union

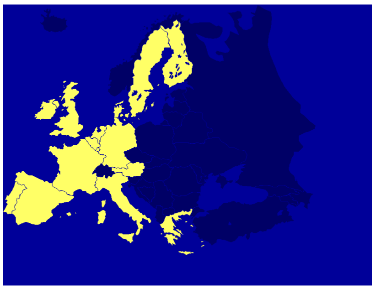

Figure 4.8 – Member States of the European Union.

The legislative framework of the EU consists of three elements: directives, regulations and decisions. Directives adopted by the Member States need to be transposed into national law. Within the EU, the Directorate General of the Environment and the Directorate General for Energy and Transport are the two with most responsibility for issues related to the environment and transportation infrastructure.

In the last ten years the EU, whose members are highlighted in Fig. 4.8, has invested heavily in the development of the Trans European Transport Network (TEN-T). The Common Transport Policy Action Programme 1995 to 2000 (COM/95/302), revised in 1998, outlined the philosophy behind the development of this transportation infrastructure network. The Action Plan states that during the development of TEN-T, environmental considerations should be taken into account and that the EC will undertake a Strategic Environmental Assessment (SEA) for all its infrastructure plans (see Chapter 6 and Section 9.2).

The 5th Environmental Action Programme further underlines the need to integrate environmental considerations in the development of transportation infrastructure. The avoidance of habitat fragmentation is not, however, mentioned explicitly. The EU has not developed any specific legislation to counteract habitat fragmentation due to infrastructure, but has incorporated the issue in several Directives and decisions:

Nature related Directives and decisions

- Council Directive 79/409/EEC referred to as the Birds Directive
- Council Directive 92/43/EEC referred to as the Habitats Directive
  Article 6 states that for plans and projects that might affect Natura 2000 sites (i.e. those designated under the Habitats and Birds Directives) an assessment needs to be undertaken to assess the environmental impact. Article 10 encourages Member States to manage landscape features that are essential for the dispersal, migration and genetic exchange of wild species.

The implementation of the Birds and Habitats Directives is a slow process. All Member States have transposed the directives into their national law but many countries are still in the process of revising and completing the list of Natura 2000 sites for submission to the EU (EC, 2000). The accession countries are currently aligning their national law and have also started to identify Natura 2000 sites within their boundaries.

Environmental Impact related Directives and decisions

- Council Directive 85/337/EEC referred to as the EIA Directive
  This Directive determines that for the construction of motorways, express roads and long-distance railways an Environmental Impact Assessment (EIA) needs to be undertaken. The responsibility for the proper execution and evaluation of the EIA lies with the Member States.
- Council Directive 97/11/CE amending directive 85/337/EEC
  The amendment increases the types of projects which are covered by this Directive from 9 to 21.
- Council Directive 20001/42/EC referred to as the SEA Directive
  This Directive is of a procedural nature. Its requirements are either to be integrated into existing procedures in Member States or incorporated in specifically established procedures. As a rule, all plans and programmes which set a framework for future development consent for projects listed in Annexes I and II to Council Directive 85/337/EEC, or which have been determined to require assessment pursuant to Council Directive 92/43/EEC, should be subjected to Strategic Environmental Assessment (SEA).
- Decision No 1692/96/EC regarding the Community guidelines for the development of the Trans-European transport network states that an EIA should be carried out for each project forming part of the TEN-T.

All Member States have transposed Directive 85/337/EEC but infringement procedures are ongoing against Ireland and Portugal due to its incorrect transposition. The Commission receives many complaints regarding the incorrect application of Directive 85/337/EEC by national authorities, mainly relating to the quality of impact assessments and the lack of weight given to the recommendations arising from the EIA (EC, 2000a). Several countries such as Portugal, Germany, Italy and the United Kingdom have not applied the Directive for projects for which the authorisation process was already ongoing when the Directive entered into force (7 June 1990). The European court has ruled that the Directive also applies to these projects. The transposition date of Directive 97/11/CE was 14 March 1999. Only Spain and Greece have not yet notified the Commission of the transposition of these Directives.

Several countries in Central and Eastern Europe are in the process of accession and as a result are adapting their national laws and procedures in order to fulfill the requirements of the Directives. Most accession countries are in the process of aligning their legislation to the two EIA and SEA Directives. Estonia, Hungary, Lithuania, Slovakia, Latvia and Slovenia have transposed the two Directives in national law (EC, 2000b-f).

The Council of Europe

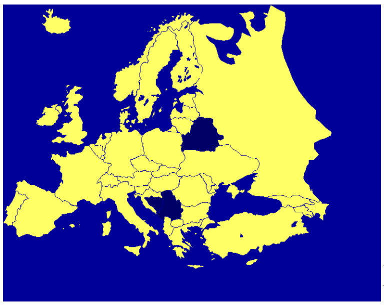

Figure 4.9 - Member States of the Council of Europe.

At present there is no legislation developed by the Council of Europe (CoE) specifically aimed at the avoidance of habitat fragmentation due to infrastructure. However, the CoE has established a group of specialists on transport and the environment who are currently drafting a ‘Code of Practice for consideration of Biological and Landscape Diversity in Transport Infrastructure’. The CoE member States are represented in Figure 4.9.

The Bern Convention (1979), the Council of Europe’s most important instrument in the field of nature conservation does not make an explicit reference to the need to avoid habitat fragmentation and to increase landscape connectivity. However, under the Bern Convention several Action Plans for threatened European species have been developed.

United Nations Economic Commission for Europe

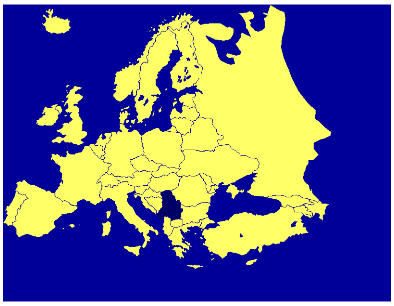

Figure 4.10 - Member States of the United Nations Economic Commission for Europe include the countries shown in the map plus Israel, United States of America, Turkmenistan, Uzbekistan, Tajikistan and Canada.

In the United Nations Economic Commision for Europe (UNECE) Member States (Figure 4.10) there are four major initiatives:

- Convention on Biological Diversity
- Convention on Environmental Impact Assessment in a Transboundary Context
- Bonn Convention on Migratory Species
- Pan-European Biological and Landscape Diversity Strategy (PEBLDS), which underlines the need to integrate biodiversity in other sectors.

Article 6b of the Convention on Biological Diversity encourages the parties to 'integrate, as far as possible and as appropriate, the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans, programmes and policies'. Also parties of the convention are encouraged to undertake EIA in order to avoid and minimise the effects of projects (Article 14a).

The Convention on Environmental Impact Assessment in a Transboundary Context (UNECE, 1991) stipulates the obligations of Parties to assess the environmental impact of certain activities at an early stage of planning. It also lays down the general obligation of States to notify and consult each other on all major projects under consideration that are likely to have a significant adverse environmental impact across boundaries. The EIA Convention entered into force on 10 September 1997, signed by all 55 states.

The Bonn Convention or the Convention on the Conservation of Migratory Species (1979) underlines the need for cross boundary co-operation in order to protect migratory species and their habitats. The Convention seeks to ensure the strict protection of migratory species in danger of extinction throughout all, or a significant portion, of their range. The Convention does not specifically address the need to avoid habitat fragmentation but does take into account the needs of migratory species. Species-specific agreements have been developed under this convention such as the Agreement on the Conservation of Bats in Europe and the African-Eurasian Waterbird Agreement. Currently 35 states are participating in this agreement.

Action Theme 1 of the Pan-European Biological and Landscape Diversity Strategy (PEBLDS) foresees the establishment of the Pan-European Ecological Network. The aim of this network is to ensure that: a full range of ecosystems, habitats and species and their genetic diversity, and landscapes of European importance are conserved; habitats are large enough to place species in a favourable conservation status; there are sufficient opportunities for the dispersal and migration of species; damaged elements of the key systems are restored and the systems are buffered from potential threats. Action Theme 2 of PEBLDS focuses on the integration of biological and landscape diversity considerations into all economic sectors (CE, UNEP & ECNC, 1996).

4.5. SUMMARY

The current distribution of species, habitats and landscapes in Europe has been strongly influenced by human activity (*e.g.* agriculture, forestry, water management and urbanisation). At present, arable land and coniferous and deciduous forest dominate the land cover across Europe. Hotspots of species richness are concentrated in the Alps, Central Europe and Southern Europe.

Habitat fragmentation is caused by a combination of natural disturbances and human activities. The changes in agricultural practice in modern times are the most important cause of fragmentation of natural and semi-natural habitats. Commercial forestry, urbanisation and the construction of transportation infrastructure can also be important, especially at local and regional levels.

The vulnerability of species and habitats to fragmentation depends on their intrinsic characteristics and on the existing human pressures. Ecosystems that are most strongly affected by fragmentation include: fens, peatland (valley bogs, raised and blanket bogs), dry grasslands, broad-leafed deciduous and mixed forest and surface standing waters.

The European Transport Network includes road, railway and waterways and partially integrates the Trans-European Transport Network (TEN-T). The use of railways and waterways has declined in the past 10 years, while the road system has been expanding across Europe. In 2001, the European Council requested the EU institutions to adopt, by 2003, revised guidelines for the TEN-T giving priority to infrastructure investment - in particular for railways and inland waterways.

Road density varies among European countries, the highest values are found in the Benelux region. Country roads do not usually feature in national transport statistics; nevertheless, they contribute significantly to habitat fragmentation due their extensive coverage, characteristics and location. The operational conditions of the HSR will necessarily cause a greater barrier effect than those associated with a conventional railway. Waterways pose a major habitat fragmentation problem in The Netherlands and France, due to their significant length and unsympathetic design.

At a European level, guidance and regulations on avoiding habitat fragmentation are incorporated in several legislative international instruments and sectoral policies. The problems surrounding the implementation of Directives 85/337/EEC and 97/11/CE indicate that the execution of EIA is not straightforward, particularly due to the lack of weight given to recommendations arising from the process.

Chapter 5. Habitat Fragmentation due to Existing Transportation Infrastructure

This Chapter quantifies the known effects on nature caused by transportation infrastructure, described in theory in Chapter 3. It begins by examining the four main aspects of fragmentation *i.e.* habitat loss, disturbance, fauna casualties and the barrier effect (Sections 5.1 to 5.4). Information is drawn from the COST 341 National State of the Art Reports, experimental research, literature studies and/or computer models. Where possible, the effects are described according to transport mode and at various scales, *i.e.* at individual, population, and landscape level. Evidence for and against the corridor function is then presented in Section 5.5. This includes the potential for appropriately managed road and railway verges to enhance connectivity in fragmented landscapes, as well as their potential for promoting the spread of invasive and edge species. Section 5.6 introduces the concept of environmental bottlenecks (or 'hotspots') between infrastructure and nature. This is a more pragmatic approach to the habitat fragmentation problem, which serves as an introduction to the methodologies discussed further in Chapter 6. A short discussion concerning the secondary effects of infrastructure follows in Section 5.7 *i.e.* subsidiary development resulting directly from the presence of the infrastructure and the resource exploitation associated with it. The chapter ends with a summary of ongoing research and relevant studies in the field.

The primary impact of new transportation infrastructure development is that of habitat loss. The density of land area under infrastructure development for each Member country has been illustrated in Chapter 4. Other less direct effects of transport networks on the natural environment relate to the potential corridor function of the habitat alongside roads, railways and waterways; the various types of disturbance impacts; fauna casualties caused by traffic using the infrastructure; and the barrier effect. These are discussed in more detail in the following sections.

5.1. Habitat loss

In Europe, the area of habitat lost to transportation infrastructure is relatively small compared to that resulting from other types of development (*e.g.* urbanisation, agriculture and intensive landuse). In Denmark, as in many other European countries, the intensification of agriculture over the past 50 years has had a much more significant effect on the loss of heath, moor, fen, meadows, marsh and lake habitats than infrastructure development (DK-SoA, 5.4.1).

However, as described in the previous chapter (Sections 4.2.1 and 4.3, Figures 4.3 and 4.4 in particular), land is under continuous pressure for new transportation infrastructure. Further expansion of the transportation infrastructure and intensification of its use inevitably involves a greater risk of intensifying the existing habitat fragmentation problem and could jeopardise the future of many important natural areas.

Section 3.2 has highlighted two aspects of habitat loss associated with transportation infrastructure development: the physical occupation of land and the degradation of surrounding habitat by disturbance and pollution (indirect effects). Total landtake varies

Hicks, C. and Peymen, J. (2002) Habitat Fragmentation due to Existing Transportation Infrastructure. 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. 73-113. Office for Official Publications of the European Communities, Luxembourg.

according to the infrastructure mode, and the scale of the development concerned. It includes both the area covered by the infrastructure itself and the associated land taken for security areas, junctions, service areas, stations, parking etc. If such areas are taken into account, overall habitat loss becomes far more significant (Table 5-1).

Table 5-1 - Direct and indirect land take by transport mode.

Infrastructure Type		Land take (ha/km)		
		Direct	Indirect	Total
Road	Motorway	2.5	5	7.5
	State Road	2	4	6
	Provincial Road	1.5	3	4.5
	Municipal Road	0.7	1.3	2
Rail	Conventional & HSR/TGV	1	2	3
Water	Canal	5	5	10

Source: EEA-ETC/CC (http://themes.eea.eu.int)

Information is readily available regarding the current length of transportation infrastructure in each country (Section 4.3). Extrapolating this data shows that *ca*. 1.2% of the total land area in the EU is physically occupied by transportation infrastructure; the road network occupies 93% of this. However, there is little data on annual land take by different transport modes.

The scale and type of historical habitat loss that has been associated with the construction of the existing transport network is difficult to assess due to the lack of records. Broad estimates can be made however, using information such as that in Figure 5.1. This shows that road and rail infrastructure withdraws land mainly from agricultural use, and to a lesser extent, from built up areas. The share of landtake in semi-natural areas and wetlands is slightly more for roads than railways.

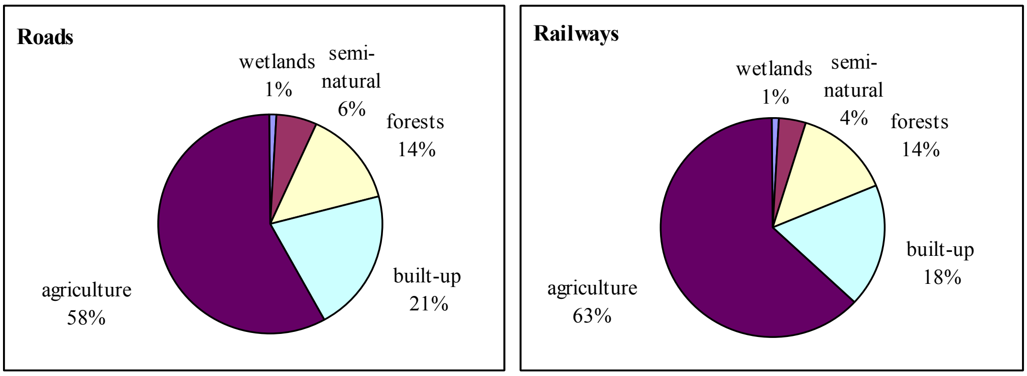

Figure 5.1 - Land take by roads and railways according to land cover type. (EEA, 2000)

Attempts have been made recently to estimate the scale of habitat lost to infrastructure for each major habitat type through GIS processing of digital and satellite imagery. Two examples from The Netherlands and the United Kingdom are outlined in Boxes 5.1 and 5.2 below.

Box 5.1 - Habitat loss due to infrastructure in The Netherlands

On a raster map, main road and railway 'pixels' were identified and the dominant value of the adjacent pixels provided. This enabled an estimate of the percentage area of the different types of landuse lost to infrastructure (see Table 5.2). It was recognised that these figures represented a gross underestimation, however, they provide a useful first attempt at measuring the extent of the habitat fragmentation problem.

Table 5-2 - Estimated area of habitat lost due to the creation of the main road and railway network.

Habitat Type	With infrastructure* (ha)	Without infrastructure* (ha)	Difference (ha)	Difference (%)
Grassland	1,372,725	1,405,741	33,017	2.3
Arable land	965,966	987,429	21,463	2.2
Deciduous forest	181,447	184,485	3038	1.6
Perennial forest	175,903	178,512	2,610	1.5
Heathland	13,415	13,463	47	0.4
Not covered	17,615	17,642	27	0.2
Other nature areas	122,471	123,342	871	0.7
Fresh water	342,032	343,633	1,600	0.5
Saltwater	431,943	432,117	174	0.04
Urban areas	429,089	451,623	22,534	5.0
Main roads and railroads	100,101	**14,720	85,381	

*Main road and railway network
**The fact that this value is not 0 is due to the dominant environment of the transformed pixels apparently also made up of road. The area losses for each unit are therefore slightly underestimated.

The 'difference' percentages show that the density of transportation infrastructure in nature areas is relatively low. Nonetheless, the total area of deciduous and perennial forest decreased by at least 2,000 ha as a direct consequence of road and railway construction (NL-SoA, 5.3.1).

Box 5.2 - Loss of peatland in Scotland, UK due to transportation infrastructure

Scottish Natural Heritage (SNH), the statutory nature conservation body in Scotland (UK) initiated a project to examine the potential fragmentation effect of roads and railways on peatlands, one of the country's most sensitive habitats. Of 27,840 ha of raised bog which once existed, only 8.4% still remains in a near-natural state. It is accepted that road building can upset the balance of peatland species by altering the bog's water regime or increasing nutrient levels in the system. The study has produced some interesting results, shown by the summary statistics in Table 5-3 and Figure 5.3.

Table 5-3 - Loss of peatland in Scotland due to transportation infrastructure.

Land Cover Class	Area dissected by roads and rail (km^2)	Possible extent of land cover of interest dissected (km^2)	Length of road and rail dissecting land cover feature (km)
Blanket bog and other peatland	7,682	4,761.4	2,397
Wetlands	97	65	166
Saltmarsh	20	19.34	18.3
ALL CLASSES	7,799	4,845.74	2,581.3

Source: Scottish Natural Heritage

The potential environmental impact of transportation infrastructure depends strongly on the type of land affected (including its immediate surroundings). In general the impact of habitat loss is greater in more intensively used landscapes, where the increasing isolation of natural or semi-natural remnant habitat patches may be critical for species survival. Similarly, habitat loss can be particularly significant in the case of rare plants with limited distributions *e.g. Borderea chouardii,* an endemic plant from the Pyrenees which is contained in Annex II of the Habitats Directive. Located in one canyon, with an estimated population of just 2,200 individual plants, it is currently threatened by the possible widening of the N-230 road between Lleida and the Vall D'Aran (north east Spain). Also, the threatened flora of the Sierra Nevada has a high number of endemic species which make up 30% of the vascular flora of Spain. Transportation infrastructure, along with urbanisation and quarrying is one of the main causes of the rarification of at least 10 taxa in this region (E-SoA, 5.4.1).

The actual amount of habitat lost specifically to infrastructure is thus difficult to assess but it is clearly considerably more than the area actually physically occupied by the infrastructure elements. Currently, little information is available regarding the impact of this habitat loss for individual species. Indirect habitat loss, *i.e.* where, as a result of infrastructure development, patches of habitat become too small, isolated, or disturbed to maintain a viable population of a given species, is also extremely difficult to quantify – hence the current lack of data.

5.2. DISTURBANCE

A variety of studies have investigated the disturbance effects of transportation infrastructure and the degree to which adjacent and surrounding habitats are impacted upon. Evidence from the National State of the Art reports shows that the disturbance effect ranges from a few metres to a kilometre from the source, depending on the species concerned and the intensity of the traffic. This confirms the theory presented in Section 3.3. In Switzerland, it is accepted that there will be a highly disturbed zone up to 50 m from a road, which experiences high levels of noise (>65 dBA), particulates and gaseous pollution; a zone of lesser ecological disturbance extends a further 100 m from the road. Gradients of response to the disturbance by individual species depend on the intensity, frequency and duration of the disturbance.

Table 5-4, based on data from Belgium (Environment and Nature Report, 1994) makes a useful comparison between the magnitude of disturbance effects according to the stage of the infrastructure's lifecycle. It highlights the fact that the magnitude of impact associated with construction of infrastructure rarely subsides during the operational phase, and in some cases it increases (*e.g.* air pollution). Even after decommissioning, some types of disturbance effect continue to persist - illustrating the long term (and even permanent) nature of the impacts on the local environment (B-SoA, 5.4.3).

Table 5-4 - Magnitude of disturbance effects between infrastructure type and according to lifecycle stage (Belgium).

Disturbance Effect	Road			Railway (and Stations)			Waterway (and Ports)		
	Stage of Life			Stage of Life			Stage of Life		
	C	O	D	C	O	D	C	O	D
Water pollution	+	+	0	+	0	0	+	++	0
Hydrological change	+	+	+	+	+	+	++	++	+
Soil contamination	+	+	0	+	+	0	+	+	0
Soil degradation	++	++	+	++	++	+	++	++	+
Noise nuisance	++	++	0	++	++	0	++	+	0
Air pollution	+	++	0	+	+	0	+	+	0
Microclimatic change	+	++	+	+	++	+	+	++	+
Visual impact	++	++	0	++	++	0	++	++	0

Source: Vlaamse Milieumaatschappij, 1994
0: none or negligible; +: incidentally; ++: often/always
C: during construction; O: during operation; D: after decommissioning

One aspect that Table 5-4 does not draw out is the variation in the disturbance effect according to the infrastructure type. The noise, vibration, chemical pollution and lighting associated with roads (particularly motorways and primary roads) is relatively intense when compared to railways and waterways. For secondary roads, the extremely variable flows and composition of traffic leads to more irregular disturbances. Railways have been identified as having a more frightening effect on wildlife than roads (NL-SoA, 5.3.2). This may be linked to the higher vibration levels experienced near railways, their more marked visual presence *e.g.* with overhead wires, the discontinuous frequency of trains, or even the conspicuous colour of some trains. Bergers (1997) investigated the relative extent of the fragmentation effects of railways as compared to motorways. The infrastructure factors that were considered relevant to the fragmentation effect included: shape, width and height, intensity of use, sound emission, barrier elements, and lights. The main difference between the modes is that the sound emission near a railway is discontinuous. It was not clear whether this, as compared to the disturbance effect of the continuous sound emission from motorways, leads to a larger or smaller disturbance effect on nearby fauna. The long periods of silence associated with railways could result in lower stress levels but the more continuous sound coming from roads could make animals more readily accustomed to it. Table 5-5 presents Bergers (*op. cit.*) estimates of the sensitivity of individual species to the disturbance effect of railways.

Table 5-5 - The expected intensity of the disturbance effect caused by sound near railways for various species groups (The Netherlands).

Disturbance	Species (groups)
Large	common buzzard, willow warbler, goldcrest, black-tailed godwit, wood pigeon, lapwing, cuckoo, partridge, oyster catcher, shoveler, skylark, golden oriole, wren
Medium	various bird species, fallow deer, red deer, wild boar, frog and toad, grasshopper
Probably	various bird species
None	newt, butterfly, spider, ground beetle
Unknown	many bird species, marten, small mammals, reptiles

Source: Bergers, 1997

An important type of disturbance is created by inland waterways (*i.e.* canals), which 'artificially' connect various water systems and supply water from 'foreign' (non-local) waters. The disturbance effect is seen in the changed composition of the natural vegetation and macrofauna. The best known example of this is the canal connection between the Rhine and the Danube, which resulted in a variety of new fish species tarriving in the rivers of The Netherlands, with widespread ecological consequences for the local populations (NL-SoA, 5.3.2). Further disturbance along waterways is caused by waves hitting the bank when vessels pass resulting, in the worst case, in the abrasion of the natural banks along with their vegetation and fauna (NL-SoA, 5.3.2). Noise disturbance resulting from intensive use (for recreation and inland navigation) may also be important, but little is known at present about the scope of such disturbances (NL-SoA, 5.3.2).

Information relating to disturbance effects at community and ecosystem level is sparse, but some specific research shows that disturbance effects on sensitive species (or groups of species) can be significant and may spread over a wide area. Table 5-6 highlights several such species and identifies some of their responses, the most evident of which is avoidance. In Norway this is illustrated by the wild reindeer, which have been observed to under-use valuable resources near roads, resulting in an increase in grazing pressure in areas outside the disturbance zone (N-SoA, 5.4.3). More specific evidence regarding individual species responses to different types of disturbance (*i.e.* chemical, noise, and visual), is presented in the following sections (5.2.1 to 5.2.3).

Observations show that disturbance causes a gradual change in the species composition of a habitat, involving a decrease in the number of sensitive specialist species and an increase in the relative proportion of generalist species. The ultimate impact of increased disturbance levels is illustrated by the case of the capercaillie (*Tetrao urogallus*) in the French High Jura region (Leclercq 1987). Numbers of this species were seen to drop in line with increasing human presence along the roads. Eventually, when the birds could no longer find any potential habitats sufficiently far from the road, this led to local population extinction (F-SoA, 5.4.3).

Table 5-6 - Species-specific disturbance effects.

Species	Disturbance	Effect of disturbance and distance of measurable effect (where available)	Source
Wild reindeer	Road usage	▪ Under-use of resources near roads, leading to reduction of available resources and over-use of remote resources	N-SoA
Thrushes, black grouse, owls		▪ Negative impact probably due to noise	S-SoA
Breeding birds	Road & railway noise	▪ Lower density of all species close to noise source	Reijnen *et al.*, 1992; Reijnen, 1995
Common buzzard, willow warbler, goldcrest, black-tailed godwit, wood pigeon		▪ Large effects predicted*	NL-SoA
Black-tailed godwit (*Limosa limosa*).	Road lighting	Reduced breeding behaviour and density	De Molenaar et al., 2000
Verge vegetation *e.g.* Norway Spruce (*Picea abies*), Scots pine (*Pinus sylvestris*)	De-icing salt	▪ Discolouring and die-back ▪ Changed species composition of road verges - spread of halophytic plant species ▪ Vegetation effects up to 40m from the road surface	S-SoA, H-SoA, N-SoA, UK-SoA, DK-SoA, Randrup and Pedersen, 1996

Source: National State of the Art reports
* Not based on field research

5.2.1. Chemical disturbance

The construction of infrastructure itself can produce changes in groundwater and surface water flows, which can have an adverse effect on the wider habitats and ecosystems of which they are a part *e.g.* through soil subsidence. These changes may also cause contaminants in the soil and groundwater to mobilise and migrate, thus affecting soil and water quality. The potential for chemical disturbance continues during infrastructure use – the main vector is via polluted runoff. In Flanders (Belgium), as in several other European countries, road and rail runoff is neither collected nor treated, but runs simply via ditches and drainage channels into local watercourses (B-SoA, 5.4.5). This means that the disturbance effect can become widespread in the surrounding landscape. Similarly, drainage ditches, excavated to prevent flooding of the road or rail surface, can have a dehydration effect on the local area. This is particularly significant with construction projects in higher altitude river valleys, fenlands and in sandy areas (Grontmij, 1995).

For railways, chemical disturbance is a particular risk where lowered line sections, tunnels and tunnel basins are constructed (NL-SoA, 5.3.2). Along electrified railways, especially on braking sections, there can be increased copper concentrations in the soil due to the wear of overhead wires. Diesel trains produce exhaust gas emissions and pollute the air with relatively low concentrations of NO_x and SO_2. The effects of these emissions on the adjacent environment have not been examined, and are therefore unknown (NL-SoA, 5.3.2).

5.2.2. Traffic noise

Section 3.3.3 highlighted the fact that most research into the effects of noise disturbance has concentrated on investigating the behavioural responses of bird species. Notably, Reijnen *et al.*, (1995; 1996) studied the effect by comparing the densities of breeding bird species in areas subject to varying traffic intensities (between 5,000 and 60,000 vehicles per day) and at differing distances from the noise source. In forests, effects were established for birds of prey, pigeon, woodpecker, thrush, tit, songbirds and crow-like birds, and in open grassland for duck, wading birds and songbirds. Figure 5.2 indicates the zones in which road traffic leads to disturbance. The forest zone is narrower than the grassland one simply due to vegetation structure (dense tree trunks), which has a muffling effect on traffic noise. It was concluded that road traffic has an effect on the density of all bird species and there was clear evidence to suggest that traffic noise was the main disturbing factor.

In Spain, similar studies have been conducted. For example, Fajardo *et al.* (1998) surveyed a 40 km road-transect for little-owls *(Athene noctu*a) to investigate whether their foraging activity was affected by traffic intensity. Owl activity was shown to be negatively correlated with traffic flow: individuals were most active when the traffic flow was lowest and vice versa. It was clear there was a disturbance effect when traffic density was high but it was uncertain whether noise or visual disturbance was the most important factor (the strong traffic headlights at night may have impeded the little-owls from detecting prey). The work of Martínez (1994), studying the location of male little bustard *(Tetrax tetra*x) territories in Spain in relation to the road network, seems to contradict Reijnen *et al.* (*op. cit*.), and Fajardo *et al.* (*op. cit*.). Roads did not appear to influence the spatial distribution of this species at all, indicating that susceptibility to noise disturbance varies greatly between different species.

In the United Kingdom, studies show that in general, birds appear to habituate to continual noises so long as there is no large ‘startling’ component. As a source of disturbance, vehicles are tolerated much more than the presence of people and cause much less of a negative effect on breeding success. It is particularly interesting to note that in the United Kingdom many of the designated Sites of Special Scientific Interest (SSSIs) used as training areas and artillery ranges by the Ministry of Defence, support diverse breeding bird populations. Although not related to transportation infrastructure, this general observation suggests that the noise disturbance effect is not largely significant and that birds may not be as sensitive to noise as other studies have suggested (UK-SoA, 5.4.3).

Wallentinus (1999) added a temporal aspect to the work of the Dutch researchers by comparing the occurrence of birds before, and 15 years after, a new stretch of Highway E18 (north of Stockholm, Sweden) was opened. Some bird species had decreased in abundance (*e.g.* thrushes, black grouse and some owls), whilst others had increased (*e.g.* opportunistic species such as wagtail, chaffinch, great tit and yellowhammer) or remained the same (*e.g.* willow-warbler, tree pipit and robin). Noise was suggested to be the triggering disturbance factor (S-SoA, 5.4.3). Similarly, Cirera (2000) reports on the effects of the construction and operation of a new road on the breeding of a pair of Bonelli’s eagle *(Hieraetus fasciatu*s) in the North-east of Spain. Over the two-year study, the pair continued to use the affected area. During the first year they reared a single chick, followed by two further chicks in the second year. A year after the road opened the pair had not laid any eggs although they continued to use the area (E-SoA, 5.4.3).

In terms of studies of the noise disturbance effect on species other than birds, the evidence is fairly scarce. One such study was made in conifer forests in The Netherlands on squirrels (*Sciurus vulgaris*)(Van Nieuwenhuizen and Apeldoorn, 1995). In this type of habitat, no effect was found on the density of squirrel nests (NL-SoA, 5.3.2).

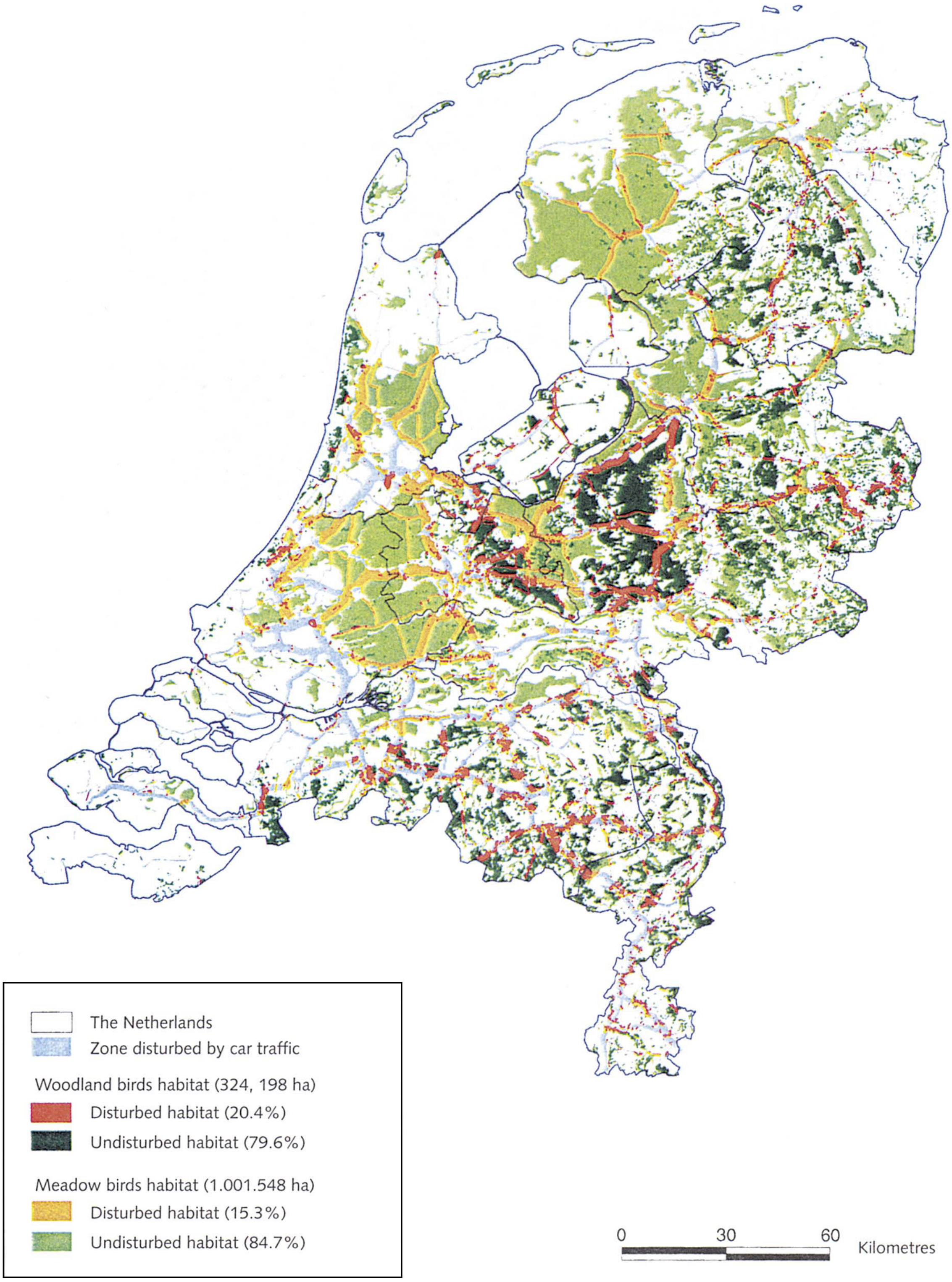

Figure 5.2 - Map showing disturbance zones in The Netherlands. (From NL-SoA, 5.3.2)

5.2.3. Visual disturbance

The extent of knowledge from field experiments concerning the disturbance effects of road lighting on flora and fauna is limited. Studies showing the adverse effects of road lighting on breeding behaviour and density have been limited to some specific species of conservation concern such as the black-tailed black-tailed godwit (*Limosa limosa*) in The Netherlands (De Molenaar and Jonkers, 1997). Road lights were shown to have an adverse effect on the density and breeding behaviour of the black-tailed black-tailed godwit in a zone of 200 to 250 m from the disturbance source (De Molenaar *et al.*, 2000). In the United Kingdom, notable species which are impacted upon include the nightjar (*Caprimulgus europaeus*) and the owl families, *i.e.* nocturnal species (UK-SoA, 5.4.3). As a consequence of the paucity of evidence, the extent of mitigation measures related to lighting proposed for road schemes is generally minimal (Markham, 1996) but this is clearly an area which requires more focused research.

5.3. FAUNA CASUALTIES

For animals that attempt to cross road and railway lines, traffic impact often leads to the death of individuals. For rare or vulnerable species can result in an overall decline in the wider population. Waterways present a similar risk to fauna in the form of drowning. A growing literature suggests that infrastructure near wetlands and ponds cause the highest wildlife mortality rates and that factors such as road width, traffic density, speed and the population size affect this rate (see Section 3.5.3). There are no central statistics on fauna casualties in Europe, but a number of separate surveys have tried to estimate the extent of the problem for different groups of species - Table 5-7 (nb. when analysing this table caution should be applied in interpreting the data – the figures presented cannot be compared directly due to the different sampling methods employed in different countries).

Table 5-7 - Overview of fauna casualties across Europe.

Species or group of species	Magnitude of effect (per annum)		Country	Source
Insects	3,000,000		France	F-SoA, 5.4.4
Vertebrates	4,000,000		Belgium	Rodts *et al.*, 1998
	41,955		Spain	Lopez Redondo, 1993
Amphibians	3,086,000		Denmark	Hansen (1982)
	24%	of all roadkill deaths	Spain	Lopez Redondo, 1993
	Up to 90%	of local populations	Hungary	Puky *et al.* 1990
	20-40%	of a breeding population	United Kingdom	Langton, 1989 *in* Treweek, 1999
	4,225	(avg figures)	Belgium	B-SoA, 5.4.4
Common toad	3,765	(avg figures)	Belgium	B-SoA, 5.4.4
Common frog	238			
Green frog	3			
Salamander species	220			
Toads	15-50%	of migrating population	The Netherlands	Van Leeuwen, 1982 *in* Treweek 1999
Reptiles	6%	of all roadkil deaths	Spain	Lopez Redondo, 1993

(Cont'd ...)

Species or group of species	Magnitude of effect (per annum)		Country	Source
				(…Cont'd)
Birds	2,000,000 653,000	on roads in total	The Netherlands	Van den Tempel, 1993; Van der Zande *et al.*, 1980 *in* Treweek, 1999
	4,000,000 10,000,000 30,000,000 - 70,000,000		United Kingdom	Hodson, 1966 *in* Treweek, 1999; Hill and Hockin, 1992; TEST, 1991
	2,013	avg	Belgium	B-SoA, 5.4.4
	3,700,000		Denmark	Hansen, 1982
	2,000,000		The Netherlands	NL-SoA, 5.4.4
	482	(over 4 yrs) 1.48/km/yr	France	F-SoA, 5.4.4
	30,000,000 – 70,000,000		United Kingdom	Harwood, Hilboune *et al.,* 1992
	36%	of all roadkill deaths	Spain	Lopez Redondo, 1993
	5,000,000 – 8,500,000	8	Sweden	Svensson, 1998 *in* S-SoA, 5.4.4
Barn owls	>1,200		The Netherlands	NL-SoA, 5.4.4
	5,000		United Kingdom	TEST, 1991 in Treweek, 1999
Mammals	1,769	avg	Belgium	B-SoA, 5.4.4
	159,000		The Netherlands	Van der Zande *et al.*, 1980 *in* Treweek, 1999
	34%	of all roadkill deaths	Spain	Lopez Redondo, 1993
	1,501,000		Denmark	Hansen, 1982
Small mammals	678,000		Denmark	Based on 3 surveys: Hansen, 1982; Thomsen, 1992; Bruun Schmidt, 1994
	429	(over 4 yrs) 1.6/km/yr	France	F-SoA, 5.4.4
Medium sized mammals	200,000 – 500,000	(5-9%)	Sweden	Goransson *et al.*, 1978
Fox	29,000		Denmark	Based on 3 surveys: Hansen, 1982; Thomsen, 1992; Bruun Schmidt, 1994
	26.6%		France	F-SoA, 5.4.4
Cat Wild cat	70,000		Denmark	Based on 3 surveys: Hansen, 1982; Thomsen, 1992; Bruun Schmidt, 1994
	16.6%		France	F-SoA, 5.4.4
Rabbit	>47,000		The Netherlands	NL-SoA, 5.4.4
Hare,	31,000		Denmark	Based on 3 surveys: Hansen, 1982; Thomsen, 1992; Bruun Schmidt, 1994
Rabbit/hare	13.6%		France	F-SoA, 5.4.4
Badger	37,500 –50,000		United Kingdom	Neal and Cheeseman, 1996; Clarke *et al.*, 1998

(Cont'd ...)

Species or group of species	Magnitude of effect (per annum)		Country	Source
				(…Cont'd)
	18-20%	of a local population	The Netherlands	Broekhuizen *et al.*, 1994; Lankaster *et al.*, 1991
	47,000		United Kingdom	Harris and Gallagher, 1989
	1,000		Denmark	Based on 3 surveys: Hansen, 1982; Thomsen, 1992; Bruun Schmidt, 1994
Hedgehog	17,000		The Netherlands	Huijser and Bergers, 1997
	13.3%		France	F-SoA, 5.4.4
	17,000		The Netherlands	NL-SoA, 5.4.4
	55,000		Denmark	Based on 3 surveys: Hansen, 1982; Thomsen, 1992; Bruun Schmidt, 1994
Marten	20		The Netherlands	Heinen, 1995
	14.7%		France	F-SoA, 5.4.4
Large mammals (roe deer, red deer, wild boar)	3,946		France	SETRA 1998b
	1,500-2,000		Spain	Fernandez, 1993
Deer	20,000-42,000		United Kingdom	UK-SoA, 5.4.4
	200,000		USA	Schafer and Penland, 1985 *in* Treweek, 1999
Roe deer			Estonia	EE-SoA
	3,500		Norway	N-SoA, 5.4.4
	45		The Netherlands	Heinen, 1995
	25,000		Sweden	S-SoA, 5.4.4
Red deer	500		Norway	N-SoA, 5.4.4
Wild boar			Estonia	EE-SoA
Moose	4,500		Sweden	S-SoA, 5.4.4
	2,000		Norway	N-SoA, 5.4.4
			Estonia	EE-SoA
	5,000		Sweden	S-SoA, 5.4.4
	2,000	p.a	Norway	
Wild reindeer	3,000		Sweden	S-SoA, 5.4.4

Source: National State of the Art reports

Among all species, the barn owl (*Tyto alba*) has been noted as one of the most severely affected by mortality due to collisions with vehicles: 44% of bird mortalities in France (F-SoA, 4.4.4.1); 52% in the United Kingdom (UK-SoA, 5.4.4); 37% in central Spain (E-SoA, 5.4.6) and; 41.5% in The Netherlands (NL-SoA, 5.3.3). The particularly high mortality for this species is ascribed to the frequent hunting activities of the owls on the verges of roads (motorways in particular), which are often excellent habitats for the field mouse (Van den Tempel, 1993).

Other than direct traffic kills, some animals, particularly birds, are injured through collision with structures associated with road and rail infrastructure *e.g.* transparent noise barriers (acoustic walls). Birds are unable to see these obstacles and collision with them is often fatal. In a tract of 580 m of glass noise barrier in Modena, Italy, M. Dinetti (pers.comm.), reported an average of 1.04 birds killed per day; species affected included sparrowhawk and kingfisher. Noise barriers also have been noted to impede the movement of small mammals, reptiles and amphibians. The differences in mortality risk associated with the different modes of infrastructure are discussed in more detail in the following sections.

Because of their particular characteristics, clearly not all species are equally affected by road kills (E-SoA, 5.4.4). The risk of animal mortality due to collisions depends on infrastructure characteristics, traffic density, habitat type, and time of the day. Assuming an animal gets as far as venturing onto the road or track surface, the probability of successfully crossing to the other side varies between species. It is a function of animal crossing speed, road width and traffic density (Table 5-8).

Table 5-8 - Risks involved for animals in crossing a road.

Animal Group	Average Crossing Speed (cm/second)	Risk of death (traffic density: 500 vehicles/hour)	Risk of death (traffic density: 1500 vehicles/hour)
Spiders	12	40%	100%
Beetles	18	25%	75%
Amphibians	30	18%	45%
Mouse / vole	42	10%	35%

Source: UK-SoA, 5.4.4

Studies in Sweden suggest that the number of casualties increase logarithmically with increasing traffic load so that roads with very high traffic volumes appear to have fewer road casualties than expected from a linear relationship (S-SoA, 5.4.4). In Spain, multivariate analyses of vertebrate mortality frequencies showed that habitat quality for each species had much higher effect on mortality rates than specific road features. Highest mortality rates occurred in undisturbed areas whereas lowest rates took place close to human habitations and bridges (E-SoA, 5.4.4).

5.3.1. Roads

Studies have demonstrated the important differences in fauna mortality rates that exist between high-capacity roads (with Daily Average Densities (DADs) between 25,000 and 50,000 vehicles) and local roads (with DADs below 5,000 vehicles) without perimeter fencing. Rosell and Velasco (1995; 1999) showed that the number of carnivore casualties on local roads was almost twice as high as on motorways, and 13 times as high for amphibians (E-SoA, 5.4.4). A similar pattern has been observed in The Netherlands where about half of the two million traffic kills on roads occur on motorways (which represent a mere 5% of the total road network), with the other million deaths on roads other than motorways (Van den Tempel, 1993). In France, the patterns of mortality are repeated, with most collisions taking place on county roads (75% from 1984 to 1986 and 63% from 1993 and 1994). Box 5.3 provides further evidence of how mortality rates vary by road type.

Box 5.3 - Badger road mortality in The Netherlands and Denmark

Over half of all traffic kills involving badgers occur on municipal roads in The Netherlands due to the extensive total length of these types of road. Data from the Badger and Tree Association for 1990 to 1996 shows that the number of badgers killed per 100 km of municipal road is much lower than the number killed on national trunk roads (Badger and Tree Association, 1998). This is connected with the lower traffic intensity on secondary roads. Similar conclusions were drawn from a study in Sonderjylland county, Denmark, where the number of mammal casualties were recorded over 20 months by the road authority (Table 5-9).

Table 5-9 - Number of mammals killed on public roads in Sonderjylland County, Denmark, according to road type (November 1995 – August 1997).

Species	Motorways	Highways	Secondary roads	All roads
Roe deer	6	19	34	59
Fox	93	75	132	300
Badger	33	22	31	86
Hare	56	198	423	677
Hedgehog	43	313	764	1 120
TOTALS	231	627	1 384	2 242
Length of road studied (km)	101	326	833	1 260
Length of class of road (km)	1 287	1 588	2 029	4 904
Casualties across network	2 960	3 017	3 449	8 827
Casualties per km of road	2.3	1.9	1.7	1.8

Source: Madsen *et al.*, 1998

In terms of the temporal variation in mortality rates, in France collisions on national roads have remained stable at 18% of the total between 1984 and 1994. Over the same period, collisions on motorways have increased by 11.5%. Four factors have been identified as causing this marked increase: a rise in the number and length of this type of highway; the more widespread use of fencing; the increased number of users; and higher vehicle speeds (F-SoA, 5.4.4).

5.3.2. Railways

Data on railway casualties is more sparse than for roads. In Denmark, as in many other countries, there are no estimates of the number of animals killed by trains, but it is assumed to be much lower than for roads (DK-SoA, 5.4.3). In the vicinity of rail infrastructure, birds are regularly killed because they fly into electrified overhead wires, and mammals, amphibians and reptiles are common casualties on the rails – either through impact with trains or through electrocution (Table 5-10). For ground-dwelling fauna, the chances of safely crossing a track are relatively high due to the comparatively low intensity of rail traffic: Bergers (1997) computed a chance of a successful crossing rate of 96% during the day and of almost 100% at night (NL-SoA, 5.3.3).

Table 5-10 - Expected mortality caused by railways for various groups of species.

Species (groups)	Mortality rate
Most bird species (particularly owl, nightjar), amphibians, reptiles	High
Mammals, various birds species	Medium
Spiders, ground beetles, grasshoppers	None
Bats, butterflies	Unknown

Source: Bergers, 1997

According to Czajkowski and Thauront (1990), avifauna mortality due to collision with trains is fairly high: between 1 and 5 collisions per km per month. In France, the number of individuals killed per year is between 480,000 and 2.4 million, with birds of prey (particularly tawny-owls (*Strix aluco*), barn-owls, long-eared owls and the common buzzard) seemingly the most vulnerable. Parameters such as train speed, topography of the line (cuttings, embankments etc) and the type of surrounding landscape play an essential role in determining mortality rates (F-SoA, 5.4.4). Overhead railway cables at a height of 6 to 12 m represent a serious hazard for low flying birds *e.g.* wood pigeon (*Columba palumbus*) and turtledove (*Streptopelia turtur*), and to some perchers *e.g.* blackbird (*Turdus merula*), song thrush (*Turdus philomelos*), and starling (*Sturnus vulgaris*).

A key problem with rail is that of electrification, especially when the electricity supply is through a ground level third rail. Electrocution is a second major cause of rail-related mortality, but it only accounts for a low percentage of rail victims and particularly concerns town birds. A study undertaken on the North HSR/TGV in France (Pons, 1994) listed 3.4 dead birds per km per month for collisions, as opposed to 30 birds per year for electrocutions. Electrocution therefore remains a much lesser risk than collision with trains and cannot be compared to mortality due to overhead electrical cables. Nevertheless, development of 25 000 Volt AC lines where the catenary suspension wire is not insulated (for HSR/TGV and in the electrification of main lines) has tended to increase this type of mortality (F-SoA, 5.4.4).

The type of railway concerned (*i.e.* high speed or traditional) also has an influence over the mortality risk for fauna: 96% of collisions on high speed lines are collisions with wild fauna, as compared to 25% on traditional lines. Roe deer are by far the most affected on high-speed lines whilst the wild boar is the most affected on traditional lines. (F-SoA, 5.4.4). Pontón (1997) surveyed vertebrate mortality on stretches of railway in Spain with different characteristics over 3 years. The 329 death records showed that high-speed railways produce many more casualties than conventional rail (about 40,000 individuals per year on one 350 km line compared to some 445,000 individuals per year on the whole rail network) (E-SoA, 5.4.4).

The impact of train collisions on moose and other large game (*e.g.* roe deer, red deer and reindeer) and other large animals (*e.g.* cattle, horses and wild boar) is well documented. Train drivers in Sweden register approximately 1,000 large game killed by trains each year. A study from the northern rail district (approximately one quarter of the rail network in Sweden) recorded 117 moose and 643 reindeer collisions over 6 months (January to June 1999). This equates to the death of approximately 5 moose per 100 km of railway per year, with peak rates during winter (Figure 5.3) (S-SoA, 5.4.4). Collisions with large wildlife are very costly due to the resulting train delays, repair costs of trains, and personnel time involved in removing the carcasses (Johansson and Larsson, 1999) (see also Chapter 6).

Figure 5.3 - Moose kill in Norway (Photo by College of Hedmark, Evenstad - Elg som næring.)

The overall figures for rail and road accidents are difficult to compare due to the inconsistency of the recording methods and the fact that a larger proportion of road accidents go unrecorded. This is because train kills of larger mammals lead to greater safety risks, so these incidents are usually registered more effectively. Studies in Norway conclude that compared to roads, railways (with their lower traffic frequency and shorter network length) represent more of a risk to game species (with approximately 1 game animal death per 4 km of railway track, compared with 1 death per 18 km of road). This may in part be because of the higher speed of trains plus the extensive use of fencing that can trap animals within the rail corridor. Animals may thus *cross* roads but wander *along* railway lines.

5.3.3. Waterways

The number of large animals that become victims of drowning in inland waterways is difficult to estimate on a European or even national scale, and for small mammals it is virtually impossible as their bodies decay quickly, are eaten, or remain unnoticed. Despite the paucity of data, it is widely accepted that thousands of animals drown each year because they cannot climb out of canals with steep banks. Of all the species of large game, the roe deer (*Capreolus capreolus*) seems to suffer the highest losses in waterways: between 1987 and 1994, more than 210 roe deer were recorded dead over a 63km section of the Twenthe canal in The Netherlands. A further study of a 14 km stretch of this canal estimated the average number of mammal deaths killed each year (Figures 5.4 and 5.5) (Heinen, 1995).

Annually in Belgium around 10 roe deer are recovered from the Albert canal between Hasselt and Bilzen. Also smaller animals such as foxes, rabbits and mice are often found (B-SoA, 5.4.4). In France, the last systematic national inquiry undertaken on the subject dates back to 1978/1980 (CEMAGREF, 1982). It recorded annual numbers of roe deer, red deer and wild boar victims at an intensity of 12 per 10 km of canal and showed that mortality figures vary considerably according to the season (peaking from March to August for roe deer during the rutting season).

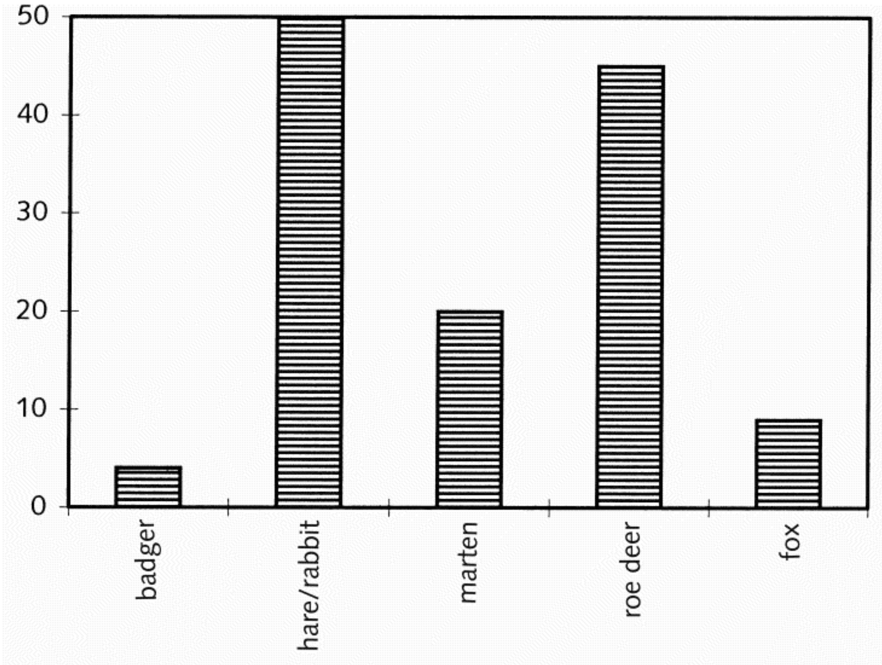

Figure 5.4 - Converted average number of victims of drowning in the Twenthe canal per year. (After Heinen, 1995 *in* NL-SoA)

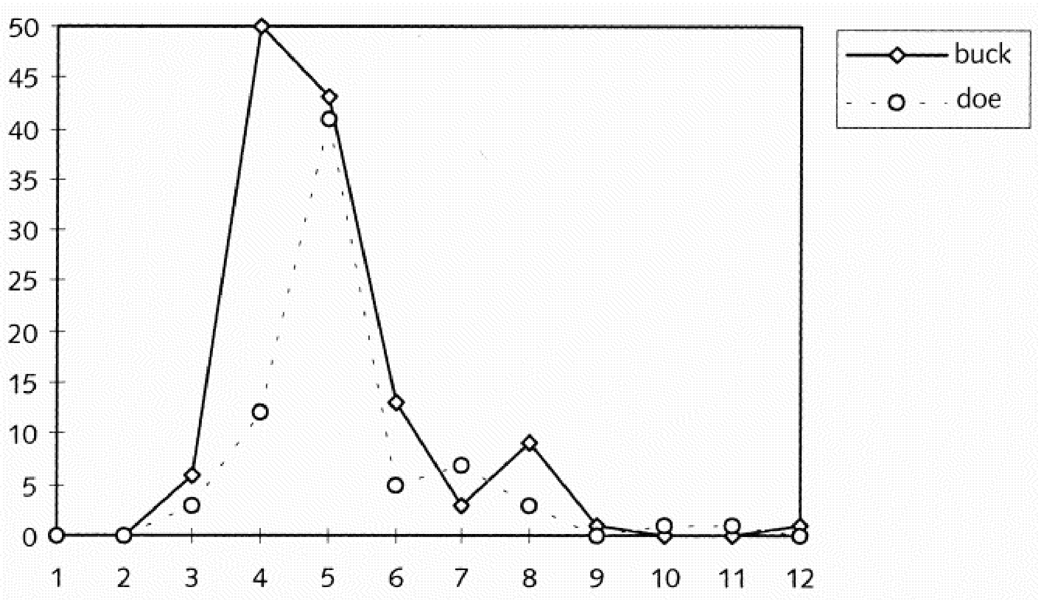

Figure 5.5 - Number of drowned roe deer (*Capreolus capreolus*) found each month in the Twenthe canals, in the period 1987 to 1994. (From Heinen, 1995 *in* NL-SoA)

Annual vertebrate mortality over 36 km of the Dehesas irrigation canal (south-west Spain) has recently been analysed by Traverso and Álvarez (2000). The study is particularly interesting because it was carried out before the canal entered into operation when it contained only accumulated rainwater. The researchers found 3,420 amphibians inside the canal (28% dead), 733 reptiles (67% dead) and 273 mammals (67% dead). A few bird carcasses were also found. The high concentration of prey inside the canal made it a good hunting ground for grass snakes *(Natrix natri*x) and viperine snakes *(Natrix maur*a), however, many juveniles of both species were found dead which suggests that they had become trapped. Rabbits *(Oryctolagus cuniculus*), Granada hares *(Lepus granatensis*) and hedgehogs were the mammal species found dead most frequently (E-SoA, 5.4.4).

Of the few studies that have concentrated on fauna mortality associated with waterways it can be concluded that the drowning of animals trying to cross waterways represents a low cause of mortality compared to that caused by road and rail infrastructure.

5.3.4. Data collection

Collecting the data required to fully assess the threat of fauna casualties caused by infrastructure development is not easy. The mortality figures quoted above undoubtedly represent only a small proportion of the total number of collisions that actually occur. For example in Sweden, it is estimated that only 50% of all roe deer accidents are registered, and approximately 70% of all collisions with moose are reported. Only about two-thirds of all collisions with wildlife that have been reported to insurance companies appear in police records (S-SoA, 5.4.4). Detailed traffic accident statistics report all accidents where there is any financial loss or human injury and this is a useful source of fauna casualty data (EE-SoA). However, not all drivers report collisions, and many animals hit on roads or railways are not killed outright. Smaller animals may be thrown by the impact or dragged away from the accident site by scavengers. After a short time, casualties are difficult to identify either because they have been eaten or run over several times (N-SoA, 5.4.4). It is apparent that in the majority of countries more information is collected for large mammals, particularly for ungulates and game species. Collisions with these animals represent not only an important traffic safety issue, but also a serious concern for game management and animal welfare (see Chapter 8). The recording systems for monitoring casualty rates relating to species other than large mammals on roads vary widely between countries in Europe. Some have formalised national systematic frameworks, while others rely on more ad hoc recording by local groups and infrastructure managers.

In The Netherlands, data relating to traffic kills on national trunk roads are gathered at a district level by inspectors working for the Directorate-General of Public Works and Water Management, as part of their daily checks of the road. The data (including information on the date, location and species group) is entered into a national computer database (NL-SoA, 5.3.2). Furthermore, in the north of The Netherlands (Limburg and Gelderland regions), the Badger and Tree Association is subsidised by the national government to record all badger traffic kills (around 335 individuals in 1998). The lack of similar systematic recording mechanisms across Europe means the full scale of the problem, including the long-term impacts of high mortality rates on wider populations, cannot be accurately quantified or addressed. More recently, radio telemetry studies have been employed as an alternative technique for gaining more of a realistic picture on mortality effects. In Sweden such studies indicate a somewhat lower contribution of traffic to overall mortality levels *e.g.* for moose, traffic contributes between 6 and 12% to the total mortality in Sweden; while hunting accounts for 60 to 80% (S-SoA, 5.4.4). Although effective, the disadvantage of radio telemetry is that it is a resource intensive method which provides species-specific results.

5.4. BARRIER EFFECT

Section 3.6 concludes that all linear infrastructure presents a barrier (or filter) to the free movement of animals. Table 5-11 illustrates the main elements associated with the transportation infrastructure that can create a barrier to movement and identifies the particularly vulnerable species. Movement of some invertebrates and mammals can be prevented altogether, especially for those species which normally disperse along lines of vegetation in the landscape (UK-SoA, 5.4.5).

Table 5-11 - Barrier effects by infrastructure element and animal species.

Infrastructure type/ Infrastructure element	Species affected	Effect on species	Source
All infrastructure			
Infrastructure verge (short grassy habitat with high disturbance levels)	Carabids (ground beetles)	Complete barrier to movement perceived several metres from the edge of the infrastructure	NL-SoA, 5.3.4; Mader, 1984; F-SoA, 5.4.5
Traffic	All species	Mortality due to direct hits and turbulence effects for flying species	F-SoA, 5.4.5
	Amphibians and reptiles	Absolute barrier	Vos, 1997
Roads and railways	Reindeer	Strong barrier effect results in isolation of a reindeer population in a previous summer grazing ground (Snohetta) resulting in lower weight and reduced breeding success of isolated population	N-SoA, 5.4.5
Roads and railways	Epizoic (mammal), synzoic (ant) and ballistic (self) dispersed plant species	Strong barrier effect	Salvig *et al.* 1997
Major transport links	Wolf and bear	Eastward expansion and recolonisation from Sweden restricted by barrier effect	N-SoA, 5.4.5
Roads			
Concrete drainage ditch	Carabids	Presents a complete barrier at 50cm depth	F-SoA, 5.4.5
Fencing	Wolf	Fenced motorway not important barrier to crossing	Blanco and Cortes, 1999
Part-fenced road	Butterfly	Partial barrier due to the difficulty of manoeuvring in flight	F-SoA, 5.4.5
Fenced major road with underpasses	Large mammals (Moose, reindeer)	Insignificant effect on populations	S-SoA, 5.4.3
Fenced major roads	Moose	Barrier effect leading to overgrazing as animals trapped in winter grazing area.	N-SoA, 5.4.5
	Lynx	Dispersal barrier likely to hinder spread of reintroduced populations	CH-SoA, 5.4.5
Road surface	Butterfly (and some other flying species)	Complete heat barrier due to microclimatic effects	Berthoud, 1968
Major road	Mice	Complete barrier	Van der Reest, 1989
Railways			
Railway*	Grasshopper, ground beetles	Absolute barrier	Bergers, 1997

(Cont'd…)

Infrastructure type/ Infrastructure element	Species affected	Effect on species	Source
			(…Cont'd)
	Mice, newts, spiders, ants	Strong barrier	Bergers 1997
	Marten, hedgehog, squirrel, reptiles, frogs, toads, butterflies	Weak	Bergers 1997
	Deer, wild boar, hare, birds	No barrier effect	Bergers 1997
Waterways			
Infrastructure crossing river valleys	kingfisher, dipper, grey wagtail	Risk barrier	Salvig *et al,*. 1997
River crossings	Fish species	Effects range from complete barrier (dam) to minor effect (pollution, or shaded and altered habitat under bridges)	B-SoA, 5.4.5
Culverts	aquatic fauna	Semi-permeable barrier	Kemper, 1998

Source: National State of the Art reports
* Information not based on field research

The barrier effect also varies between the transport mode concerned. The main differences are outlined in the sections below.

Roads

The relatively narrow width of secondary roads (especially in rural areas), as compared to motorways or main roads means they are less likely to form an absolute barrier for fauna movement. The consequence of this is that animals are more likely to attempt to cross (NL-SoA, 5.3.4). Palomares (1997) studied crossing rates by young Iberian lynx during their dispersal across several types of roads. All individuals that encountered small local roads crossed them, intermediate roads were crossed by about 80% of dispersing lynx, while only half of the individuals encountering a motorway in their path attempted to cross. This pattern clearly suggests that the significance of the barrier effect to lynx movements is directly related to the width and traffic intensity of roads. The major response mechanism to this barrier effect is likely to be the behavioural avoidance of lynx to large roads (E-SoA, 5.4.5).

A further barrier effect of roads can arise as a consequence of winter road maintenance: this is particularly evident in the alpine countries. Snow-ploughing to keep roads open in the winter can result in high banks of ice and snow being piled up on either side of the road. The snow walls may be so high as to create total barriers to the movement of species, or may trap them on the road (Figure 5.6).

Figure 5.6 - Picture of snow wall created by snow ploughing which can act as barrier to reindeer movement. (From N-SoA)

Railways

Important barrier elements of rail infrastructure are the ballast-bed (supporting the rails), aerial contact lines (particularly for species such as birds and bats), fencing, track-side ditches and in some cases the radically elevated or sunken track. No specific field research has been carried out to investigate the barrier effects of railways, however, some conclusions can be drawn indirectly from other ecological monitoring work. In Limburg, The Netherlands, for example, the colonisation patterns of seven new ponds by four species of newts, was monitored (Lenders, 1996). This group of pools happened to be dissected by a railway line; the results showed that even though migration did occur between pools on the same side of the tracks, no movement was recorded between the pools located on opposite sides of the line (NL-SoA, 5.3.4). Research carried out by Bergers (1997) has shown that:

- railway lines can be expected to have a large barrier effect for smaller, crawling animals (insects, spiders, amphibians, reptiles and small mammals);
- birds are apparently not hindered very much by railway lines;
- in general, large mammals (roe deer, red deer, wild boar, badger) are easily able to cross railway lines that are not fenced off (NL-SoA, 5.3.4).

The most important development in rail transportation in recent years, and by far the most significant one with regard to the barrier effect, is the arrival of High Speed Rail (HSR/TGV). Maximum speed on most lines currently ranges from 100 to 160 km/h (although speeds could potentially reach 300 to 350 km/h on lines built in the future. The perimeter fencing constructed along high-speed tracks means they form a formidable barrier to transversal animal movements. The length of high-speed railway will increase steadily over the next few years, hence intensifying the fragmentation problem (E-SoA, 5.3.3).

Waterways

Recent investigations on the barrier effect of tunnels and culverts on (semi-) aquatic animals such as fish and otters indicate that many of the existing culverts under roads impose movement barriers to fish and often act as traps (Grahn and Öberg, 1996; Abrahamsson and Pettersson, 1997; Spansk, 1997; Bergengren, 1999). Inventories in the Västernorrland, in Sweden, showed that 88% of all culverts comprised some kind of barrier to aquatic fauna (Bergengren, 1999).

5.4.1. Vulnerable species

Transportation infrastructure does not always represent a total barrier to animal movement, even for species which exist in already fragmented populations. However, reduced crossing rates and/or increased mortality could disrupt sink and source dynamics and thus increase their risk of extinction, at least at a local level. The impacts on some of the more common species associated with the barrier effect are discussed in more detail below.

Mammals

Small forest mammals are reluctant to venture onto road surfaces where the distance between the forest margins and the surface exceeds 20 m (see Section 3.6.2). In several studies on small mammals, this barrier effect was considered to be more important than either traffic flows or type of road surface (Secrett and Cliff Hodges, 1986). More recently, Richardson *et al.* (1997) compared small mammal movement along a busy dual carriageway and a quiet paved test track of similar width. They confirmed that roads appeared to be significant barriers to field voles (*Microtus agrestis*), bank voles (*Clethrionomys glareolus*) and wood mice (*Apodemus sylvaticus*), and both road width and traffic density contributed to this effect (UK-SoA, 5.4.5). Studies such as Mader (1984) and Richardson *et al.* (1997) show that for very sedentary species such as dormice (*Muscardinus avellanarius*), bank voles (*Clethrionomys glareolus*) and yellow-necked mice (*Apodemus flavicollis*), any alien habitat including a road is a barrier. For populations of large migratory animals (*e.g.* wild reindeer and moose in Norway), the barrier effect can be particularly severe (Box 5.4).

Box 5.4 - Traditional migration routes and home ranges crossed by new roads are a problem for large game species and increase traffic accidents.

The best-known example of the effect of infrastructure barriers in Norway is that of the wild reindeer (*Rangifer tarandus*) population on Dovrefjell (Skogland, 1986; Bodal and Heggdal, 1999). 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 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 heavy snow, a percentage of the Snøhetta population cross the road and rail barrier, an action which may help to maintain the sub-population. (N-SoA, 5.4.5)

Birds

Methods for crossing motorways by birds were studied by Muselet (1987) along the A10 in France. Low flying species *e.g.* greenfinch (*Carduelis chloris*) and blackbird modify their flight path to cross traffic lanes in response to the barrier effect. The cross section of the road is critical in determining the path which the birds take across the infrastructure. An increase in traffic can disturb the birds to the extent that they refuse to cross the motorway altogether (F-SoA, 5.4.5).

Invertebrates

Research into the use of road verges along motorways in The Netherlands by ground beetles found none of these insects in the first few metres of the verge. Other studies confirm that beetles rarely enter the road verge and hardly ever cross it. If the verge consists of a short grassy habitat, it represents a barrier to these species (NL-SoA, 5.3.4; Mader, 1984). In a French study, the density of carabids measured at 5 m from the road surface was 2 to 3 times lower than at 10 m further away, indicating that the barrier effect is *perceived* by these animals even several metres before the highway (F-SoA, 5.4.5).

Plants

Plants adapted to wind and water dispersal will rarely be obstructed by the barrier effect associated with transportation infrastructure. However, those species reliant on animals for dispersal may be indirectly affected (Table 5-12).

Table 5-12 - Outline of barrier effects on plants, described according to specific dispersal strategies.

Dispersal strategy	Dispersal vectors	Species examples	Barrier effect
Wind	Wind	Rose bay (*Chamaenerion angustifolium*)	No barrier effects except for very high dams
Water	Water	Marsh marigold (*Caltha palustris*)	No barrier effect if the flow of water is not obstructed
Epizoic	Mammals	Goosegrass (*Galium aparine*)	Most larger roads will be barriers
Endozoic	Birds	Hawthorn (*Crataegus laevigata*)	No barrier effects even if many birds are killed by traffic
Synozoic	Ants	Hedge violet (*Viola rechenbachiana*)	Even a very narrow road (<2 m) will be a barrier
Ballistic	The plant itself	Wood sorrel (*Oxalis acetocella*)	Even a narrow road (<5 m) will be a barrier)
By censor mechanisms	Wind	Milfoil (*Achillea millefolium*)	Traffic infrastructure broader than 10 m will have a barrier effect
Without special adaptations	Humans	Red clover (*Trifolium pratense*)	No barrier effects if human passage is possible

Source: Salvig *et al.*, 1997

5.5. CORRIDOR FUNCTION

As discussed in Section 3.4, transportation infrastructure can provide a linear dispersal corridor which facilitates the migration of plant and animal species. Ecological management in many European countries over recent decades has produced verges which are rich in native flora and fauna. Intensification of agriculture has meant that plant species formerly common in grasslands and extensively used fields, now find their best habitat conditions in road and railway verges. The presence of native species which are not indigenous in the surrounding landscape may indicate either habitat differences along the verges, or the use of verges as a dispersal corridor through an otherwise unfavourable landscape (UNA, 1993/1995).

Verge habitat is important for many animal species including diurnal butterflies, ground carabid beetles (NL-SoA, 5.3.4) and bees, invertebrates and reptiles (Gonseth, 1992) and small mammals (Bourquin and Meylan, 1982). The verge habitat can function as a source for dispersion and the colonisation of new areas (*e.g.* Flanders, B-SoA, 5.4.2) and has been shown to increase the movement of butterflies (N-SoA, 5.3.6), snails (Wirth *et al.*, 1999), mice (B-SoA, 5.4.2), foxes and roe deer (Salvig, 1991). Squirrels, tree martens, badgers and bats have also been shown to move along verges with well developed shrubs and wooded areas (B-SoA, 5.4.2). In many cases more research is necessary to determine the use of the verge as habitat and/or as a corridor for the movement of individual species. Some of the existing evidence for the corridor effect is presented below for the different transport modes.

Roads

Studies in The Netherlands investigating the possible corridor function of verges alongside motorways for ground beetles (NL-SoA, 5.3.4), suggested that the verge must include a zone that is sufficiently wide and that has the same properties as the adjacent habitat and that the total verge must have a width of 15 to 30 m (NL-SoA, 5.3.6). In France, faunal movements parallel to the road were measured from tracking marked carabids, butterflies, rodents and radio-equipped snakes. The longest movements of butterflies and snakes were recorded along the motorway, with a maximum movement of 520 m in 24 hours recorded by a male grass snake during a period of sexual activity (*i.e.* whilst seeking a partner) (F-SoA, 5.4.2).

Another function of the road verge linked to movements was identified in France for flying species *i.e.* the provision of a migratory axis. In an agricultural zone, the painted lady butterfly (*Cynthia cardui*) was found solely in verges of the A10 motorway. The butterfly was considered to be using these linear spaces during long migratory journeys as a visual marking, but also as a feeding ground (due to the frequent presence of wildflowers as a source of nectar and food plants for the larvae). In the same way, migratory flights of birds were observed along certain motorway routes *e.g.* flights of barn swallows moving up the Rhone valley in spring along the A9, and pied flycatchers flying south in Autumn along the A10 in the Niort plain (F-SoA, 5.4.2).

Railways

Covered parts of the railway track (*e.g.* ramps, verges, ditches, etc.) can create special plant and animal habitats. Some 1,100 plant species have been found alongside Dutch railways (75% of the Dutch flora), including many rare and endangered species. In addition, fauna surveys alongside tracks found a large variety of animals, especially reptiles and insects

(Koster, 1991). As well as resulting in the loss of habitats, the presence of a railway can therefore also lead to an increase in habitat-specific species (NL-SoA, 5.3.6).

Waterways

Canal banks play a crucial role as connection zones between various natural habitats. Species that use the banks for dispersion include the grass snake (*Natrix natrix),* beaver (*Castor fiber)*, otter (*Lutra lutra)*, water shrew (*Neomys fodiens*), Daubenton's bat (*Myotis daubentonii)*, dragonflies and small reed birds. Each species has a specific habitat requirement fulfilled by the waterway: the beaver moves by swimming along a bank at a distance of several metres; the white-legged damselfly (*Platycnemis pennipes*) needs vegetation for cover since it is not a very good flyer; and the grass snake will move along a bank only if it provides enough cover (NL-SoA, 5.3.6).

5.5.1. Negative corridor effects

The corridor function presents a potential danger to nature conservation interest by facilitating the spread of non-indigenous alien invasive species, diseases, pests and predators. Across Europe there is clear evidence of the existence of the corridor effect operating to produce undesirable consequences, and reducing the natural biodiversity value of the area. The spread of mayweed, for example, and other garden escapees has the potential to seriously threaten some semi-natural vegetation types. The spread of rhododendron, ragwort and giant hogweed in the United Kingdom are clear examples of roads acting as corridors for highly invasive plants (UK-SoA, 5.4.2). Similarly, in Spain, the expansion in range of the narrow-leaved ragwort (*Senecio inaequidens*), a non-native invasive weed, has been noted to be facilitated along road verges and is now causing serious problems for agriculture (Pery *et al.*, 1998). In France, colza, sunflower, wheat and barley plants have started growing along motorway edges, including the central reservation, at several kilometres from production zones. Mountain plants found in the Landes Forest were probably brought there by visitors from the Pyrenees, and fruit trees (apple, peach and pear) have germinated from discarded pips and cores thrown out of passing vehicles (Meunier, 1998). Studies in Norway indicate that road bridges and tunnels are facilitating the spread of invasive species and predators to previously isolated islands. In the Mediterranean areas of Spain, road and railway verges are recognised as contributing towards the spread of forest fires: of approximately 20,000 forest fires which occur annually in the country, some 20% originate along transportation infrastructure. Such forest fires are one of the most important threats at present to nature conservation in countries of the Mediterranean regions. As a result, verge management practices (*e.g.* cutting, use of herbicides etc) must be specifically designed and applied in order to limit the growth of vegetation along the strips either side of the road or railway.

5.5.2. Corridor management principles

When considering the corridor function, a clear distinction must be made between true ecological corridors and infrastructure corridors which act as linear elements in the landscape and that may potentially conduct the movement of animals or plant seeds. The potential of verges as corridors will depend very much on site-specific conditions: while verges may enhance connectivity in highly degraded or transformed landscapes, their usefulness as corridors where nature is well conserved is less clear. Also, the type of verge management which is often required to enhance the corridor function of roads may be incompatible with other overriding priorities *e.g.* fire prevention in southern Europe, or measures to reduce collisions with ungulates. Research in the United Kingdom outlines the following criteria as being most important to corridor function:

- the wildlife corridor should be as continuous as possible to ensure the survival of those species with little ability to cross inhospitable areas;
- a corridor needs to be as wide as possible to maximise habitat area and to minimise the risk of being degraded by events such as fire and predation;
- a corridor will have the most benefit for the widest range of wildlife if it is predominantly composed of semi-natural habitats;
- a corridor should be as diverse in vegetation composition and age structure as possible, so that there is a wide range of potential users; and
- a corridor should act as a conduit for colonisation or recolonisation of sites, linking areas which are reservoirs of species.

It should be noted that these principles were derived in relation to northern European situations and are hence more appropriate for application there (UK-SoA, 5.4.2).

5.6. EFFECTS ON POPULATIONS

Estimates of the overall impact of roads on animal populations can differ widely depending on the type of data collected and method of analysis used. The specific effects of transportation infrastructure on fauna at population level are extremely difficult to determine because there are frequently a combination of contributing and inter-related factors involved. Data relating to bird and mammal road mortality in the United Kingdom indicates that none of the 100 species recorded had a road mortality rate sufficiently high enough to negatively affect population size at the national level (Hodson, 1962; 1966). Despite this, mortality rates are apparently significant for a few species listed as nationally endangered or threatened (Bekker and Canters, 1997; Forman *et al.*, 1997). The most accurate surveying method to estimate the impact of roads on populations involves radio-tagging a sample of animals and studying their movements through to eventual mortality (E-SoA, 5.4.6). Although the mortality rate is closely related to population size, the source and sink effect of the road and the negative influence of casualties at the population level have not been demonstrated (Baudvin, 1996). However, it is accepted that the fragmentation effect at population level is species-specific: those with large home ranges suffer more significant impacts from habitat fragmentation (Table 5-13).

Table 5-13 - Population effects of infrastructure according to species.

Species	Impact	Population effect	Source
Badger	18-20% population killed annually on roads	Reduced survival effect of local populations	Braeckhuizen *et al.* 1994; Lankaster *et al.,* 1991
Breeding birds (forest and meadow)	Disturbance by traffic noise	Reduced population density.	Reijnen *et al.*, 1992
Hedgehog	6-9% of population killed annually on roads	Local extinction near very high road densities but RTAs are of minimal importance in relation to the total annual mortality	Huijser and Bergers, 1997; D-SoA, 5.4.5

(Cont'd…)

Species	Impact	Population effect	Source
			(…Cont'd)
Fish	Reduction in biomass of a stretch of river by 30-50%		Wasson, 1998
Amphibians	Fauna casualties Increased road density	Extinction or reduction of local populations, especially where a road borders a breeding lake. Decreased number of species. Occurrence at lower densities.	Ryser 1988; Van der Sluis and Vos, 1996; Vos, 1997; Vos and Chardon, 1998
Toads,	Fauna casualties	Local population extinction	Salvig, 1991
Hare	Traffic casualties	Limiting factor for spring breeding population	Danmarks Statistik, 1996; Pfister, 1998
	Negative effect of fragmentation	Decreased population density	
Otter	Traffic casualties	Most frequent cause of death, so possibly most signficant threat but further research needed.	Skov og Naturstyrelsen, 1996
Pheasant, partridge, blackbird	Bird species most frequently killed	No significant effect on breeding populations	Madsen, 1993
Roe deer	Fragmentation effect, particularly in areas of high density of transportation infrastructure	Reduced roaming distances over last two decades.	Müri, 1999
Iberian Lynx	7% of population killed on roads (traffic is the 2nd most important cause of mortality)	Reduced immigration levels and local extinction due to increased isolation.	Rodríguez and Delibes, 1990; Palomares *et al.,* 1991; Gaona *et al.,* 1998
Black-tailed godwit	Road lighting	Reduced breeding behaviour and density.	De Molenaar, Jonkers and Sanders, 2000

Impacts on some of the most vulnerable species are discussed in more detail below.

5.6.1. Sensitive species

Lynx

In a sample of 356 Iberian lynx known to have died between 1978 and 1988, 25 (7%) were killed on roads (Rodríguez and Delibes, 1990). This percentage is seventy times higher than that recorded between 1958 and 1977. In an intensive radio-tracking study of the Iberian lynx Doñana population (south-west Spain), road traffic was the second most important cause of mortality (after illegial hunting), accounting for an estimated 6-10% of annual mortality rate (Ferreras *et al.*, 1992; Rodriguez and Delibes, 1992; Ferreras, 1993). Ferreras (1994) extended this sample to 29 Iberian lynx deaths, 21% of which were caused by vehicles on a road bordering the western side of the Doñana National Park. This motorway divides two nuclei of the Doñana population of Iberian lynx (Palomares *et al.*, 1991; Gaona *et al.*, 1998). A detailed model was produced of the dynamics of the Doñana lynx metapopulation. This indicated that the high mortality recorded on the motorway might reduce immigration in the smallest nuclei and could result in its local extinction because of increased isolation (Gaona *et al.,* 1998).

Badgers

Badgers (*Meles meles*) are rare in The Netherlands and about 20% of the annual badger population is assumed to be killed on roads, and vehicle traffic is considered to be a predominant threat to the species (*e.g.* Van der Zee *et al.*, 1992; Broekhuizen *et al.*, 1994). From 1981 to 1993, the Institute for Forestry and Nature Research in The Netherlands collected 523 badgers killed by traffic in order to study their procreation. The study showed that badgers in The Netherlands have the largest litter size in Europe, and this is a direct result of the high traffic mortality rates. The pressure on the badger population in The Netherlands is fairly high: at least 11% of all litters are lost because the mother has a traffic accident. The capacity of the population to compensate for the high mortality by maximising the litter size perhaps is already being used to the fullest (Broekhuizen *et al.*, 1994). Further compensation for traffic mortality by increasing litter size more is improbable. In some social groups there is only one female present: if that female dies, the loss of reproductive capacity can only be remedied by the immigration of a new female. The number of traffic kills compared to the total size of the population is very high. Models show that a high local mortality of adult animals markedly reduces the survival potential of local populations (Lankester *et al.*, 1991; Verboom *et al.*, 1991).

Neal and Cheeseman (1996) and Clarke *et al.* (1998) estimate that at between 37,500 and 50,000 badgers are killed on the roads in the UK each year: the equivalent of one badger from each family group (Harris and Gallagher, 1989). In addition, for every lactating sow killed there may be further mortalities of dependent cubs underground. This potentially poses a serious threat to the badgers breeding population (Secrett and Cliff Hodges, 1986). Although the badger population is currently increasing in many parts of the UK (Clarke *et al.*, 1998) and the number of casualties appears to be a sustainable loss, road-traffic mortality may be important at the local and metapopulation levels in areas where badgers are at moderate to low density (UK-SoA, 5.4.4).

Although road mortality is considered as one of the largest single causes of death in badgers in Sweden, the population as a whole does not appear to be suffering adversely from traffic losses (S-SoA, 5.4.6). Eriksson and Helldin (*in prep.*) suggest that even with a low traffic flow and road network as sparse as in Sweden, the estimated road mortality rate in badgers is close to the maxima that the national population can compensate for. This implies then that the road mortality is already limiting badger populations in those regions with the most intense traffic.

Otters

Road mortality accounted for 64% of all known causes of death in otters registered by the Swedish Museum of Natural History between 1975 and 1998 (SNRA, 2000). In this country it has been noted that infrastructure is one of the factors (beside chemical pollution) which is preventing the Swedish otter population from recovering from the earlier local extinctions (S-SoA, 5.4.6). Likewise in Denmark, where the otter was once one of the most threatened animals, with road mortality contributing significantly towards the population's decline. Now, due to the installation of mitigation measures to provide safe passage under roads, the Danish otter population is increasing. Similar efforts are being made in the United Kingdom, where otter road deaths are considered to be responsible for up to 60% of overall mortality. More research is required to try and determine how significant road casualties are in terms of overall population dynamics.

Hedgehog

The hedgehog is one of the smaller mammals in Europe that seems to be severely at risk from road traffic and may require special attention in order to prevent local extinctions (Göransson *et al.*, 1978; Huijser *et al.*, 1998; Reicholf and Esser, 1981; Rodts *et al.*, 1998). It is a common species in The Netherlands, and is a frequent victim of traffic. In order to determine the effect of roads on population size, the capture-mark-recapture method and track studies were used to determine the relative hedgehog density in various areas (Huijser and Bergers, 1997). Each year, 6 to 9% of the hedgehog population is killed by traffic: as a result, the size of hedgehog populations can be up to 30% lower than the size of comparable populations not subjected to traffic effects. Males are more frequently killed in traffic, but as the species is not monogamous, there is no threat to reproduction. Where road and traffic densities are high, local populations can become extinct and networks can become less durable (NL-SoA, 5.3.3).

Birds

Studies confirm that the bird species occurring in greatest number along roads are also the species most frequently killed by traffic. Detailed studies of pheasant, partridge and blackbird show that traffic casualties do not reduce the breeding population size considerably (Madsen, 1993). The vulnerability of raptors and nocturnal birds of prey has also been recognised (Box 5.5) and is linked to their hunting habits along verge habitats.

Box 5.5 - Barn Owl: Road Traffic Accident Impact at Population Level

A study on mortality of the barnowl (*Tyto alba*), over a 300 km motorway network in eastern France (1992 to 1999) shows that mortality levels fluctuate from one year to another, and depend on the status of the population on each side of the motorway. Years of high mortality follow good reproductive years for the owl and, on the contrary, years with low mortality indicate that the basic population is low. The variation in barnowl numbers is linked to winter weather. In harsh, snowy winters, it is more difficult for the owl to hunt rodents (hidden by the snow) and birds emerge from winter much thinner. The owl's weight at the end of winter determines its ability to reproduce. A harsh winter leads to low reproduction, therefore few young birds and a lower mortality rate in the following September. Population monitoring of this sort does not assist in determining the significance of the motorway impact on the state of the population. No conclusions can therefore be drawn between the source and sink effect of the motorway (Baudvin, 1996; 1998).

Amphibians

Much attention has been paid to road mortality in amphibians. Infrastructure is considered as one of the major factors responsible for the decline in these species worldwide (Vestjens, 1973; Blaustein and Wake, 1990; Reh and Seitz, 1990; Fahrig *et al.*, 1995). Amphibians are especially sensitive to road mortality as they exert seasonal migrations that, if they lead across trafficked roads, may cause considerable losses. For instance, Van Gelder (1973) found that roads with a traffic volume as low as 10 vehicles per hour could cause a 30% mortality in female migrating toads (*Bufo bufo*). Roads with more than 60 vehicles per hour represented an almost complete barrier. Vos and Chardon (1998) calculated that breeding ponds near motorways had a significantly reduced probability of being inhabited by frogs than undisturbed ponds farther away. Sjögren-Gulve (1994) found that trafficked roads in the suburbs of Stockholm isolated amphibian populations effectively. The risk for local extinctions rose significantly as road density and traffic volume increased.

Shifts in population dynamics

The importance of traffic casualties at population level varies between different areas according to the population health and local habitat. In The Netherlands, hedgehogs may be locally endangered by traffic casualties, whereas in Denmark access to good wintering places is more important in population regulation (Madsen, 1993). The overall range and intensity of pressures on a population (from all causes) may influence the extent of the effects of transportation infrastructure for populations. This may explain the differences in impact between different regions and countries. In terms of genetic isolation, species with a greater ability for dispersion will be least at risk (B-SoA, 5.4.6).

Habitat fragmentation may also be considered to have some beneficial effects for some populations by increasing the structural diversity of the landscape matrix and increasing the variability between fragments. Where there is high connectivity between major patches, predators may find the new habitats provide more feeding and denning opportunities than previously (UK-SoA, 5.4.6). However, any perceived benefits for a population may come at the expense of other species which were previously exploiting the fragmented habitat. The most important consideration in these types of study is the question of scale. Although population effects may be minimal at a local level, habitat fragmentation may cause irreversible negative impacts at the landscape scale (see Section 2.6).

5.6.2. Overview of environmental bottlenecks

Environmental bottlenecks (blackspots) are areas of conflict created where ecological corridors and transportation infrastructure coincide. Frequent traffic accidents in one locality is an indicator of the presence of a bottleneck. They arise from the spatial coincidence of good quality habitat for the affected species (*e.g.* Babiloni, 1992) and either a high traffic density or high speed of vehicles (*e.g.* Hernández, 1988; Gragera *et al.,* 1992; Reolid and Zamora, 1992; Fernández, 1993). Natural environmental bottlenecks also exist in the form of river valleys, and mountain ranges which restrict long-distance species movement. Establishing the exact location of these conflict points is essential in order that remedial action can be taken to maintain and/or restore the natural ecological corridors and associated movement of fauna. The variety of approaches employed across Europe are illustrated in Table 5-14.

Two main approaches to the identification of environmental bottlenecks are:

- strategic or model based approaches; and
- observation of existing fauna routes or blackspots by the evaluation of migration routes and/or the monitoring of fauna casualties.

The former tends to focus on large or game species, or on overlaying a notional ‘green corridors’ map with a transportation infrastructure map; the latter concentrates on target groups such as amphibians, endangered species, or larger species which are a hazard to motorists. Both approaches are appropriate for assessing new or existing infrastructure and may be applied equally at national and local level.

Table 5-14 - Approaches to the identification of environmental bottlenecks.

Approach	Results	Consequence	Source
Map overlay of target habitats and infrastructure network	Map which identifies conflict areas needing ground truthing	Target areas for survey and mitigation measures	H-SoA; NL-SoA; B-SoA
Map overlay of target species occurrence data and infrastructure network	Map which identifies conflict areas needing ground truthing	Target areas for survey and mitigation measures	H-SoA
Identification of former, current and potential wildlife corridors by use of fieldwork and GIS.	Map identifying locations which should be targeted. Assessment of the functionality of identified wildlife corridors.	Identification of corridors are functionally impaired. Feasibility and priority lists for restoration	NL-SoA; CH-SoA; CZ-SoA
Identification of sites with significant fauna casualties	Map identifying problem locations	Plans for appropriate action or mitigation measures	NL-SoA; CH-SoA; CZ-SoA (for otters); H-SoA (reptiles and amphibians)

Model based approaches

The modelling approach is particularly useful for large-scale work (*e.g.* at a European level) and for facilitating the spread of species back into areas in which they have become endangered or extinct. However, several modelling techniques have been successfully implemented on a variety of spatial scales in The Netherlands (see Chapter 6 for more detailed information) and experience shows such approaches are appropriate to a regional scale upwards. Modelling has the potential to enable researchers to identify the total length of conflict areas. In The Netherlands this has been calculated as 909 km of roads and 610 km of railway. In Denmark, small-scale modelling has highlighted the fact that areas of conflict (*i.e.* bottlenecks) are more common at junctions than on open roads. This is probably due to design, afforestation and fencing of junctions in a landscape where fences may function as conduction lines for fauna, and fauna are attracted to afforestation (Madsen *et al.,* 1998). In the Czech Republic, the Transport Research Centre (CDV) is creating a Unified Transport Vector Map. Digital maps of transportation infrastructure and protected areas or USES (Sustainable Ecological Network) intersections are overlain in order to identify hot spots (CZ-SoA, 6.8 and 7.4). In Hungary, a 'habitat value and traffic map' illustrates the environmental bottlenecks created by roads for amphibian and reptile species. 10x10 km raster maps on the distribution of these species were modelled over the road network map, taking into account other environmental factors such as temperature, soil type, precipitation, relief, vegetation and depth of soil. The resulting map proved useful and could be applied immediately in the planning process. However, ecological modelling of a wider range of species needs to be improved before it can be applied more comprehensively (H-SoA).

Monitoring of mortality

In France, there is a compulsory requirement to monitor new motorways (over all or part of its length) and collect information on fauna mortality for 5 years after opening (Law on Guidelines of Domestic Transportation and circular of March 1996). This enables fauna casualty 'black spots' to be identified which may not have been predicted in the Environmental Impact Assessment (EIA) and for further mitigation measures to be constructed retrospectively. In addition, sections of special roads (generally local or county roads) identified as accident-prone for fauna are monitored by the local or national authorities in order to determine whether mitigation is required. These observations concern both large and small fauna (red deer, roe deer, wild boaramphibians, otters, beaver, and fish). Mitigation is installed, where needed, to eliminate conflict points between the ecological networks and existing infrastructure. Specific projects are also concerned with wider monitoring for individual species (Boxes 5.6 and 5.7).

Environmental bottlenecks are often more widely identified on a less formal level, particularly in relation to wildlife mortality. For example, in the United Kingdom blackspots for traffic accidents involving deer are identified in National Parks through observation of mortality events and signs are put up accordingly to warn motorists of the increased dangers in specific areas. At a local scale, there have been several attempts to locate potential conflict points between wildlife and planned roads in order to evaluate the need for mitigation measures (*e.g.* Pettersson, 1997; Lagerkvist, 1998). The studies tried to identify possible hotspots for vehicle-wildlife collisions using topographical and land cover data in combination with hunting statistics, local wildlife casualty reports, as well as the experiences of the local hunters. So far, predictions from these studies have not yet been tested (S-SoA, 5.4.7).

Widening the approach

The examples above show that most bottleneck studies have been carried out on the road network. Very little attention has been given, as yet, to identifying rail and waterway bottlenecks. The Netherlands appears to be pioneering work in applying modelling techniques to consider the other transport modes. In an analysis for The Netherlands National State of the Art report, the existing railway network was compared with: all nature and forest areas within the National Ecological Network; Nature Protection Act areas; nature areas in regional and zoning plans; and public recreational facilities. For each province, a breakdown of the number of intersections (*i.e.* potential bottlenecks) between these protected areas and rail infrastructure, and the total length of the intersections was produced: 281 intersections were identified over a total distance of 610 km. The severity of the bottlenecks varies markedly, and depends on such factors as the width and height of the track, the shielding of the track by means of ditches or fences, the intensity of rail traffic and the species found on either side of the track (NL-SoA, 5.3.8). With regard to fragmentation caused by waterways, the Road and Hydraulic Engineering Division has published a series of documents which describe all the state waters, and for each one the bottlenecks are identified (Duel, 1992). These kinds of initiatives should be applied more widely to produce a comprehensive European bottleneck map, which will be invaluable in future strategic infrastructure planning.

Box 5.6 - Division of territories for Large Mammals in France: Areas of free movement of red deer (ONC, 1998)

A national inventory of the French red deer population has been set up in France to identify the main contact points between their habitat and the infrastructure network and to measure fragmentation of their territory. The approach adopted by the 'Ministère de l'Aménagement du Territoire et de l'Environnement' (MATE) and the 'Office National de la Chasse' (ONC) has a dual objective:

- to identify the priority issues in terms of maintaining functional, ecological corridors or those threatened in the short term, and
- to defragment corridors which no longer allow free movement of red deer in the medium term.

The initial phase, instigated in 1996 drew up a national map showing: areas of red deer distribution; areas of functional free movement; areas within the red deer zone interrupted by public works over the last ten years; and the major existing linear structures. The following formula was used to calculate a fragmentation index:

$$\frac{\text{length of linear infrastructures* and watercourses (in km)}}{\text{area of the red deer zone (in km}^2\text{)}}$$

* Motorways, regional roads, HSR/TGV and canalised rivers

At this stage 'the inventory of areas of free movement of the red deer (*Cervus elaphus*)' does not yet constitute an operational tool which can be used in environmental impact assessments. It only concerns red deer, and its value as an 'instrument' for measuring fragmentation is questionable, given that it is a non-threatened game species, managed artificially. France, which by western European standards, is a large country, has chosen to approach the fragmentation problem by focusing on specific species whereas other, smaller countries may find a habitat approach more appropriate (F-SoA, 5.6).

Box: 5.7 - Bottleneck survey in the Province of Utrecht, The Netherlands

The Province of Utrecht surveyed and defined the ecological bottlenecks caused by the national and provincial roads in the Utrecht Hill Ridge area (Bureau Waardenburg, 1993). Roads were split into three categories according to their width and traffic intensity. The type of barrier effect these roads created were classed as follows: physical barrier (the road comprises a limitation of the habitat on both sides of the road); landscape barrier (the road - comprising the hard surface and any configured road verges - forms such an unattractive habitat for the animal species that the species does not traverse it or does so only incidentally) and; a risk factor for crossing animals. A road could be allocated to all three classes *e.g.* a motorway is a physical barrier to soil-bound organisms (such as the vole, slow-worm and ground beetle); the open character, the six traffic lanes and the wide verges form a landscape barrier to forest fauna; and the intensive traffic represents a big risk to crossing game. For all provincial roads a map has been produced showing the bottlenecks and which type of barrier they present (Figure 5.7). Thirteen bottlenecks were caused by provincial roads, and two by local roads (Bureau Waardenburg BV, 1993). The study has resulted in the following observations:

- Class 2 roads (two-lane) form a landscape barrier to species, which have a small action radius (small mammals, amphibians, lizards and invertebrate soil fauna). The road isolates the populations of these species. The dispersion of this group is therefore very limited or is excluded.
- Class 2a roads (two-lane low-intensity) will be frequently crossed by animals with a large action radius (pine marten, fox and badger).
- Class 2b roads (two-lane high-intensity) form a physical barrier. Populations on either side of the road are practically isolated from each other. For animals with a large action radius, the risk under high traffic intensity is so high that the road is crossed only incidentally.
- Class 1 roads (local, low-intensity) form a physical barrier to animals with a small action radius. For animals with a large action radius, the road is a risk barrier.

(Cont'd…)

Box: 5.7 - (…Cont'd)

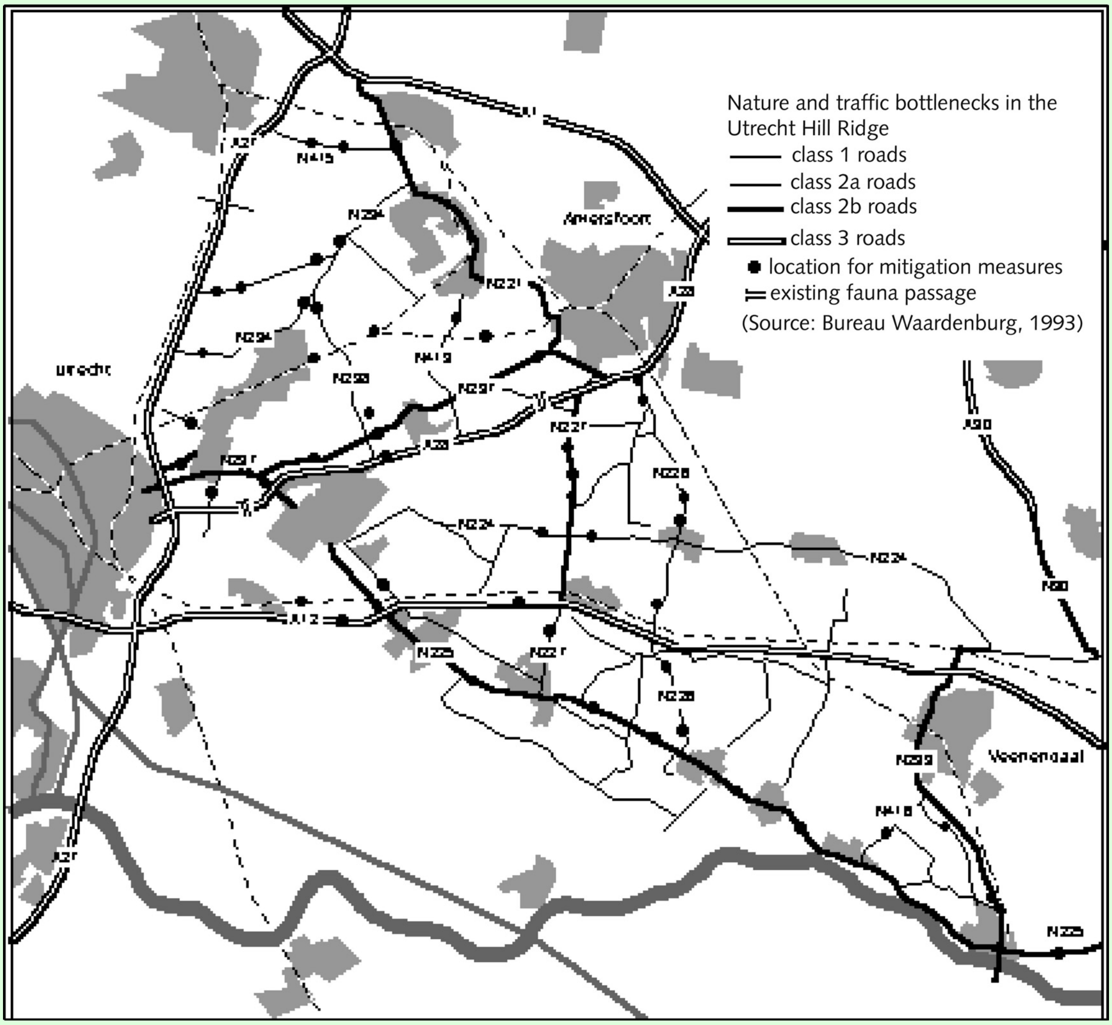

Figure 5.7 - Bottleneck map for Utrecht Hill Ridge. (From Bureau Waardenburg BV, 1993)

5.7. SECONDARY EFFECTS OF TRANSPORTATION INFRASTRUCTURE

Closely associated with the habitat fragmentation caused by infrastructure networks, are secondary effects linked to infrastructure development such as changes in types of landuse, expansion of settlements, and scale of resource exploitation. Networks of small forest roads provide hunters and tourists access to otherwise undisturbed wildlife habitats. New settlements and housing estates may follow the construction of new regional roads and in turn require the construction of local access roads. Primary roads may stimulate the establishment of shopping malls, petrol stations or industrial plants outside urban areas, with the subsequent change in land development. Construction of a new motorway or high-speed railway also influences the local road network in that new access roads may be needed for agriculture or forestry. These secondary effects are usually outside the responsibility of the transport sector, but should be considered in EIA studies, especially in strategic impact evaluations.

In the National State of the Art reports, although secondary effects were defined and recognised as being important (*e.g.* B-SoA, 5.5; F-SoA, 5.5; NL-SoA, 5.5; E-SoA, 5.5; S-SoA, 5.5; CH-SoA, 5.5), the direct link to effects on biodiversity had rarely been made (E-SoA, F-SoA).

With regard to fauna, ecological observations generally show that the detailed planning of the watercourses intercepted by infrastructures is neglected (F-SoA, 5.5): former ecological and landscape continuities (*e.g.* riparian forests) are often not re-created as part of the development. Watercourses are recalibrated which leads to a return of headwater erosion, sometimes spectacular, resulting in a simplification of the fluvial ecosystem and significant consequences for the benthos and fish communities *i.e.* causing a decline in biomass and fish diversity. Simplification of fluvial ecosystems associated with infrastructure development in the floodplain or in mean water bed of rivers has consequences on terrestrial vertebrates such as the beaver, mallard (*Anas platyrhynchos*), little ringed plover (*Charadrius dubius*) and kingfisher (*Alcedo atthis*), who no longer find the requisite conditions for their survival in the ordinary river banks.

Conclusions from ecological surveys reveal that the impact of motorway construction on the fauna extends far beyond the land reserved for the structure itself and is such that the indirect effects are often, in fact, more significant than the direct effects.

Another secondary effect is ribbon building (*i.e.* the construction of buildings along new infrastructure): this has been widespread for many years in Belgium (B-SoA, 5.5). Especially after the 2nd World War, ribbon building has quickly affected open space. Distribution centres have settled alongside roads and business parks have been erected alongside main traffic axes to allow for 'just-in-time' production and the co-location of the transport, storage, and distribution components of a business on one site. Ribbon development intensifies, both visually and functionally, the disintegrative influence of linear transportation infrastructures.

In the higher Tajo basin (central Spain), increased urbanisation and accompanying development of the transportation infrastructure network have been identified as the main factors underlying geographical differences in the pattern of otter re-colonisation between 1984 and 1995 (Cortés *et al.,* 1998). During this period there was no noticeable otter recovery in areas where large cities had an aggregated distribution, while a marked recovery was experienced where cities of medium size were distributed homogeneously.

The well-known influence of road density at the regional scale over the degree of human development and the degradation of natural habitat has been illustrated in Spain by a number of studies (E-SoA, 5.5). Naves (1996) shows a clear inverse spatial relationship between the density of roads and brown bear productivity, in terms of the number of years when females with cubs were observed during a ten-year period. Based on radio-tracking data and sign surveys, a habitat assessment for the brown bear was made in the eastern population of the Cantabrican Mountains (Clevenger and Purroy, 1990; Clevenger *et al.,* 1997). Road density in primary habitat was 0.55 km/km^2 , much lower than in secondary and unoccupied habitat, 0.79 and 0.85 km/km^2 respectively. These differences were attributable to the mean density of unpaved roads, as in secondary (0.57 km/km^2) and unoccupied habitat (0.63 km/km^2) this was more than twice the mean density recorded in primary habitat (0.28 km/km^2). Road density conceivably determines the probability of human-bear contacts, which in turn is a predictor of human-caused bear mortality - the most immediate threat to the Cantabrian bear population (Clevenger *et al*., 1997; Wiegand *et al.,* 1998). Similarly, models of Iberian lynx distribution indicate that the probability of lynx occurrence in 100 km^2 blocks, where a 28 km linear transect crosses about eight roads, is almost four times lower than in blocks where no road is intersected by the transect (Rodríguez, 1997).

The construction of road infrastructure in the Czech Republic is accompanied mainly by parking places connected with the service areas (refreshments, restaurants, etc.) and filling stations (CZ-SoA, 5.5). The frequency of resting places ranges between 10 and 30 km depending on the size of the settlement and the associated facility, and is set by Czech Republic standard. The EIA procedure helps to choose “good places” for the accompanied infrastructure. Roads built before 1992, however, had no consideration of environmental impacts but, until now, no significant negative impacts of secondary infrastructure on the wildlife have been observed.

As mentioned before, the creation of infrastructure accelerates the economic development of regions, and thereby the urbanisation process. The pattern of reclamation is highly determinative of further urbanisation and the use of the landscape (Figure 5.8). Generally speaking, however, this development is not autonomous. The final effect is determined by the direction given to the urbanisation process by regional planning authorities.

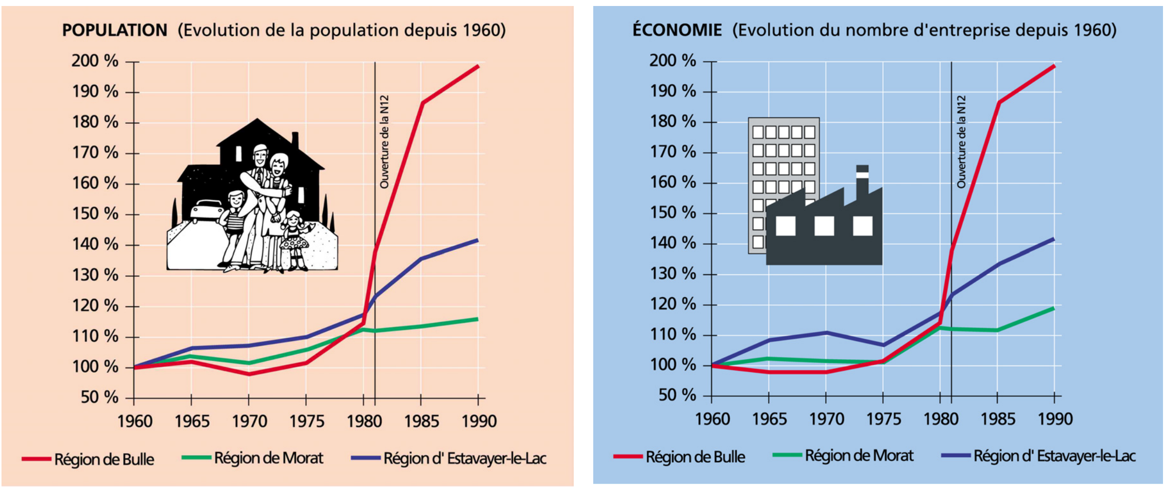

Figure 5.8 - The impact of highway construction (N12, Switzerland) on the population size and number of businesses in the vicinity around the highway (Bulle), compared to areas without a highway (Morat and Estavayer-le-Lac). (From: Direction des travaux publics du canton de Fribourg, 1996)

The importance of secondary effects shows that it is necessary to undertake a lomg-term, strategicglobal analysis on how to deal with potential problems rather than relying on simpler short-term technical solutions in terms of design and management. This is illustrated by the case of a large wildlife overpass recently constructed (in 1997) over the railway and highway leading from Oslo city centre to Oslo National airport in Norway. The benefits of the ecoduct have potentially been compromised due to the difficulty in ensuring there are no future changes in landuse in the areas adjacent to the measure. Subsequent landuse changes have already taken place which are likely to diminish the value of the large investment in the ecoduct. As a consequence of the subsequent development, the locations of moose crossing points will have to be revised, incurring further costs (Kastdalen, 1999).

5.8. ON-GOING RESEARCH AND REVIEW OF RELEVANT STUDIES

Despite the general awareness of the problem and the urgent request for planning tools, empirical data on the actual impact of infrastructure on wildlife is still scarce. During the 1970’s, comprehensive research on the influence of roads on nature has been conducted, but with a focus on environmental rather than ecological aspects (e.g. Göransson *et al.*, 1978). Major gaps in (ecological) knowledge have been identified throughout this and earlier Chapters concerning, for example, the width and quality of the disturbance zone along infrastructure, the barrier effect of roads and road traffic and the associated mortality in wildlife, differences in the impact between road and railway, and methods to predict potential hotspots of ecological conflicts during the planning phase. Also, further improvement is needed in the design and implementation of mitigation measures, as well as the quality control of existing measures through follow-up studies (S-SoA, 5.6).

Many projects on the detailed ecology of specific species are relevant, increasing our knowledge of the impact of habitat fragmentation even though they often do not refer directly to transportation infrastructure. It is a common feature throughout Europe that the two sides of the problem, *i.e.* habitat fragmentation and transportation infrastructures are not really considered together. The work of engineers, ecologists and landscape architects remain separate. Other research projects deal partially with the fragmentation problem, but more from the point of view of populations than habitats. These studies come mainly from public research organisations and Government departments. More specific ongoing studies can roughly be ascribed to one-or-more of the following categories:

- Project-related follow-up studies of impacts and/or mitigation measures (efficiency control)
- Problem-oriented studies (field studies and simulation modelling)
- GIS-studies with remotely sensed data
- Implementation/testing in actual infrastructure projects
- Development of indicator systems and evaluation methodology

Table 5-15 shows a selection of the most relevant studies and ongoing work in Europe with regards to habitat fragmentation.

Table 5-15 - Relevant studies and ongoing work.

Study	Details	Source
'Fauna elements on road verges along the E314 motorway' study by Aeolus Environmental and Nature Advice Agency (1999)	Motorway cuts through 3 important heathlands. Comprehensive inventory used to investigate the verge corridor function. Does the E314 serve as a dispersal corridor for species between the 3 similar habitat areas?	B-SoA
VLINA-projects (Vlaams Impulsprogramma Natuurontwikkeling – Flemish Incentive Programme for Nature Development) (since 1996)	Main aim is to investigate the relationship between effective population size, isolation and genetic diversity. The influence of species characteristics (size, dispersion capacity) and habitat characteristics (age, stability) will be determined.	B-SoA
'Quantitative evaluation of the connecting function of landscape elements from connectivity models', University of Antwerp (ongoing)	Study of 5 species commonly found in small habitat fragments (<5ha) to compare and contrast the effects of landscape structure and species-specific parameters on population size and dispersal.	B-SoA
The effects of fragmentation on population size and gene flow in carabid beetles (ongoing)	Research project at the University of Berne	CH-SoA
Dispersal strategies for vertebrates and vascular plants	Investigated dispersal strategies in order to predict the barrier effect of transportation infrastructure.	Salvig *et al.* (1997) in DK-SoA
The Danish forest and Landscape Institute	Studies on fragmentation and barrier effect on recreation	Kaae *et al.*, 1998 in DK-SoA
Ph.D. thesis - various	By Miriam Serrano at the University of Navarra on landscape fragmentation produced by roads, and by Luis Sanz on the effects of roads on wildlife.	E-SoA
Investigation into biological connectors in relation to transportation infrastructure in Catalonia	Team working in collaboration with the University of Barcelona	E-SoA
Fragmentation of forests by major infrastructures	Infrastructure density is calculated for each forest pixel.	IFEN, 1999 in F-SoA
Division of territories for large mammals, areas of free movement of red deer	A mapped inventory of groups of red deer and the main remaining exchanges was undertaken in 1996 over the whole national territory.	ONC, 1998 in F-SoA
Identify areas representing a national issue for biodiversity and the fragmentation	Aims to prioritise, on a national level, the areas most sensitive to risks of territory split by major infrastructure projects.	CETE de Lyon et INGEROUTE, 1999 in F-SoA
The barrier effect of roads	Thesis in progress (INRA/CNRS Rennes)	F-SoA
Road mortality/landscape fragmentation relationships	County association (Ornithology Group of Deux-Sèvres)	F-SoA
Norwegian Institute for Nature Research – various research projects	GIS modelling of fragmentation effects on the dispersal of animals, development of methods for assessing sensitivity of different natural areas to road construction, road ecology in relation to game species, reindeer ecology in relation to disturbance and fragmentation by infrastructure, bird population studies related to road development, river ecology and road building.	N-SoA

(Cont'd…)

Study	Details	Source
		(…Cont'd)
Grimsö Wildlife Research Station, SLU – various research projects	Movements of radio marked wolves and lynx are studied in relation to the road network (Jens Karlsson). Movements of large and medium sized mammals along and across roads are studied from snow-tracking data to reveal eventual barrier thresholds caused by traffic (Andreas Seiler). Radio marked moose are tracked to study their migratory behaviour and the influence of highway fencing (John Ball).	S-SoA
Highway 31: To investigate the predicted barrier and disturbance effects of the planned road on mammals	Data on the occurrence of wildlife, birds and vegetation before road construction have been collected for 3 years (1997-2000) by snow tracking and breeding bird surveys. The study will continue after road construction. Inventories on traffic casualties will be added and the use of the planned fauna passages will be studied by video and track counts. The final report is due in 2005/6.	Seiler and Folkeson, 1996; Seiler *et al.*, 2000 in S-SoA
Highway 4 in the High Coast area: To investigate the barrier effect on moose and the efficiency of the two moose underpasses. The project is commissioned by the SNRA and was conducted between 1998 and 2000. It is planned and organised by Grimsö Wildlife Research Station, SLU.	The project contains five sub-projects: 1) mapping of migration distances by marking moose in winter habitats and collecting the markings during regular hunting in summer habitats; 2) estimation of changes in moose densities by pellet counts on both sides of the new road; 3) inventory of browsing damages in young spruce plantations and estimation of available biomass for browsing; 4) snow-tracking along the new road to reveal the immediate barrier impact on moose; 5) evaluation of the use of moose passages by track counting on sand beds and in snow.	Seiler, 1999a; Seiler *et al.*, 2001 in S-SoA
Research project: Ecoways commissioned by the SNRA and contains several sub-studies that contribute to a PhD-study on fauna casualties. Altogether, it aims at the development of tools and indicators that can be used to evaluate fragmentation pattern at landscape level and provide support to improvement plans for the existing road network.	Aims include 1) identifying and mapping of conflict points between roads and the ecological infrastructure in the landscape; 2) mapping and analysis of hotspots in fauna casualties, especially moose-vehicle collisions with GIS; 3) field inventories of existing barriers and passages to wildlife, such as culverts, tunnels, bridges, overpasses; 4) evaluating of the need for improvement and mitigation measures using data on fauna casualties as indicator for the quality of the barrier effect. The project has been planned in cooperation between Grimsö Wildlife Research Station Swedish National Road and Transport Research Institute and SNRA.	Seiler, 1999b in S-SoA
Fauna casualties – A GIS study	This project focuses on the spatial distribution of casualties in medium-sized and larger mammals in relation to landscape and road characteristics. It seeks to develop a predictive model that can help to identify and evaluate the risk for fauna casualties and find adequate mitigation measures.	S-SoA
English Nature, in particular, has been active in researching habitat fragmentation in the United Kingdom.	Responsible producing a series of inter-related reviews as part of its Commissioned Research Programme.	English Nature, 1993;1994a; 1994b; 1994c; 1994d; 1995; 1996 in UK-SoA

(Cont'd…)

(…Cont'd)

Study	Details	Source
National survey of wildlife road casualties: the Mammal Society and The Hawk and Owl Trust to run from June 2000 until May 2001	The aim is to identify factors which cause wildlife to fall victim to vehicles in high numbers along certain sections of road.	UK-SoA
Small Mammal Study (University of Birmingham, Jackie Underhill): part funded by the Highways Agency	Measuring the extent of road avoidance by wildlife, specifically on road verges in deciduous woodland habitat.	UK-SoA
Small Mammal Study (University of Bristol, Lincoln Garland): 3 year study funded by the Highways Agency	Aims to increase the knowledge of small mammal populations on road verge habitat, and specifically, determine which road verge characteristics affect small mammal abundance and diversity. During the course of the study data is also being collected on barn owls (*Tyto alba*), in order to provide an insight into the relationship between small mammal and predator casualties.	UK-SoA

It has been shown that there is a wide range of research work being undertaken throughout Europe around the subject of habitat fragmentation and infrastructure. The priority must be to share the results of such studies widely in order to avoid the replication of work and to advance the knowledge of this complicated subject area as rapidly as possible.

5.9. SUMMARY

This Chapter has confirmed that the fragmentation effect caused by the present network of transportation infrastructure is substantial throughout much of Europe. It varies in significance according to the type of infrastructure concerned and the intensity of its use. For example, a dual carriageway with a concrete central reserve is less of a problem for fauna than a fully fenced motorway. Similarly, a 'traditional' railway line has less impact than a high speed line (HSR/TGV) protected by a double layer of fencing. All things being equal, infrastructure with heavy traffic flow has a greater severance impact than a less intensively used link. Continued increases in traffic density in recent decades have greatly increased the number of fauna casualties (Section 5.3) as well as magnitude of the barrier effect created by infrastructure (Section 5.4). Consequently, in some areas of Europe vulnerable species are showing negative effects at a population level (Section 5.6). The methods for identifying and quantifying the wider ecological impacts of habitat fragmentation are so new, and the knowledge required is so detailed, that many effects may not be evident for many years to come. Best practice therefore dictates that the precautionary principle should be applied in infrastructure planning and management in order that habitat fragmentation be minimised, and that these time lag effects be taken into account.

Chapter 6. Minimising Fragmentation through Appropriate Planning

This chapter gives an overview of the existing planning policies and instruments that can contribute to the avoidance or minimisation of habitat fragmentation. The legal framework both for impact avoidance and the protection of natural areas is also dealt with here given its direct implications for the planning process. Avoidance tools will be discussed on a more technical level in Chapter 7. Strategic Environmental Assessment (SEA) and the identification and development of ecological networks are discussed as key steps in minimising habitat fragmentation. The integration of ecological values within the development planning process of different economic sectors *e.g.* transportation is also discussed.

Models and indicators are important instruments for the large-scale planning of transportation infrastructure. Their value in the monitoring of current trends and in the evaluation of different future scenarios is explained and their potential future role in SEA is identified. The most widely used models and indicators are presented to illustrate the types of possible approach to assessing the scale and nature of the fragmentation problem.

6.1. LANDUSE PLANNING POLICY AND GUIDELINES

Good landuse planning is a tool which has enormous potential for minimising future habitat fragmentation caused by the different human demands on the landscape, in particular that caused by transportation infrastructure. Currently, three international institutions are taking forward the subject of the prevention of habitat fragmentation in the planning phase: the Organisation for Economic Co-operation and Development (OECD), the European Commission (EC) and the Council of Europe (CoE).

Since the 1960s, initiatives have been undertaken to formulate a common vision on landuse planning for specific regions in Europe *e.g.* The Netherlands (Rijksplanologische Dienst, 1999). In 1991, the Committee on Spatial Development was formed which marked the start of the co-operation in landuse planning within the European Union (EU) and in 1993 the European Consultative Forum on the Environment was formed under the 5th Action Programme on the Environment, along with the Environmental Policy Review Group, with the purpose of advising the EC on policy development. This Forum set up a Working Group on Urban and Spatial Issues with the objective of developing the 'European Spatial Development Perspective: Towards Balanced and Sustainable Development of the Territory of the European Union' (European Commission, 1999). This document establishes the guidelines for initiatives regarding spatial development in Europe within a framework for sustainability, with special attention to the precautionary principle. Aspects such as the need for balancing environmentally sustainable development and market competitiveness are included in the guidelines.

Piepers, A.; Alvarez, G.; Bouwma, I.M.; De Vries, H. (J.G.) and Seiler, A. (2002) Minimising Fragmentation Through Appropriate Planning. 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. 115-128. Office for Official Publications of the European Communities, Luxembourg.

The Sixth Programme of Community Action on the Environment encourages the use of planning tools as a system for improving environmental protection and achieving regional sustainable development. In this Programme, the EC goes beyond a simple declaration of good will to promote the integration of strategic planning principles and procedures in order to reduce current negative environmental trends.

On the 6th October 1999 the CoE, supported by the European Councils of Cardiff and Vienna, adopted a strategy for the 'Integration of the Environment and Sustainable Development into Transport Policy' (document 11717/99 TRANS 197 ENV 335). The strategy encourages Member States to 'establish and apply a sustainable transport system which allows for the movement and development of individuals and commerce in a safe manner compatible with human health and that of ecosystems'. The CoE has invited the candidate countries to follow this path when elaborating their national and local strategies during the period prior to adhesion.

The European Landscape Convention, promoted by the European Council, gathers together all existing knowledge, procedures and techniques with the aim of integrating the multifunctional facet of landscapes within the planning process. The Convention aims to underline the importance of landscapes that must be protected by means of political, scientific and technical means and gives high priority to public participation, which is recognised as a crucial tool in the planning process.

Landuse planning in Europe is the responsibility of the national administrations and in all countries it is undertaken at the local level. Local planning authorities define new infrastructure requirements and assign land in local development plans. These plans, which are revised periodically, have to adhere to all the legal elements of landuse planning at a higher rank (*i.e.* regional, national and international levels) and constitute an accessory instrument for preventing, at a local scale, the alteration of natural areas and key corridors of connectivity between them. In many countries landuse planning is also undertaken at a regional level. For example, in Spain (E-SoA, 4.5.1) there is an initiative in which the Catalan government has prepared a proposal for guidelines (pending approval by the Catalan parliament) that define the obligation to consider, in local and regional plans (*e.g.* urban landscape plans, Local Agenda 21 Plans and other elements of territorial planning), the prevention of alterations to areas considered as having a strategic interest for the connectivity between protected areas. In some countries *e.g.* The Netherlands, landuse planning documents are also developed at the national level (Rijksplanologische Dienst, 1999).

6.2. PLANNING FRAMEWORK AND INSTRUMENTS

The objective of spatial planning is to organise functions and space in such a way that it shows the best mutual relationship, or to develop human and natural potentials in a spatial framework in such a way, that all can develop as well as possible (Buchwald and Engelhardt, 1980). In general, infrastructure has a major impact on the quality of the land and on its ecology. For this reason it is increasingly recognized that more sustainable approaches are needed for planning and managing landscapes worldwide. Appropriate tools are needed to effectively apply sustainable principles to planning and management. The spatial dimension of sustainability engages processes and relations between different types of landuse, ecosystems and biotopes at different scales, and over time. Therefore, ecological knowledge is essential when planning for sustainability. Sustainable landuse planning requires a thorough analysis of the current patterns of landuse, the likely changes that will ensue and the potential impacts associated with these changes. Landscape ecological concepts offer important possibilities for developing sustainable landuse planning (Botequilha Leitão & Ahern, 2002; Jongman, 2002).

6.2.1. Regional planning

At regional level in Europe there exist a number of financial instruments which have been established to promote development and transboundary co-operation in the field of spatial planning, *e.g.* the INTERREG funds. In providing economic aid for such initiatives it is possible to impose, as a condition for financing, the obligation to integrate environmentally sustainable criteria within plans and projects.

The firm will of the EC with regard to environmentally sustainable development has materialised in the form of Structural Funds and Cohesion Funds, from which many transportation infrastructure projects benefit. Regulation (EU) 1260/1999, by which the general dispositions are established with regard to Structural Funds, establishes the obligation to carry out environmental monitoring of the Regional Development Programmes. It also provides other associated planning instruments of use during project implementation. An evaluation of the repercussions of certain public and private projects on the environment is further regulated by Directive 97/11/CE (the EIA Directive). This promotes the application of the precautionary principle at the earliest possible phase, *i.e.* prior to the financing of projects. The implications include the possibility of financial penalisations and withdrawal of finance if it is shown that the projects have a significant effect on the environment. The fragmentation of habitats by transportation infrastructure, and especially any effects on the Natura 2000 Network, must be avoided if one wishes to use European funding, in order to comply with European legislation. The European Commissioners for Regional Policy and for the Environment have made clear statements regarding this. Regularly, the European Environmental Commission intervenes in planning and project development by prosecuting the Member States for their lack of sufficient consideration of the effects on these specially protected wildlife habitats. In some cases, the transportation infrastructure scheme has been subsequently abandoned.

6.2.2. Environmental Impact Assessment (EIA)

More than acting as an instrument in itself, the EIA procedure provides an important legal framework in which planning is carried out. EIA is, at present, the central tool for advocating the avoidance of habitat fragmentation in Europe. However, most countries point out that measures for the prevention of habitat fragmentation need to be applied earlier in the planning stages, *i.e.* during preliminary studies before the formal EIA. This is often when the least-impact corridor is chosen. For this purpose, Norway has published guidelines for the routing of transportation infrastructure in the landscape (Norwegian Public Roads Administration, 1994). The EIA process provides an adequate framework within which effective planning may be carried out. More and more frequently, projects in which route options and mitigation measures have been poorly considered during the design phase are running into problems during the EIA process because of ecological incompatibility. At best, time and money is lost and in some cases the project may even be abandoned if ecologically sustainable criteria have not been given due regard during the planning phase.

Route choice and design is part of project level EIA and can avoid serious impact on habitat fragmentation, especially because several different alternatives must be analysed and the least impact option must be chosen. Nevertheless, more often EIA procedure tries to mitigate the effects of a chosen alternative, by means of small changes in routing, construction of tunnels and viaducts, or the application of mitigation measures (see Chapter 7). Nevertheless, the shortcomings of EIA in adequately safeguarding against ecological degradation have been recognised by the European Spatial Development Perspective, particularly the fact that this instrument is often wrongly interpreted and implemented (European Commission, 1999). The European Commission highlights the need for Strategic Environmental Assessment (SEA) to identify the longer-term ecological effects and it also stresses the need for monitoring ecological changes with appropriate indicators.

6.2.3. Strategic Environmental Assessment (SEA)

In the EU Directive 2001/42/CE regarding the 'Evaluation of the Effects of certain Plans and Programs on the Environment', provides new opportunities for evaluating habitat fragmentation at a higher spatial scale. This new legislation (see also Chapter 9) establishes mechanisms that will allow for the analysis and prevention of habitat fragmentation due to territorial, spatial and urban planning (which includes transportation infrastructure), new road plans, etc. At present most countries analyse the effect of each project at an advanced stage in its development, without considering the synergic effects caused by the landuse changes that are brought about by each individual project, or the sum of the combined effects that are produced by different infrastructures in the same territory. This is a new way to introduce strategic territorial analyses in politics (Oñate *et al*., 2002).

SEA legislation is still in a transposition phase in most European countries and clearly defined procedures, such as those for EIA, are not yet in place. However, in some countries, *e.g.* The Netherlands, procedures similar to SEA are already being applied. Also, indicators and GIS techniques have been used in an assessment of methodologies used in the Spatial and Ecological Assessment of the Trans European Transport Network (TEN-T) undertaken by the European Environment Agency (EEA, 1998). In this analysis, both proximity to, and fragmenting of, nature conservation areas was considered.

6.3. ECOLOGICAL NETWORKS

By identifying the ecological network of a region or country the spatial requirements of nature are expressed and can be taken into account during the spatial planning process. The legal protection of sites included in such networks allows for them to be given due consideration in landuse planning for other types of development *e.g.* those associated with infrastructure. In order to include biodiversity conservation in landuse planning and to avoid further fragmentation of valuable nature areas, several European countries have developed national or regional ecological networks (see Figure 6.1). Ecological networks try to tackle the underlying causes of the decline in nature, *i.e.*:

- the absolute loss of habitats;
- the negative impact on vital conditions (e.g. due to the quality of soil and water, change in land or water management) and;
- wildlife areas diminishing in size and/or by becoming isolated.

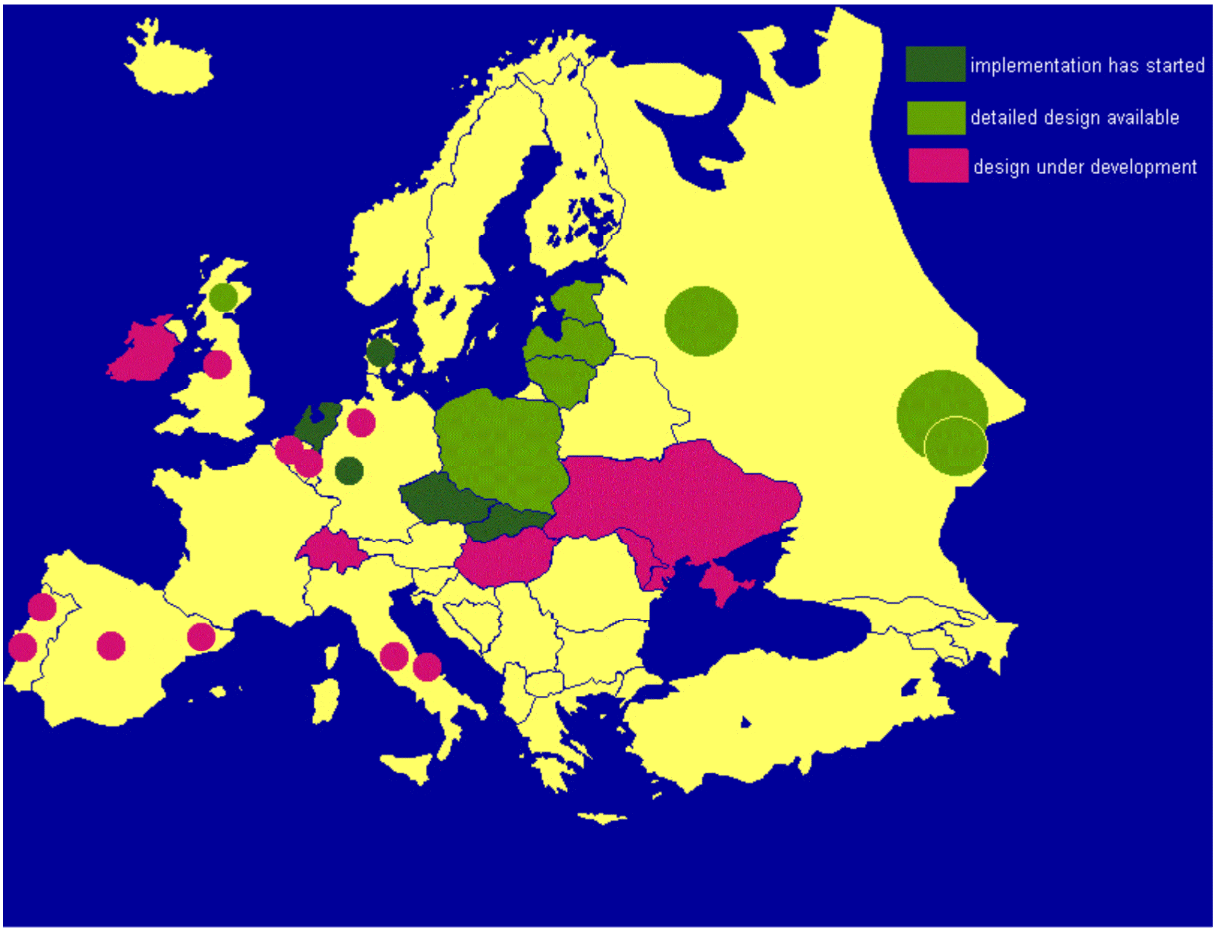

Figure 6.1 - Overview of regions and countries that are in the process of developing networks. (Revised from Jongman, 2000)

Within EU, the most significant instrument for landuse planning with regard to nature conservation is the ecological network currently being established under Natura 2000 within the framework of the Birds and Habitats Directives (adopted in 1979 and 1992 respectively). This network includes both Special Protection Areas (SPA) for birds and Special Areas of Conservation (SAC) which must be identified and designated by the Member States. As part of the process of establishing Natura 2000, each country must first draw up a list of Sites of Community Importance which must then be designated as Special Areas of Conservation. This process must be completed by 2004 at the latest.

The European Commission proposes the establishment of an ecological network in Europe, as is being developed under Natura 2000, but also recognises the fact that ecological continuity is required between protected areas in order to assure the biological diversity of Europe (European Commission, 1999). In this regard, initiatives are being undertaken in different countries to define ecological networks which integrate with and link the sites included in Natura 2000. Once established, the ecological corridors must also be preserved in order to guarantee connectivity between the sites that form the network, and as a result guarantee its functioning. The mapping of these ecological networks will improve the possibilities for analysing the effects that the development of new infrastructure can cause on ecological function.

Under Article 6 of the Habitats Directive, the development of new plans or projects which may have significant effects on Natura 2000 sites must take into account the ecological values and criteria of the site. In cases where significant negative effects cannot be avoided, and no other viable alternative exists, then Article 6 of the Directive establishes the obligation to apply compensatory measures in order to guarantee protection of the overall coherence of Natura 2000 (see section 7.4). Also, the Member States are obliged to inform the EC of the compensatory measures that have been adopted. In planning road and railway infrastructure, Natura 2000 must be a fundamental consideration, not only because it reduces its impact on protected sites but also time, effort and money may be saved if expensive, last-resort, compensatory measures can be avoided.

In Belgium, Estonia, Hungary, Switzerland and The Netherlands, the existing ecological networks are used as tools to identify bottlenecks between nature and infrastructure (B-SoA, 4; EE-SoA, 5; H-SoA; CH-SoA, 4; NL-SoA, 4).

Specific planning instruments also exist for protected areas, *e.g.* management plans, which regulate activities within and uses of the sites. In drawing up these plans, it is possible to include restrictions to prevent transportation infrastructure from affecting the site or compromising the connectivity with other areas of natural interest.

6.4. MODELS TO PREDICT FRAGMENTATION

The development of a series of validated indicators and models to measure and predict the degree of habitat fragmentation is an urgent requirement. Tools are needed which allow different development options to be compared to identify the least damaging option (in terms of the habitat fragmentation it causes). To address this challenge, some countries in Europe have already made progress and some of their experiences are reviewed in this section. Although the need for a quantifiable evaluation of large-scale ecological effects is apparent, especially in terms of strategic assessment, the methodology is still in its infancy. None of the countries contributing to COST 341 has reported a regular use of computerised models to evaluate the fragmentation impacts of infrastructure.

Over recent years, however, technology such as computer hardware, Geographic Information Systems (GIS) and simulation software, as well as the necessary databases on nature, land cover and wildlife have improved considerably. Much of the ongoing landscape ecological research now involves GIS-based spatial assessment using remotely sensed data such as satellite images. Through combination of GIS data and simulation programmes, the door to spatially explicit modelling has been opened. When used in a GIS environment, simulation models can create various landscape scenarios and visualise them in 2D or 3D-format. They enable habitat fragmentation, corridors, barriers and bottlenecks (at the present time or in the future) to be visualised from a human or animal perspective. The identification of barriers to animal movement is a first step in the defragmentation of landscapes. Once the location of barriers are known, fully functional corridors and wildlife crossing structures can be established at optimum locations to promote ecological connectivity on the ground. More importantly, by simplifying reality, models can facilitate the identification of the critical factors which are driving the fragmentation process and which should become the focus for mitigation effort. Models can also help to identify gaps in our knowledge regarding species ecology and to address questions that are otherwise difficult to study empirically *e.g.*:

- At what point does the degree of habitat fragmentation become critical?
- What is the optimum spatial configuration of linked habitat patches?
- Where are the optimum locations for wildlife corridors?
- Where are potential barriers or bottlenecks located?
- What effect will the restoration of habitats (e.g. the creation of a corridor or the development of transportation infrastructure) have on specific species?

Broadly, simulation models used in the analysis and evaluation of fragmentation impacts can be divided into three categories:

- Dispersion models
  Individual-based simulation models focused on animal movements and spread across a mosaic of habitats (such as those derived from field or satellite mapping). Usually species-oriented, they require detailed knowledge of the species in question and can cover both local as regional scales. Examples of commercially available models are e.g. GRIDWALK, POLYWALK, and SmallSteps. The modelling results can be presented visually as maps showing the relative abundance of the species after a given time. Dispersion models are mostly a scientific tool that can help to locate barrier conflicts and evaluate landscape connectivity from the point of view of individuals.

- Metapopulation models
  Numerical models that simulate the survival of local populations using birth, death and migration dynamics in relation to habitat quality, size, and connectivity. These models are species-specific, relating more to regional than local scales, but not all are spatially explicit (i.e. the spatial arrangement of habitats is not always considered). Examples include METAPHOR, RAMAS, and META-X. These models usually result in tables on the survival probabilities of metapopulations or single local populations. They help to evaluate landscape suitability for populations of species.

- Expert systems
  Models that make statements about the expected or possible existence of ecosystems and viable network populations based on information from thematic landscape databases. Examples are GREINS, LEDESS, and LARCH. These models facilitate the comparison of different landscape scenarios and thus support decision-making.

A wide variety of computer models that could be used for the analysis of fragmentation effects exist, but most have been designed purely for scientific purposes, or to study a particular species or problem. Many models may be applied to investigate barrier, isolation, disturbance or mortality effects, but none has yet considered the direct effect of infrastructure per se (*e.g.* traffic density, noise, road width). Many of the (traditional) GIS-based assessments and expert systems are not spatially explicit, meaning that they do not consider the spatial arrangement of habitats (*e.g.* distance, clumping, size variation etc.). Few models are flexible enough to be used across a wide range of environments or are applicable to a range of different species. Examples of models currently available (mostly commercially) are listed in Table 6.1.

Table 6-1 - Examples of available simulation programs (both scientific and commercial) currently available for the analysis of fragmentation impacts on species and populations.

Model Type	Name	Country	Description	Reference
Dispersion	GRIDWALK POLYWALK SMALL-STEPS	NL	These models aim to determine the accessibility of neighbouring habitats and to identify dispersion streams and "bottlenecks". GRIDWALK is based on raster data and is most suitable for large-scale analyses. POLYWALK was developed for vector-based GIS. SmallSteps considers important species-specific responses to landscape, habitat and infrastructure components.	NL-SoA, 9.4
	DISPERS	BE	Simulates habitat accessibility for a specific species or group of species.	B-SoA, 8.4
	-	SE	A set of dispersion models has been developed at the SLU to predict invertebrate movements.	S-SoA, 8.4
	-	NO	NINA is working on various GIS-based models of habitat fragmentation related to animal movement, *i.e.* dispersion models. The work involves varied species from moose to small butterflies.	N-SoA, 8.4
Meta-population	METAPHOR	NL	Computes the chance of survival in a metapopulation in relation to the quality and the spatial arrangement of habitats, age and sex structure of local populations and other intrinsic factors.	NL-SoA, 9.4
	RAMAS®-GIS	USA	Metapopulation, GIS-based simulation software. Includes a set of different software packages, mainly for scientific use.	
	META-X®	Germany	Metapopulation, GIS-based simulation software assists the development of species' protection plans, habitat network design, and technology assessment.	
	Flashing models	NL	Compute extinction and colonisation probabilities for specific species in a given area.	NL-SoA, 9.4
	-	DK	Frogs and roads	Hels, 1998
Expert systems	LARCH	NL	Evaluates effects of landscape composition on a given species. It is based on spatial rules developed in METAPHOR. Assists with landscape ecological analysis.	NL-SoA, 9.4
	LEDESS	NL	Decision-supporting system testing development proposals for ecological and environmental feasibility. Based on GIS, it contains, amongst others, a vegetation and a fauna module.	NL-SoA, 9.4
	GREINS	NL	Developed for the evaluation of development scenarios for nature (*e.g.* vegetation structure) based on abiotic habitat factors (*e.g.* soil, hydrology).	NL-SoA, 9.4
GIS-assessment (examples)	-	DK	Danish Forest and Landscape research institute has developed a GIS-based model to illustrate the barrier effect of infrastructure on recreation (measured as loss of accessibility to the landscape).	Kaae *et al.*, 1998

(Cont'd...)

(...Cont'd)

	-	CH	GIS model that illustrates landscape	Hel-Lange, 2000

Model Type	Name	Country	Description	Reference
			connectivity for amphibians in one area of Switzerland.	
	-	FR	GIS-based analysis of landscape pattern and habitat sensitivity.	
	EVV	NL	The Traffic and Transport Evaluation instrument (EVV), developed by the Environmental Science Center in Leiden, aims to address regional infrastructure problems. The model has not been applied in practice, but its basic concept is still valid.	Cuperus and Canters, 1997

The models described in Table 6-1 are all available, either from universities or commercially, but none has so far been regularly used in strategic assessment. Before simulation models can be fully implemented in the spatial planning sector, some major obstacles must yet be overcome. Among these, the lack of knowledge on the actual response of wildlife to infrastructure is the most prevailing. Until now, the majority of studies on the ecological effects of infrastructure have been descriptive and the empirical data is usually insufficient to construct predictive models (compare Chapter 3). Few studies have focused on general pattern and process or tried to identify thresholds in impact-effect relationships. The contribution of road traffic to the barrier effect for fauna, for instance, is fundamental to the overall fragmentation effect, yet is seldom quantified. Critical thresholds in traffic volume for animal movements have also not yet been established clearly (see Chapter 3.5). The relationship between traffic-related mortality, traffic volume, animal density and mobility, are crucial factors that could be easily quantified, but so far lack sufficient empirical data.

Other obstacles in the development of predictive models are related to shortcomings in GIS techniques, insufficient resolution of spatial data and classification of satellite images. Depending on the differences in scale (extent and resolution) and quality (accuracy) of base maps and thematic map layers, the results of GIS models can be misleading and may fail to detect important aspects. It is a common problem that data obtained from different sources *e.g.* agencies, authorities, and governments can vary greatly in accuracy and it is not always possible to combine different data sets. Remotely sensed data, derived from aerial photography or satellite imagery provides an efficient tool for a large-scale landscape classification, but in many aspects these data must be combined with, or complemented by, field inventories to provide a more complete picture. The spatial and thematic resolution of a data set must be adjusted for each specific case: the accuracy of analysis does not necessarily increase with a higher resolution. The techniques relating to the acquisition and analysis of remotely sensed data are continuously improving, putting an increasing demand on the accuracy of ecological background data.

As long as the basic ecological information relating to the response variable, *i.e.* the species, is insufficient, interpretation of spatial indicators, fragmentation indices, or GIS models remains nothing but guesswork. What is needed is an integrated development of simulation models, evaluation criteria and indices, resulting in a reliable empirical database that allows for generalisations and extrapolations. Computer models can be sufficiently complex to make reliable predictions, but at the same time, they should also be simple enough for application in SEA. To accomplish this, further international and interdisciplinary research is needed.

6.5. INDICATORS AND INDEXES OF FRAGMENTATION

Indicators are quantified information which help to explain how things are changing over time. They are broad-brush, aggregated statistics which give an overall picture. The three basic functions of indicators are simplification, quantification and communication. When reference data (the maximum that can be realised) or target data (policy goals) are linked to indicators, it gives them a gradient-measuring function (Hinsberg *et al*., 1999). Indicators can be used for planning purposes as well for comparing the values in different planning scenarios.

The fragmentation of the natural environment has effects on the continued existence of species in the natural landscape. Populations disappear and are no longer compensated for by migration from neighbouring areas. This results in the appearance of gaps in the relationships between the various species (*e.g.* predator/prey relationships) disturbing the balance to an even greater extent. It is almost impossible to chart or to predict the final effects of this process on the biodiversity. Nevertheless, in order to make statements about the fragmentation effects caused by the construction and use of infrastructure, indicators are an extremely valuable tool which should be utilised.

It appears that indicators for habitat fragmentation due to infrastructure are not widely used in the countries participating in COST 341. Only two countries (Norway, and The Netherlands) mention the yearly application of an indicator for monitoring (de)fragmentation on a national level. In The Netherlands this indicator has been adopted officially and the latest policy documents have included goals based on this indicator (Ministerie van Verkeer en Waterstaat, 1999). Some other countries *e.g.* France, the Czech Republic, Estonia, Hungary, Switzerland and the United Kingdom have undertaken surveys in which some kind of indicator has been utilised. It is not clear whether these indicators will continue to be used for monitoring in the future. In the National Reports, some figures are given which can also be considered as indicators for the degree of habitat fragmentation but which may not have been utilised for this purpose up until now.

Table 6-2 gives an overview of the various indicators that are used in the contributing countries. They may be classified according to the various scales to which they apply *i.e.* regional, national and European. The European Environment Agency (EEA) has pioneered work at the European level. One such project has been set up for identifying indicators that can be tracked and compared with concrete policy objectives - The Transport and Environment Reporting Mechanism (TERM). The European indicators given below come from the first indicator-based TERM report (EEA, 2000).

Figure 6-2 compares one of the indicators *i.e.* the landtake by infrastructure as percentage of total country area, for different European countries.

Table 6-2 - Overview of the various indicators that are used across Europe.

Type of Indicator	Country	Scale	Used For	Frequency of Use	References
Density of infrastructure	F	n	Assessing fragmentation of forests	single survey	F-SoA, 5.6
idem	N, DK, CH, E, B, S, CZ, EE	r, n	Describing habitat fragmentation	single survey	N-SoA, 4.1 DK-SoA, 5.4.1 CH-SoA, 5.3 E-SoA, 5.3 B-SoA, 5.1 S-SoA, 5.3 CZ-SoA, 3.2 EE-SoA
Mesh-width between infrastructure	NL, S	r, n	Describing habitat fragmentation	single survey	NL-SoA, 5.2 S-SoA 5.4.1
Fragmentation Index = length of linear infrastructure/area of red deer zone	F	n	Expressing area of habitat fragmentation for red deer	single survey	F-SoA, 5.6
Disturbance-free natural areas (based on distance to nearest human-made installation)	N	n	Monitoring habitat fragmentation on a national level	yearly	N-SoA, 4.3 and 8.3
Number of intersections between infrastructure network and supraregional biocorridors	CZ	n	Evaluation of permeability	single survey	CZ-SoA, 6.3
Percentage of supraregional wildlife corridors disrupted	CH	n	Assessing condition of supraregional wildlife corridors	single survey	SGW, 1999
Length of intersections between infrastructure and nature areas	UK	r	Assessing loss of peatland	single survey	UK-SoA, 5.4.1
idem	NL	n	Policy evaluation	yearly	Ministerie van Verkeer en Waterstaat, 1999
Length of unsolved intersections reproduced as a percentage of the total length of intersections	NL	n	Policy evaluation	yearly	Ministerie van Verkeer en Waterstaat, 1999
Average size of landuse areas or size and number of landuse areas with and without infrastructure	NL, S	n	Describing habitat fragmentation	single survey	NL-SoA, 5.3.1 S-SoA, 5.4.1
idem	H	n	Describing habitat fragmentation	single survey	H-SoA, 5.3.1
idem	EE	n	Determining pressure of transport sector on natural diversity and evaluating changes	research recently being launched	EE-SoA
idem	Europe	Eu	Policy evaluation	regularly	EEA, 2000
Area:contour ratio of habitat patches with and without infrastructure	H	n	Describing habitat fragmentation	single survey	H-SoA, 5.3.4

(Cont'd...)

Type of Indicator	Country	Scale	Used For	Frequency of Use	References
					(...Cont'd)
Landtake by infrastructure as a percentage of total country area	E, S, DK, EE	n	Describing habitat fragmentation	single survey	E-SoA, 5.3 S-SoA, 5.4.1 DK-SoA, 5.4.1 EE-SoA
idem	Europe	n	Policy evaluation	regularly	EEA, 2000
Number of SPA's* and Ramsar wetland areas with infrastructure within 5 km of their centre	Europe	Eu	Policy evaluation	regularly	EEA, 2000

* SPA - special bird area. Special bird areas are those designed by the EC Birds Directive; Ramsar wetlands are those designated in the global Ramsar Convention for the protection of wetlands.

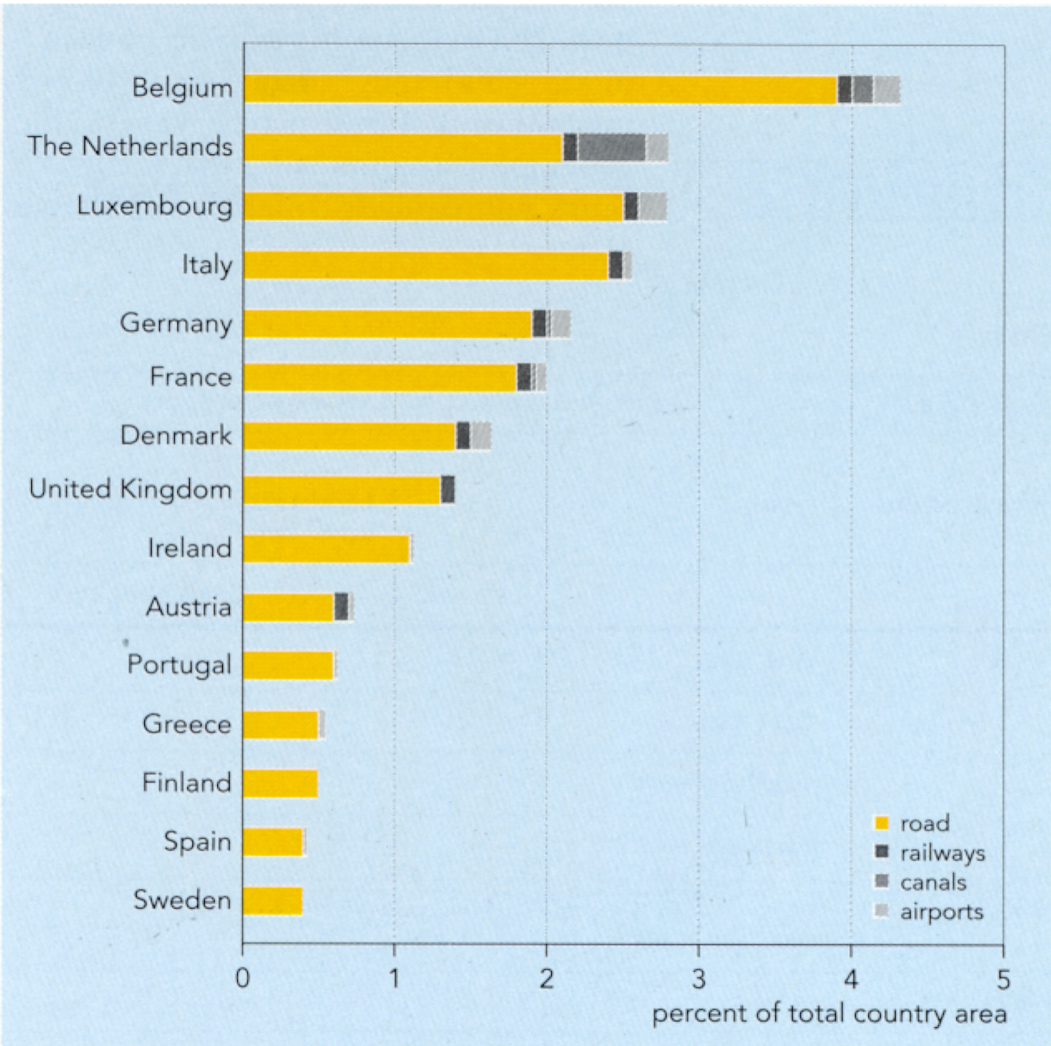

Figure 6.2 - Landtake by infrastructure in 1996 as a percentage of total country area for different European countries. (From EEA, 2000)

Examples of indicators cited in the National Reports and suggested to be of potential future use for measuring fragmentation are included in Table 6-3.

Table 6-3 - Overview of potential new indicators for measuring fragmentation.

Type of Indicator	Country	Scale	Target	References
Density of infrastructure weighted by traffic intensity	NL, E, F	r, n	Determining effects of mobility scenario's, reflecting changes in degree of pressure	NL-SoA, 9.3 E-SoA, 8.3 F-SoA, 8.3
Average distance between same landuse areas or habitat patches	F	r, n	Monitoring increase of isolation	F-SoA, 8.3
Average number of neighbouring habitat patches per habitat patch	F	r	Quantifying spatial context	F-SoA, 8.3
Length of parallel infrastructure[#]	CZ	r, n	Measuring multiplied fragmentation	J. Dufek (*pers. comm.*)

parallel infrastructure = 0.3 km to 1 km distance between *e.g.* new motorway and original road

Ideally, a good indicator of habitat fragmentation should take the following aspects into consideration (Infra Eco Network Europe, 1999):

- size of land units;
- quality of land units;
- location of intersection;
- vulnerability of land units; and
- degree of connectivity between land units.

The density of infrastructure is useful for allowing comparison at a national level with other countries, but it really only indicates the degree of physical fragmentation of territory and does not consider the natural matrix on which the infrastructure network is superimposed (E-SoA, 8.3). Other indicators do have an ecological component, but none of those on Tables 6-2 and 6-3 integrates all the five relevant aspects stated above. This is a task for the future: to develop indicators that integrate as many aspects as possible and yet are simple and pragmatic. Recent research in Germany represents the first step towards this goal. Jaeger (2001) has developed three new, coherent indicators of fragmentation: i) degree of landscape division; ii) effective mesh number and iii) effective mesh size. Together these reflect the chance that two animals released at two different locations in one unit, will meet each other: the more barriers the unit contains, the smaller this chance.

Because some species are much more sensitive to fragmentation at a particular scale than others due to variations in mobility, behaviour and habitat requirement, indicator species will be selected for assessing the effects of fragmentation in Denmark (*e.g.* Hammershøj and Madsen, 1998). Estonia and Sweden are following the example of The Netherlands, Switzerland and the Czech Republic by determining the conflict points between the infrastructure network and nature areas and corridors (EE-SoA; Seiler, 1999). In order to make more effective use of the available information on countryside change, including satellite cover data, and to have a more co-ordinated approach, countryside indicators are being developed in the United Kingdom (UK-SoA, 8.6.1). In Norway, more detailed indicators will be developed based on the indicator that is used for monitoring habitat fragmentation on a national level, *i.e.* disturbance-free natural areas, for specific animal species, since the degree to which animals are disturbed by man-made installations varies greatly between species (N-SoA, 8.3).

6.6. SUMMARY

The principles of the 1992 Convention on Biological Diversity underline the importance of avoiding, mitigating and compensating for nature conservation impacts associated with transportation infrastructure. There are different instruments to avoid habitat fragmentation in the planning phase:

- Recommendations and codes of good practice have been published by different European institutions to promote the mitigation of the effects caused by transport networks on nature in the early stages of their development;
- Regional planning (particularly that utilising European Funds) must aim to balance the objectives, economic cohesion and environmental protection in decision-making;
- The procedures of EIA and SEA are important tools which should help project developers, planners and decision makers;
- National and regional nature protection instruments (e.g. nature reserves, maps of the ecological networks) as well as urban and territorial planning procedures are used;
- The Natura 2000 European network and the related European Directives aimed at the protection of habitats are formal documents that should oblige the integration of sustainable criteria and ecological considerations in infrastructure planning.

Simulation models that can be used for the analysis and evaluation of fragmentation impacts can be divided into three categories: dispersion models, metapopulation models and expert systems.

Computer models can be sufficiently complex to make reliable predictions, but at the same time, they should also be simple enough to reach an implementation in SEA planning routines. To accomplish this task, further international and interdisciplinary research is needed.

It appears that indicators for habitat fragmentation due to infrastructure are not widely used in the countries participating in COST 341. Only two countries (Norway, and The Netherlands) mention the yearly application of an indicator for monitoring (de)fragmentation on a national level.

Density of infrastructure is useful for allowing comparison at a national level with other countries, but it really only indicates the degree of physical fragmentation of territory and does not consider the natural matrix on which the infrastructure network is superimposed.

Chapter 7. Avoidance, Mitigation, and Compensatory Measures and their Maintenance

In this Chapter, an overview is given of the different ways to tackle the problems of habitat fragmentation from the point of view of the infrastructure planner and constructor. Firstly, three principal approaches to the problems are described: avoidance, mitigation and compensation. Different kinds of technical solutions (mitigation measures) *e.g.* fauna passages, are described in broad terms, followed by examples of compensatory measures as applied in different countries. Best practice regarding the maintenance of various types of measures is then presented. The Chapter ends with a description of various approaches and methods for evaluating the effectiveness of individual measures and some conclusions relating to the results of the few scientifically performed follow-up studies are given.

Since this Chapter is based on information presented in the National Reports, the emphasis is on providing a description of the actual situation in Europe. Thus, measures applied very commonly throughout Europe may receive more attention, even if they have been shown to be less effective than the more rarely applied measures. Best practice advice regarding all issues discussed in this Chapter forms the basis of the European Handbook '*Wildlife and Traffic – A European Handbook for identifying conflicts and designing solutions*', the parallel publication of COST 341.

7.1. DISTINCTION BETWEEN AVOIDANCE, MITIGATION AND COMPENSATORY MEASURES

The measures taken in different countries to counteract the problems of habitat fragmentation caused by infrastructure can be grouped under the terms 'avoidance', 'mitigation' (*i.e.* reducing the impact) and 'compensation', a distinction which is followed in this Chapter. However, it should be noted that there is considerable overlap between these categories. There is a general consensus that avoidance measures should be considered first, followed by mitigation measures, and that compensatory measures should only be included if avoidance is not possible and mitigation measures are insufficient. The distinction and hierarchical structure are clearly made *e.g.* in The Netherlands (NL-SoA, 7.1) and in Germany (see *e.g.* Pfister *et al.,* 1997), while in other countries the distinction is less clear and the term mitigation is used to cover most aspects.

Avoidance, mitigation and compensation are usually embedded in the administrative and legal framework. In European Union countries, this is done under the EC Directive for Environmental Impact Assessment (EIA) (85/337/CEC) which requires *e.g.* that in the planning phase of large-scale developments (*i.e.* prior to decision-making), the environmental impacts of alternative routings have to be assessed and compared with each other. Non-EU members have usually developed similar legislation.

Keller, V.; Bekker, G.J.; Cuperus, R.; Folkeson, L.; Rosell, C. and Trocmé, M. (2002) Avoidance, Mitigation and Compensatory Measures and their Maintenance. 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. 129-174. Office for Official Publications of the European Communities, Luxembourg.

7.2. AVOIDANCE OF HABITAT FRAGMENTATION

In most cases where a project is re-routed to avoid core nature areas, fragmentation is not completely avoided but translocated into less sensitive areas. This process involves the selection of the least-impact corridor. By choosing alternative routings, the dissection of local habitat, intrusion into sensitive areas, and disturbance of sensitive populations can be avoided. However, this only displaces the overall fragmentation effects and creates new problems elsewhere (even though the consequences to local populations might be less significant there). It is important to understand that fragmentation has large-scale effects which cannot be completely mitigated. In actual fact there is a fine grading of the levels of avoidance, from the more absolute in the form of deciding to abandon a project to the more fine, based on an appropriate choice of route alignment and design. The following examples illustrate different degrees of avoidance.

Avoidance by abandoning the project

A forest access road was planned through the ravine shown in Figure 7.1. However the value of the undisturbed natural forest ecosystem, harbouring many rare plants and animals, was evaluated as being higher than the utility of the road, so the project was abandoned.

Figure 7.1 - A project to build a forest access road was abandoned in this forest ravine in Marbach Canton Luzern, Switzerland, its impact being evaluated as too high. (Photo by Andreas Stalder)

Avoidance by building a structure with no barrier effect: viaducts and tunnels

Viaducts, like the structure shown in Figure 7.2, can be used to avoid the barrier effect by allowing the free passage of all species through the habitat. They are especially functional where rivers/valleys are to be crossed. However, the road still causes disturbance (noise and dust particles) and has an impact on the landscape. Viaducts should thus be considered more as a mitigation measure than as a way to avoid habitat fragmentation completely.

Figure 7.2 - Viaduct on the A12, Coltano, province of Pisa, Italy. The barrier effect is avoided. (Photo by Marco Dinetti/Ecologia Urbana)

Avoidance through a choice of a least-impact corridor

The route first projected in 1972 for the A1 motorway between Yverdon and Avenches in Switzerland ran along the southern shoreline of Lake Neuchâtel. It was planned to widen the existing shoreline route. This would have completely cut off the lakeside area from its hinterland (Figure 7.3.). Following massive opposition from environmental groups, a new route was selected. In the course of the impact study, the alignment was refined and a hillside location with numerous bridges, viaducts and tunnels was selected, thereby limiting the barrier effect. Figure 7.4 illustrates one of those tunnels.

Figure 7.3 - Development of alternative routes for the highway A1 between Yverdon and Avenches in Switzerland. The original route alongside the lake, was relocated to the hinterland using a series of tunnels and viaducts. (Bundesamt für Strassenbau, Schweiz. Nationalstrassen N1. Reproduced by courtesy of the Federal Office of Topography, Berne, BA024489)

In the COST 341 member countries, the principle advocating the strict avoidance of habitat fragmentation remains uncommon. The avoidance cases described are situations where the impact outweighs the utility of the infrastructure. Such choices appear in the early planning stages (scheme phase). The only example given in the National State of Art Reports is from the United Kingdom (UK-SoA, 7.2). In the case of the A406 East London River Crossing a 9.83 km four-lane road and new bridge over the River Thames was planned. The route bisected Oxleas Wood, a SSSI and ancient woodland. Other possible routes were deemed too costly and the scheme was finally abandoned.

Tunnels are often used in mountainous countries to avoid very sensitive areas where no alternative routes are possible. A cheaper alternative for a tunnel is the 'cut-and-cover' option (*e.g.* A12 Hackney to M11 link, United Kingdom) which conserves land and reduces traffic noise.

Figure 7.4 - The route of the A1 along the lake of Neuchâtel in Switzerland was pushed back into the hillside using an alignment of tunnels, bridges and viaducts so as to avoid or minimise fragmentation. Here the tunnel of Arrissoule. (Photo by Jean Jeker)

An increasingly common strategy for avoiding new fragmentation is the use of existing transport corridors. In The Netherlands, the latest policy documents advocate minimising the construction of new infrastructure through the optimisation of transport capacity within the boundaries of existing infrastructure, *i.e.* avoiding new infrastructure construction or widening by improving the utilisation of the existing network. Examples of these measures include controlled access, rush-hour lanes, dedicated lanes for trucks and dynamic route information panels.

Avoidance criteria

The national criteria used for avoidance are diverse. The Estonian Transportation Development Plan (accepted by the government in March 1999) states the avoidance of fragmentation as an overall goal (EE-SoA, p. 13). In Hungary, no linear infrastructure is allowed to cross strictly protected areas or habitat of strictly protected species (H-SoA, 7.2). In Spain, endangered species also receive particular attention with an aim to avoid the fragmentation of their habitats (E-SoA, 7.2). The Strategy for the conservation of the endangered Iberian lynx (*Lynx pardinus*) is an example that includes the establishment of the obligation to maintain the connectivity between the different nuclei of populations and to restore the ecological corridors between them. In France, nature areas with a high heritage and functional value, extensive rural areas with just one tenant, and regional ecological corridors are avoided wherever possible. In Denmark, the avoidance strategy gives priority to rare and vulnerable species (*i.e.* species on the red data lists), special areas for conservation (EU-habitat areas, protected areas etc.), unregulated river valleys and watercourses, important ecological infrastructure, and dispersal corridors in fragmented areas.

The need to seriously assess alternative routes (and also designs) is becoming more essential, in order to comply with the European Directives and national or regional protection instruments. In the future, it is likely that there will be a reluctance to accept significant impacts unless it can be demonstrated that there are no practical alternatives.

7.3. MITIGATION MEASURES

7.3.1. General approaches, types of measures

There are a wide variety of measures available for mitigating against fragmentation effects. A distinction can be made between measures aimed at reducing the impact on animal populations by reducing traffic-related mortality, and measures directly aimed at reducing fragmentation by providing links between habitats severed by the infrastructure *e.g.* wildlife crossing structures or fauna passages. In practice, the distinction is often not so clear. Fences, for example, are effective at reducing the number of collisions between large mammals and cars, but at the same time they increase the barrier effect. Thus fences can be regarded as a mitigation measure only when implemented in combination with fauna passages that compensate for their potentially negative effects. On the other hand, well-designed underpasses for otters that link their habitat and thus reduce fragmentation can, at the same time, reduce the numbers of animals killed on the road: otters will prefer the underpass to crossing the road at the surface.

Besides these measures aimed at reducing fragmentation directly there are a wide range of measures to mitigate other effects of roads and railway lines. Some countries, in particular The Netherlands, treat measures to reduce disturbance of habitats alongside traffic infrastructure as part of the overall package of measures to reduce habitat fragmentation (NL-SoA, 7.3). However, in some countries disturbance effects, which lead to a loss of habitat quality, are considered as a form of habitat loss, or they are treated together with other emissions such as chemical pollution. For this reason they are often not referred to explicitly in impact assessments. There are no mitigation measures for habitat destruction – this has to be compensated for, if it cannot be avoided.

In the following sections the different measures are treated separately. However, it should be emphasised that a combination of measures will be most effective in mitigating against habitat fragmentation. In fact, many of the case studies of projects mentioned in the national State of the Art Reports include a package of different types of measures.

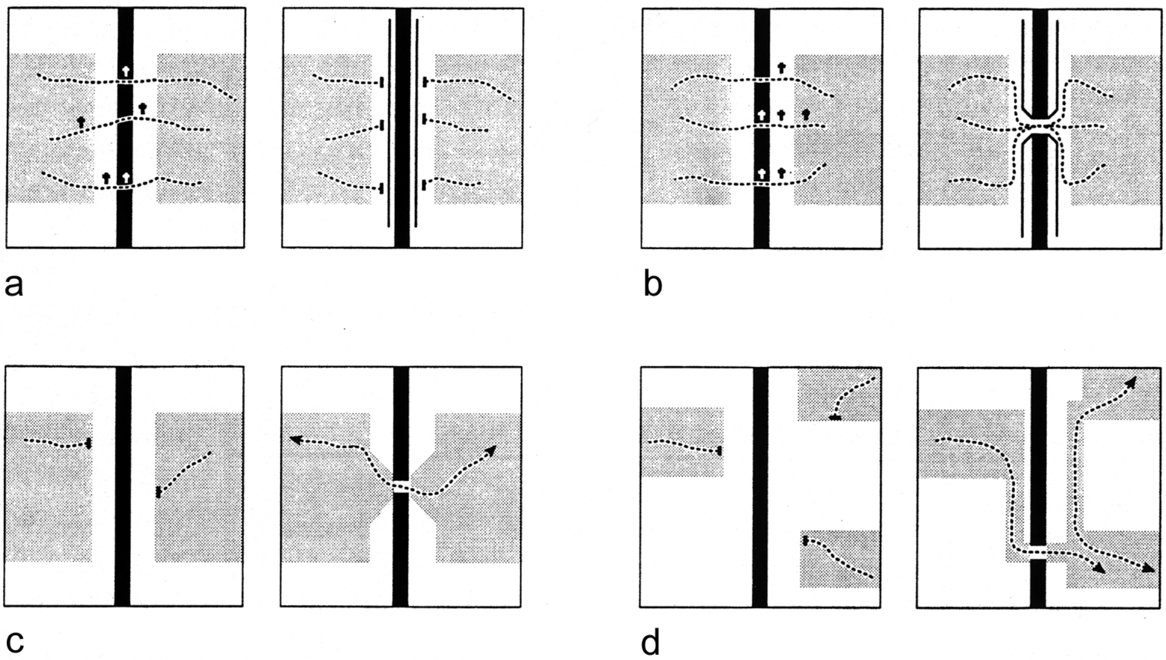

Figure 7.5 - Principles of mitigation measures (Modified after Oord, 1995): a/b: Reduction of mortality: Restriction (due to fencing) of the animal's ability to cross or provision of safer possibilities to cross (fencing combined with passages). c/d: Elimination of the barrier effect by linking isolated habitats (modified road verges with passages across the traffic infrastructure, with or without additional links between habitats on the same side of the road).

The following types of practical measures relating to the principles illustrated in Figure 7.5 are applied in Europe:

1. Elimination/reduction of barrier effects and isolation of habitats:

- Artificial crossing structures built specifically for wildlife e.g. fauna passages
- Modification of structures built for other purposes e.g. adapted culverts, viaducts
- Modification of road surfaces.

2. Measures aimed mainly at reducing mortality:

- Physical barriers e.g. fences, screens
- Artificial deterrents e.g. reflectors, mirrors, smells
- Adaptations of habitat e.g. planting or removing vegetation, guiding structures
- Adaptations of infrastructure e.g. fauna-exits in fences or along canals, modifications of canal banks, markings on transparent noise-barriers
- Reduction of impact from vehicles e.g. speed limits, warning signs, combined systems (e.g. infrared sensors plus warning signs), temporary road closure.

All COST 341 countries apply mitigation measures which are broadly similar in design. However, the standards, approaches and frequency of application of measures varies between countries. In most countries the historical development of measures is similar. Typically, the first measures were taken to reduce conspicuous cases of traffic mortality such as accidents with large mammals and amphibians killed on spawning runs. Thus measures to prevent accidents with mammals were usually the first to be applied, followed by specific projects for amphibians. Only when it was realised that road mortality was not the only issue to be considered and that measures like fences actually increased habitat fragmentation, were other measures introduced and applied.

In the following two sections the different measures are described in more detail. Emphasis is put on fauna passages as they are specifically aimed at reducing habitat fragmentation (other measures often have a different original purpose). It should be noted that in particular projects, different mitigation measures are often combined and in many cases have to be combined in order to achieve the desired effect. Thus, fences are used not only to hinder animals from crossing a motorway but to guide them to an appropriate fauna passage. Measures to reduce disturbance by light or noise, while not eliminating the barrier effect, may have a secondary function in helping to increase the acceptance of a fauna passage by animals.

7.3.2. Measures aimed at reducing the barrier effect

7.3.2.1. Measures specifically designed for wildlife: fauna passages

Knowledge regarding the design and construction of specific crossing structures for wildlife has spread across Europe. Most countries make similar distinctions between different types of fauna passages. Some, like France, The Netherlands and Switzerland, have developed guidelines on design and minimum requirements (SETRA and MATE, 1993; Oord, 1995; Müller and Berthoud, 1997). The implementation of the measures, however, varies widely between countries. With the exception of The Netherlands and France, where a compilation of existing regional inventories is under way, there is no comprehensive register of the number and type of passages built. Therefore, a comparison between countries has to remain qualitative rather than quantitative.

Basically, fauna passages can be grouped into two broad categories: passages under the road or railway line and passages above the infrastructure. Over- and underpasses are often further grouped according to their dimensions, which are linked to the target species involved. An additional distinction is often made between passages designed for the exclusive use of animals, and joint-use passages which are combined with a track or road for humans. The distinction between the two in many cases is fluid, since so-called exclusive passages may also be used by humans. Even if a track is not included in the design, the frequency of human use may be more of an important disturbance factor. So-called wet passages or culverts are usually not designed exclusively for animals, but are constructed at sites where streams have to be crossed. They are discussed in the next section.

Underpasses for small animals, tunnels, pipes

Underpasses for small terrestrial animals consist of concrete or metal pipes or rectangular tunnels with a diameter between *ca.* 0.3 and 2.0 m. They may be built to allow a variety of small animals to cross or be targeted at particular species. Apart from some badger tunnels, the bottom is usually covered with soil (Figure 7.6).

Underpasses for medium-sized and large mammals

Larger underpasses are usually constructed for mammals varying in size from foxes or brown hares *Lepus europaeus* to large species like red deer *Cervus elaphus* or moose *Alces alces*. The recommendations on dimensions vary, but widths of 5 to 12m for smaller species and

25m or more for larger species are common. The height varies as well between *ca.* 3 and 5 m according to the target species. Sometimes a minimum ratio between length, height and width is used to indicate minimum requirements. The bottom of the underpasses is covered with soil. In large underpasses some vegetation may grow, but usually there is not enough light and water available (Figure 7.7).

Figure 7.6 - Underpass for small animals in Germany. (Photo by Verena Keller)

Figure 7.7 - Underpass under a high-speed railway line in France. (Photo by C.E.T.E. de l'Ouest)

Amphibian tunnels

Crossing structures for amphibians have been designed in many countries with the aim of leading toads and frogs safely across roads on their way to and from their spawning grounds. Tunnels usually consist of a system which traps the animals then channels them to the crossing structure. Single-pipe (two-way) crossings have been found to be more effective than double pipe (one-way) systems in the long term for a larger spectrum of amphibians (Grossenbacher, 1985; Ryser, 1988), as they enable the animals to move freely in both directions. The double-pipe system, forcing animals to move in one direction only, is most effective for toad species. Although targeted at amphibians, both types of tunnel are also used by other small terrestrial animals.

Wildlife overpasses

Overpasses for wildlife, often called 'ecoducts' after the term coined in The Netherlands, are basically all types of bridges covered with natural vegetation. They are more common on motorways than railway lines, where overhead power lines may hinder their construction. The width of overpasses varies from *ca.* 8 to 80 m. The funnel-shaped (parabola) design developed in France with a width at its narrowest point of 8 to 15 m has been adopted subsequently in other countries, *e.g.* The Netherlands, Luxembourg, Norway, Sweeden and Switzerland. Broader structures, more common in Germany and Switzerland, are usually only slightly funnel-shaped (Figure 7.8 and Figure 7.9). The vegetation on the bridge is designed to guide the target species, and preferably a variety of other animals as well, across the road or railway line.

Figure 7.8 - Wildlife overpass near Lipník nad Becvou in the Czech Republic. (Photo by Vaclav Hlavac).

Figure 7.9 - Wildlife overpass across a high-speed railway line (TGV Nord) in France, shortly after construction. (Photo by Jean Carsignol/CETE de l'Est).

Target species are often the larger mammal species, and hedges are often planted across the bridge to provide a guiding line, cover and protection from light and noise from the road. Additional lateral screens are also common. Where small vertebrates and invertebrates are concerned, the vegetation is designed to resemble, as far as possible, that adjacent to the bridge to provide a continuous habitat corridor. Overpasses may or may not be combined with a road: agricultural or forestry tracks with limited public access are a common feature on many overpasses.

Landscape bridges

Overpasses with a width of over 100 m are designed to re-establish, as far as possible, the vegetation and landscape structures present prior to infrastructure development. They thus resemble a conventional tunnel bored under a hill. The main difference is that the depth of the soil covering the artificial bridge is significantly less, which can limit the growth of trees in particular. The distinction between wildlife overpasses and landscape bridges is artificial: the only difference lies in their width.

Tree-top passages

Tree-top passages, consisting of a narrow structure built high above the road, are a special type of structure designed for climbing animals such as red squirrels (G.J. Bekker, *pers. comm.*). Such passages have only recently been trialled in Spain and Scotland and further testing is to be carried out in The Netherlands (based on experiences from Japan).

7.3.2.2. Structures adapted for wildlife: combined fauna passages

Combined fauna passages make use of engineering structures that are built for other purposes, *e.g.* for crossing streams or valleys.

Viaducts

Viaducts are a common feature in hilly countries. Where a road or railway line crosses a valley high above ground on a viaduct, the vegetation under the bridge is preserved (Figure 7.10). Well-designed viaducts across rivers allow the riparian ecosystem, including the shores, intact and undisturbed as possible. Animal movement corridors often follow watercourses and these can be preserved without a need for modification as long as the corridor is kept free of obstruction. Viaducts are a possible solution not only for deep valleys but other habitats such as wetlands, in particular those at a lower level than the infrastructure traversing them. In such cases, the construction of a viaduct rather than an embankment preserves the habitat and provides the necessary connection between the habitat on either side of the infrastructure. Such solutions are favourable for invertebrates and small vertebrates but even low viaducts are also accepted by larger mammals. Modifications necessary to ensure animal movement consist mainly of preserving or re-establishing the vegetation underneath the viaduct (perhaps with the addition of further guiding structures), and measures to prevent obstruction or misuse by humans.

Modified road underpasses and bridges

Underpasses can be adapted to facilitate the movement of animals by adding a soil-covered strip of several metres alongside the road. A row of tree stumps or similar natural structures can be added to provide cover and increase the acceptance of the underpass by animals (Figure 7.11). Similarly, a road bridge can provide a crossing opportunity if a narrow vegetated strip is added on one or both sides (Figure 7.12). Such structures, particularly suitable for forestry or agricultural roads with low traffic intensity, can increase the general permeability of the landscape for invertebrates and small terrestrial vertebrates. While some underpasses have been adapted in that way *e.g.* in The Netherlands, bridges with a vegetated strip are less common. If the vegetated strip becomes wider, these under- or overpasses are usually called multi-purpose passages.

Figure 7.10 - A viaduct in England, leaving the natural landscape and vegetation intact. (Photo by Highways Agency, U.K.)

Figure 7.11 - A large modified underpass in The Netherlands, combining a road (behind the screen) and a fauna passage with tree stumps. (Photo by G.J. Bekker)

Figure 7.12 - A multi-purpose overpass combining a forestry road with a vegetated strip, France. (Photo by Jean Carsignol/CETE de l'Est)

River crossings

Viaducts are an obvious solution to leave a river ecosystem intact. However, where a bridge is built across a river or a stream, the movement of terrestrial animals is often hindered because the river is canalised and lacks a suitable bank structutre. The preservation of the natural riverbed allows aquatic animals to move freely. If a bridge opening is widened, *i.e.* the pillars are set back from the riverside, banks covered with soil can be created to provide a habitat which facilitates the movement of terrestrial animals. The wider the bridge opening and the more light reaching the floor, the more likely it is that vegetation will be sustained. This is beneficial for animals such as invertebrates that are unlikely to cross open ground devoid of vegetation (Figure 7.13). Such adaptations are reported mainly from The Netherlands, France, the United Kingdom and Switzerland (NL-SoA, 7.3; F-SoA, 7.3; UK-SoA, 7.3; CH-SoA, 7.3).

Wet culverts

Culverts built to lead small streams or drainage water under roads or railway lines can be designed or improved to function as movement corridors for small animals, both aquatic and terrestrial. Design features such as steps that make a culvert inaccessible for aquatic animals have to be avoided and terrestrial or semi-terrestrial animals need a dry bed on the side of the water. Existing culverts have been improved (modified) by the installation of a ledge that stays dry even at high water level. Such modified culverts are widespread in The Netherlands (NL-SoA, 7.3). So-called eco-culverts are designed from the beginning to fulfil two purposes (water transport and fauna passage): a few can be found in The Netherlands (NL-SoA, 7.3). In other countries, *e.g.* the Czech Republic and the United Kingdom, adapted culverts have been built mainly for otters (CZ-SoA, 7.3; UK-SoA, 7.3).

In countries with a mediterranean climate, drainage culverts are dry most of the time. Where they have a large diameter to cater for torrential rains *e.g.* in Spain (Figure 7.14) or Cyprus, they can be used as passages for small terrestrial animals without much modification (E-SoA, 7.3; CY-SoA 5.1).

Figure 7.13 - A river crossing with vegetated banks allowing the crossing of terrestrial animals, in France. (Photo by Jean Carsignol/CETE de l'Est)

Figure 7.14 - A drainage culvert in Spain, used as a fauna passage. (Photo by Carme Rosell/Minuartia Estudi Ambientals)

7.3.2.3. Other measures to reduce the barrier effect

Where infrastructure poses a physical barrier to the movement of animals and traffic-related mortality is not a major concern, other measures to facilitate fauna crossing can be applied. Only few such measures are reported, but if applied more widely they could have a significant effect.

The width of the tarred surface of a road is a significant factor determining the ability of invertebrates to cross. In Switzerland, a system of building agricultural roads with two narrow concrete strips divided by a vegetated strip has proved to increase the movements of invertebrates and to be beneficial for plants (CH-SoA, 7.3).

Also, in Switzerland, the design of the kerb has been adapted to facilitate the movement of small vertebrates: a sloping border is installed on the vertical kerbstone which allows the animals to climb up. Adaptations of the drainage system and escape ramps for drains reduce the risk of drowning for amphibians and small terrestrial animals and reduce the barrier effect of canals for terrestrial animals (CH-SoA, 7.3).

In northern Sweden, openings are created in fences to allow moose and reindeer to cross. These openings are combined with warning signs and, at some sites, automatic warning lights that indicate the presence of wildlife. Scientific evaluation of this method is still required but it seems likely that this kind of measure could become more widely applied along highways with intermediate or little traffic. Similar openings are also built in Norway. Observations on wolves, which move long distances along fenced highways to opening points, indicate that wide-ranging animals like large carnivores may learn to cross highways at dedicated safe places (J. Karlsson, *pers. comm.*).

7.3.3. Measures aimed at reducing mortality

Fences/Screens

Fences are usually put up to prevent large and medium-sized mammals from venturing onto the road or railway line. They usually consist of a wire mesh fixed to posts with the mesh size decreasing towards the bottom to keep small animals out. In order to prevent animals from passing under the fence, the wire is often dug into the soil.

All countries construct fences along parts of their infrastructure, but fencing is most common where deer, moose or wild boar occur. Fences are most frequently built along motorways, and in recent years have become more commonly associated with high-speed railway (HSR/TGV) lines. In Switzerland and Spain, fences are compulsory along motorways, in Spain this is also the case along HSR lines (CH-SoA, 7.3; E-SoA, 7.3). In France, HSR lines and new motorways are fenced in, whilst older motorways and other roads are only fenced in areas with populations of large mammals, *i.e.* mainly in wooded areas. This principle is also applied in many other countries. In Norway, the use of wildlife fencing is integrated into the road planning system for new roads and fences are added to existing roads with high accident rates or wildlife activity (N-SoA, 7.3). In Sweden, the number of fences is likely to increase, but it is commonly accepted that fences have to be combined with fauna passages (A. Seiler, *pers. comm.*).

The requirements for fence design vary between countries, but most countries have guidelines relating to height, mesh size and the requirement for fixing the fence underground. In general, a height of 2 to 2.5 m is required in areas with red deer or moose (Figure 7.15), with lower heights used in areas with roe deer.

Fences have proven effective for moose and deer in particular, while brown bears (*Ursus arctos)* have been reported to climb over them and badgers or wild boar may easily dig or squeeze under the fences when they are not properly fixed or dug into the ground. When fences are breached in this way or when animals enter a motorway at junctions, the danger is that the animals can get trapped between the fences. In The Netherlands, special exits are inserted in the fences that allow animals to escape (NL-SoA 7.3). Such structures are rare or non-existent in most other countries.

While fences are effective in reducing mortality and preventing accidents with vehicles, they also create a physical barrier for animals. This increases the problem of habitat fragmentation for species for which roads or railway lines are otherwise not a problem. Today awareness is increasing that, when fences are erected, the permeability of the infrastructure has to be maintained by other means, *e.g.* with fauna passages.

Figure 7.15 - Fence for roe deer and wild boar in Switzerland. (Photo by Bjørn Iuell)

Fences are also constructed for amphibians. They are often part of specific systems (*e.g.* Figure 7.16) and were dealt in Section 7.3.2. For amphibians, temporary fences, often consisting of simple plastic sheets, are put up during the spawning season. Toads and frogs are caught in buckets dug into the soil at regular intervals along the fence. In Switzerland, this system is often run by volunteers who carry the trapped animals across the road from where they continue their run to spawning grounds. Temporary fences are also used in Spain, Italy and in France along narrow roads.

Figure 7.16 - Combined fence to keep out large mammals as well as small animals, *e.g.* amphibians (Photo by J. Peymen)

Artificial deterrents

The most commonly applied measure aimed at deterring mammals from crossing roads are reflectors, *e.g.* metal bands put around trees, that are designed to reflect the headlights of approaching cars. The use of reflectors is widespread throughout Europe, although general experience and some studies have shown that they are not very effective (De Molenaar and Henkens, 1998). Recently, deterrent systems using chemical or natural odours applied to a carrying substrate and placed along the road have been developed. The substances work as a repellent for mammals which smell them. Such systems have been installed in Germany, Switzerland and Norway, but so far there is little evidence regarding their effectiveness (CH-SoA, 7.3; N-SoA, 7.3). There have been tests in Sweden using wolf urine and artificial wolf scent to scare ungulates away from roads. Preliminary results suggest that scents do not work at all, because animals soon become habituated (A.Seiler, *pers. comm.*)

Adaptations of the habitat

The vegetation on the road verge or in the central reservation can be used to attract animals or guide them away from the infrastructure. By modifying the vegetation type and structure, the danger of animals being killed can be reduced *e.g.* the planting of hedges has been used to guide terrestrial animals along the infrastructure, often in conjunction with fauna passages. Conversely, vegetation clearance close to the infrastructure has been employed to reduce the attractiveness of the habitat as a foraging area and to improve the visibility of large animals. In Norway (N-SoA, 7.3) mitigation measures are aimed mainly at reducing the number of potentially fatal collisions between cars or trains and moose. Vegetation clearance has been effective in reducing the numbers of accidents and, as a result, reduces the need for fencing.

Tall vegetation can be used to encourage birds to fly up and over the infrastructure at sufficient height to avoid vehicles (Muselet, 1985). Birds are often attracted to road verges or the central reservation by the presence of berry-bearing species *e.g.* holly (*Ilex aquifolium*), especially during the migration period. Avoiding planting of these attractive food plants in the vicinity of the road therefore reduces the risk of collisions. Tree planting has also been proposed in France to create a flight corridor for bats (F-SoA, 7.3).

Adaptations of infrastructure

Few countries report on adaptations of the infrastructure itself to reduce mortality. In The Netherlands, France and Belgium, the risk of animals drowning in artificial waterways has been reduced by creating special fauna-exits or softening the slope of the canal banks (F-SoA, 7.3; NL-SoA 7.3). In The Netherlands and Spain, noise barriers have been constructed to protect natural habitats and breeding birds from noise, but in general, noise barriers are still primarily constructed to protect humans. In recent years, noise barriers or walls along motorways (and less frequently railway lines) are increasingly being designed as transparent screens. The number of bird collisions can be reduced by marking the transparent walls with stripes (Schmid and Sierro, 2000) or with a high density of raptor silhouettes (Fangarezzi *et al.* 1999) and by avoiding the planting of shrubs or trees in the vicinity of transparent barriers. In Switzerland, Italy, Hungary and Slovenia, a few examples of marked noise barriers exist (Figure 7.17), but the technique has, so far, not been widely applied across Europe.

Infrastructure lighting can act as traps for flying animals, particularly invertebrates and as a result, some countries report measures to adapt lighting schemes. In Switzerland and Spain, the use of sodium lamps, directional lighting, and screens are reported to reduce the numbers of casualties (CH-SoA, 7.3; E-SoA, 7.3). In The Netherlands, adapted road lighting is being tested in order to reduce the disturbance effect on wildlife (De Molenaar and Jonkers, 2000).

Figure 7.17 - A transparent noise barrier in Switzerland marked with stripes to reduce collisions of birds. (Photo by H. Schmid)

Reduction of impact from vehicles

Reducing vehicle speed is an effective way of minimising both the frequency and the consequences of collisions for animals and humans. However, speed reduction of a sufficient magnitude to have an effect is difficult to implement, and is inappropriate for infrastructure designed for high traffic speed such as motorways. In The Netherlands, speed reduction is sometimes implemented on minor roads to increase traffic safety and reduce disturbance, with the beneficial effect of increasing safety for animals (NL-SoA 7.3). Wildlife warning signs (*e.g.* Figure 7.18) are widespread but they do not always lead to the desired adaptation in drivers' behaviour since drivers become accustomed to them. In order to increase driver attention to warning signs, several countries have experimented with the use of temporary signs, signs with flashing lights during periods of high danger and the application of seasonal speed limits associated with warning signs. More sophisticated systems have been developed in recent years, including infrared sensors for detecting larger mammals. As animals approach the road, a sensor causes a speed limit signal underneath the wildlife warning sign to flash. Tests in Switzerland and Norway (and to some extent Sweden) showed that this system was effective in reducing the number of collisions with red and roe deer or moose (Amundsen, 1997; Kistler, 1998). So far, these new systems have been installed at only few sites and need further monitoring of their overall costs and effectiveness. Temporary closure of roads, reported from Switzerland and The Netherlands (CH-SoA, 7.3; NL-SoA 7.3), is sometimes used when minor roads are being crossed by amphibians during the spawning season. Sometimes the ban is only imposed on driving at night, when amphibian activity is greatest.

Figure 7.18 - A wildlife (moose) warning sign from Norway. (Photo by Bjørn Iuell)

7.3.4. Implementation of mitigation measures in Europe

The implementation of mitigation measures in Europe varies widely between countries, but in most, measures to reduce mortality are more common than measures aimed at reducing actual fragmentation. The only country with an overall plan to avoid new fragmentation by linear infrastructure and to restore links between already fragmented habitats is The Netherlands (NL-SoA, 7). Elsewhere, mitigation measures are mainly planned and discussed on a project basis and the restoration of links between habitats destroyed previously is an issue which is only starting to be considered *e.g.* in Switzerland, France and Germany.

The differences between countries become clear when considering fauna passages, although a fair comparison is difficult due to a lack of statistics (Table 7-1). Fauna passages are relatively common in The Netherlands, France, Germany and Switzerland (NL-SoA 7.3; F-SoA, 7.3; CH-SoA, 7.3). Tunnels and (adapted) culverts are more widespread and reported from most countries. Measures to reduce accidents with large mammals are most widely applied in northern Europe. The differences in implementation of mitigation measures can only partly be attributed to differences in road density, although the countries where fauna passages have become common all have a dense road network. Northern and eastern European countries with their large unfragmented spaces and low density of transport networks have so far been little concerned with the problem of habitat fragmentation; accordingly, few mitigation measures are reported by them. With the rapid increase in traffic in eastern Europe, mitigation measures along the newly built motorways are becoming more and more of an important issue.

Table 7-1 - Overview of fauna passages constructed across Europe.

Country	General	Over-passes	Under-passes	Dry tunnels	Wet culverts	Treetop overpasses	Amphibian tunnels	Comments
B (Flanders)		+ (1)	+	+	+		++	
CH		++	+	++	++	-	++	
CY			++	++				
CZ	Since 1996, several passages constructed as part of new infrastructure	+	+	+	+	-	++	
DK	60 (mostly small) in Jutland	+ (1)	+	?	?		?	
E	Many adaptations of existing structures	+ 1	+	++	+	+ 1	+	
EE	Some structures planned	-	-	-	-	-	-	
F	350-400 fauna passages overall	++	++	++	++		++	
H	Mainly in new projects	+ 2	+	+	+	-	+	
NL	National roads	+ 4	+ 1	++ >290	+ 8	-	++ c. 80	Also many adapted culverts etc.
	Railways			+ >10	+	-		
	Secondary roads			++ >260		-		
N	30 passages	+	++					
S	Few passages	+	+	+	+	-	+	
UK		+	+	++	++	?	++	

Sources: National State of the Art reports
+ small number built ++ larger number built, regularly constructed in new projects; - none built

Wildlife overpasses have so far been built in relatively small numbers across Europe (Table 7-2). Apart from France, Germany and Switzerland, no country has reported more than ten overpasses. Variation in the width of overpasses is evident when comparing French and German examples: in France most overpasses have a width of 8 to 25 m, whilst in Germany the overpasses are usually larger. In Switzerland and The Netherlands, both narrow and broad overpasses have been constructed.

Table 7-2 - Approximate number and dimensions of wildlife overpasses in COST 341 member countries and/or IENE European participating countries. Only structures with a width of <1000 m built for wildlife built or in construction until 2000. For details see Annex V.

Country	Approximate number of overpasses	Range of widths used	Comments
Austria	27	15 – 600 m, 'game overpasses' 15-70 m	Mostly combined with agricultural roads
Belgium	>4	mainly 3-10 m	
Cyprus	None		
Czech Republic	1	80 m	Not combined with roads
Denmark	1	20 m	
Estonia	None		
France	> 20	mainly 8-15 m	Usually funnel-shaped design, *i.e.* width at entrance larger, with and without agricultural/forestry roads. At least 1 over railway
Germany	26	8-800 m, mainly 25-80 m	With and without agricultural/forestry roads. 1 over railway
Hungary	2	20 m	No roads
Italy	4	60-800 m	
Luxembourg	2-3	*ca.* 20-500 m	
The Netherlands	5	14-50 m	Not combined with roads
Norway	5	17-90 m	Combined with local/forestry roads. Additionally several very narrow overpasses. 1 over railway
Poland	4	*ca.* 5 m	Combined with forestry roads
Portugal	Unknown		
Russia	None		
Slovenia	None		1 planned
Spain	8	10-20 m	
Sweden	1	17 m	Widened bridge for local access road
Switzerland	22	3.5-200 m, mainly 25-100 m	Some combined with agricultural/forestry road, 2 over railway
United Kingdom	4	Unknown	2 over railways

Sources: National State of the Art reports and COST/IENE National Co–ordinators (*pers.comm.*)

7.4. COMPENSATORY MEASURES

7.4.1. What are compensatory measures?

The notion that natural habitats and qualities are subject to continuing loss and degradation due to spatial development has given rise to the introduction of an ecological compensation principle in several European countries, *e.g.* Switzerland, Germany and The Netherlands (see Table 7-3). The compensation principle requires that specified natural values, such as those inherent in wetlands or old-growth forests, should be replaced when they are impacted on by an approved, human intervention. This principle shows a strong analogy with the USA no-net-loss policy for federal wetlands, which prevents the further decline in area and quality of existing wetlands. In practice, compensatory measures are strongly 'surface-oriented', and focus on the loss of habitat or threat to individual species. However, ecological compensation should cover the complete spectrum of impacts, including habitat degradation (*i.e.* where habitat remains intact but is impacted upon) and the loss of functions (*i.e.* where habitat remains intact but is not accessible).

It should be emphasised that ecological compensation is a 'last resort' solution. First principles are that ecological damage should be prevented by sensitive project planning and design. Any residual impacts should then be mitigated as far as possible, but if mitigation is not enough, compensatory measures should be applied in order to reach a 'no-net-loss' situation. European experiences show that compensatory measures are often considered in the planning phase of a project. Problems arise, however, in the implementation phase of a compensation plan. Legal tools for obtaining lands for compensation objectives are weak, so compensatory measures often have to be implemented on a voluntary basis, and rooted in agreements between project developers and landowners or land-users. This is in contrast with the procedure for obtaining land for infrastructure development, which is usually supported by legislation on expropriation. So, whilst highway or railway construction will always be implemented according to the routing decision, realisation of the compensatory measures is surrounded by uncertainty *e.g.* relating to unanticipated secondary development.

Diversity of compensatory measures

Compensatory measures include habitat creation *i.e.* the conversion of land to promote the development of new nature qualities (*e.g.* woods, river beds, etc.) (see Table 7-4). Habitat enhancement may encompass the adaptation of farming practice to benefit the nature qualities desired (*e.g.* meadow-birds or plants). Artificial wetlands (not necessarily ponds) may be created in order to attract species such as amphibians and reptiles, however the created habitat may bear little resemblance to the one impacted upon from the landscape-ecological point of view. Undertaking research (so that compensatory measures could be targeted for the benefit of species) is also sometimes classed as compensation, though this is not considered to be good compensation practice. It is clear that compensation has ambiguous aspects, and 'best practice' regarding implementation of the a compensation principle varies among the countries that have adopted it.

Compensation policy in COST 341 member countries

Examples of compensatory measures associated with highways and implemented as a direct result of the EU Birds and Habitats Directives are not known yet (see Section 7.1). The process of implementing the Directives into the national legislation of the EU Member States is in full progress. In countries where the Directives have already been implemented at the national level, too short a time has passed for experiences on compensatory measures to be critically analysed.

Few countries have developed legislation on ecological compensation or have formulated a compensation policy for sites not covered by the Directives. Switzerland embedded ‘compensatory measures’ in the Nature and Landscape Protection Law (1967) and The Netherlands, Switzerland and Denmark have developed legislation on compensation for forest clearances. According to the respective Forestry Acts, trees that are to be cut for development purposes have to be replanted. Of the three countries mentioned, Switzerland and The Netherlands have implemented a ‘no-net-loss’ principle for impacts on vulnerable areas of national importance. In the Netherlands, a method has been developed for quantifying the number of hectares requiring compensation following infrastructure work (NL-SoA, 7.5).

Five COST 341 member countries have formalised policy on applying compensatory measures: Denmark, Spain, The Netherlands, Switzerland, and the Czech Republic. Three countries have internal guidelines, leading to a regular or irregular application of compensatory measures and six countries do not mention formal policy or internal guidelines (Table 7-3).

Table 7-3 - Formal policy of COST 341 member countries, or internal guidelines on compensating for ecological impacts by highways.

Country	Legislation, formal policy ① or internal guidelines on compensation	Compensatory measures applied
Belgium	—	— (limited)
Cyprus	—	—
Czech Republic	formal policy ③	+ (regular)
Denmark	legislation ②	+ (irregular)
Estonia	—	—
France	internal guidelines	+ (irregular)
Hungary	—	—
Norway	internal guidelines	+ (irregular)
Romania	—	— (limited)
Spain	— ③	+ (irregular)
Sweden	legislation	(limited)
Switzerland	legislation ②⑤	+ (regular)
The Netherlands	legislation ②; formal policy ④	+ (regular)
United Kingdom	internal guidelines	+ (regular)

Source: National State of the Art reports
—: not formulated/applied; +: formulated/applied
① formal policy is defined here as regional or national compensation policy that is laid down in formal documents such as Policy (Action) Plans; it may not be embedded in legislation, but forces the regional or national governments to implement (compensatory) measures.
② for forest clearances (Forestry Act)
③ international guidelines applied (EU Habitats Directive)
④ for impacts on vulnerable areas of national importance
⑤ for impacts on landscapes, sites and natural monuments of national importance

7.4.2. Overview of compensatory measures in COST 341 member countries

A general overview of the compensatory measures applied in the COST 341 member countries is given in Table 7-4. The process of planning or implementing compensatory measures began in the mid-1980s and applications are growing. Experiences so far indicate that compensatory measures include a broad range of measures:

- creation of new habitat, by land conversion (e.g. farm land into forested land);
- enhancement of habitats formerly degraded by past development (e.g. by restoring soil or hydrological conditions or applying a management regime to the land), thus facilitating the development of specific nature qualities;
- activities that accompany the development and/or the physical compensation (e.g. the installation of environmental education areas and the translocation of the species negatively impacted upon).

In Switzerland and The Netherlands, experiences are growing regarding the monetary compensation costs relating to acquisition, design and management of the compensation areas (Kägi *et al.,* 2002). However, the few examples do not allow more generalised conclusions to be drawn other than in very broad terms: per project compensatory measures have been estimated to cost up to 2% of the total project budget.

Table 7-4 - Compensatory measures associated with infrastructure and applied by some of the COST 341 member countries.

Country	General principles on compensatory measures	Specific projects with compensatory measures
CZ	Construction of amphibian pools (several hundred constructed on an annual basis)	Projects not specified
DK	Digging ponds; planting new forest and; planting of shrubs bearing fruit and berries to replace woodland edges	Projects not specified
F		*Normandy bridge*: on-site creation of a tidal reservoir, introduction of grazing, and information for the public *A29*: introduction of grazing on a 11 ha wetland site *A39*: 24 ha wetland restored *A585/A51*: restoration of groundwater level by creating a new channel (planned) *A31*: creation of a 15 ha ecological site, adjacent to the road (planned)
NL	Compensation generally encompasses development of new habitat or enhancing existing habitat	Compensation introduced in planning phase of 25 highway projects (requiring 1,300 ha of new habitat to be developed) – 3 compensation plans for highway projects in operation; Compensation applied to 4 rail projects (including compensation via tunnel contruction for several kilometers and physical compensation of 200 ha through habitat enhancement)
N	Construction of a new river bed in order to provide good fish habitat	Projects not specified
RO	Compensatory measures for reconstruction of new habitat area	Projects not specified

(Cont'd…)

Country	General principles on compensatory measures	Specific projects with compensatory measures
		(…Cont'd)
E	Compensation is applied where infrastructure affects Special Protection Areas (SPAs) for birds and sites proposed for inclusion in the Natura 2000 network through application of the Habitats Directive (SACs). Most compensatory measures currently being applied or proposed consist of the creation of new habitats or the improvement and legal protection of existing ones, especially steppe habitats for birds, riparian forests, gravel pits, ponds, priority habitats, etc. Recovery plans are also implemented and measures are applied to recover local populations of endangered species. Such measures sometimes consist of diminishing existing impacts (burying existing power lines underground to reduce electrocutions for birds, elimination of uncontrolled waste dumping, etc).	There are 16 projects being developed at present which (will) involve compensa-tory measures. In most of these the measures consist of the acquisition and/or restoration of habitats (mostly steppe and riparian habitats, cork oak woodland), and/or measures designed to strengthen the populations of threatened species affected by the infrastructure (*e.g.* lesser kestrel, great bustard, little bustard, sandgrouse, Bonelli's eagle, Spanish imperial eagle, otter). Noteworthy projects: *M-50 (Stretch 1, Madrid)*: Acquisition of 300 ha of alternative habitat for the lesser kestrel; Construction of new building for nesting and relocation of affected lesser kestrel colony; restoration of riparian habitat. *M-50 motorway (Stretch 2, Madrid):* Burying of high voltage power lines to reduce mortality of steppe birds such as the great bustard. *R-3 motorway (Madrid):* Increase in the surface area protected by the existing Special Protection Area for birds equivalent to the area of lost habitat; habitat restoration and improvement; population monitoring. *A-381 motorway (Andalusia):* Habitat improvement for the otter; development of conservation plans for raptors; habitat restoration programmes; translocating of affected species. *Llobregat railway link (Catalonia):* Acquisition and restoration of habitats; restoration of gravel pits; restoration of riparian vegetation; increase in surface area of existing wetlands areas by 2.5 ha.
CH	Compensation aiming (1) to ensure the preservation of regional biodiversity, (2) to re-establish ecosystems of the same biological value, (3) to regenerate natural mechanisms for the regulation of natural habitats and species, and (4) to restore the links between natural habitats; restoration of degraded habitats reopening of streams that have been canalised underground; recreation of hedgerows systems or networks of wetlands with new ponds; and restoring rivers beds	*A16 Jura*: development of compensation sites (125 ha) in mountainous habitat *A6 Courfaivre*: creation of a 10.5 ha network of hedgerows and copses *West Porrentruy*: establishment of wintering grounds besides present spawning sites, creating ponds *Strada Bypass*: re-establishment of the dynamics of the alluvial sites by reshaping a river bed (30 ha) *Railway Line Zurich*: substitution habitats for various species
		(Cont'd…)

Country	General principles on compensatory measures	Specific projects with compensatory measures
		(…Cont'd)
UK ①	Creation of breeding ponds for translocated amphibians; woodland plantation and supplementary feeding for dormice while planting reached maturity; woodland translocation; road verges sown with wildflower mix; earth worms inoculated to enhance drainage, aeration and structure of soil; translocation of dormice; habitat management of woodlands and hedgerows to provide vegetation 'linkages' between (dormouse) habitats	Projects not specified

Source: National State of the Art reports
① also (sometimes) referred to as 'mitigation'

Gaps in knowledge

As experiences are evolving in this field, gaps in knowledge are associated with basic principles and processes *e.g.* the realisation of 'no-net-loss', but specifically further work is required on establishing:

- A clear decision-making procedure that ensures projects follow the sequence of avoiding, mitigating, and in the last resort compensating for adverse ecological impacts.
- A standardised method for identifying where mitigation and compensatory measures are required. At present the methods applied show considerable variation between and within countries in terms of the impacts that warrant the consideration of ecological compensation, the way compensatory measures are calculated, and the detail with which measures are described.
- A standardised method for estimating compensation costs, in order that realistically priced compensation plans can be prepared.
- The feasibility of reaching no-net-loss, specifically for ecological qualities that require a long time or specific circumstances (e.g. maturation, hydrology) to develop.

7.5. EXISTING STANDARDS FOR MEASURES: JUSTIFICATION AND MINIMUM REQUIREMENTS

Mitigation measures involving animals and infrastructure form a relatively new field of knowledge combining civil engineering and ecology. Designs are largely based upon existing knowledge and experience within civil engineering but developed further utilising knowledge of ecological principles (as described in Chapter 2). Many questions are being raised regarding, for example, the dimensions of wildlife overpasses, the 'relative openness' of an underpass, the number of passages required and the combination of measures necessary in order to create or maintain the functioning of a specific connecting passage (Clevenger, 1998). Designs vary between countries, partly due to different traditions and partly due to different ecological conditions. The relative newness of the subject explains why only a few formal quality standards have been formulated so far. The first few measures were built in the 1970s in France (Bernard *et al.*, 1987) and The Netherlands (Bekker and Canters, 1997). In the 1980s the number of countries where passages were built was slowly increasing but the process was hindered by the lack of experience with design, construction and maintenance of provisions for animals (UK-SoA, 7.5). Moreover, only a small number of evaluations have been carried out on the effectiveness of the provisions by the target species (Pfister *et al.*, 1997; Van der Linden, 1997; Rosell *et al.*, 1997; Veenbaas and Brandjes, 1999; H-SoA, 7.5). There is almost a complete lack of insight into the effects of measures at the population level. Based on the early experiences and evaluations, designs can be improved and well-balanced standards can be formulated.

All sorts of books, manuals, course books and brochures provide the background to the problems and possible solutions to habitat fragmentation, based on the knowledge available. The most important ones are listed in the COST 341 European Handbook '*Wildlife and Traffic – A European Handbook for identifying conflicts and designing solutions*'. Reviews and/or manuals concerning mitigation designs are available in various countries (DK-SoA, 7; F-SoA, 7; NL-SoA, 7; S-SoA, 7; CH-SoA, 7; UK-SoA, 7.5), showing which measures and which types of passages are suitable for the various species. These reviews help to identify the most suitable solutions. Technical descriptions to augment these practical aids are only available in Switzerland (CH-SoA, 7), France (F-SoA, 7) and The Netherlands (NL-SoA, 7). Guidelines and information (from examples to more general rules of thumb) have also been published in Austria, Norway, The Netherlands and Sweden, although their status is often neither official nor mandatory. In the Czech Republic the Ministry of the Environment is preparing guidelines for the creation of multifunctional culverts (CZ-SoA, 7.5). This is based on ecological data relating to several species and on technical demands.

Denmark has designated, as standard, a number of primary rules of thumb for subterranean passages that are already in use in a number of countries. These involve the minimum sizes and specific design for ungulates (deer), riparian species and fish (DK-SoA, 7.5). The Danish approach to these problems identifies a clear link between de-fragmentation for the environment and de-fragmentation for the recreational movement of humans. There are no guidelines in Hungary (H-SoA, 7.5).

In Norway and Sweden, guidelines have been developed for preventing collisions between vehicles and animals (N-SoA, 7.5, S-SoA, 7). Requirements have also been formulated in most countries for fences in relation to the types of animals involved. UK guidance on a number of aspects of road design (alignment, planting etc.) identifies features which are beneficial for nature and the landscape but suggestions are mainly qualitative (UK-SoA, 7.5.2). In Estonia (EE-SoA) actions are partly directed towards counteracting fragmentation, but there are no formal standards.

The first manual in The Netherlands to deal with habitat fragmentation also involves a general approach for finding the right design on the basis of an analysis of the surroundings, making use of setting priorities (Oord, 1995). Evaluation and maintenance aspects are also considered from the very beginning. As a result of this methodological approach, all aspects of the process are covered systematically. At the same time a checklist of the Directorate-General for Public Works and Water Management of The Netherlands is in use for transforming ordinary road bridges into 'ecological bridges'.

In Austria checklists are also employed to identify those aspects that are (or could be) involved and which information has to be documented when planning, renewing and maintaining linear infrastructure. In Austria standards have been formulated relating to the collection and assessment of information about game animals and their habitats, as well as for deducing necessary mitigation measures (Völk *et al.*, 2001).

In Switzerland the ‘Departement of Environment, Transportation, Energy and Communication’ published standards on the width of wildlife overpasses for roads receiving federal subsidies in 2002 (M. Trocmé, *pers. comm.*). The standard width has been established as between 40 and 50 m, with exceptions (larger or narrower) possible according to individual circumstances.

In Spain there are no universal standards or minimum requirements for avoidance, mitigation or compensatory measures. Each road project has an Environmental Impact Declaration (EID), often published by the autonomous communities; the measures in these EID’s are obligatory (E-SoA, 7.5). Many measures are based on the recommendations of environmentalists.

Most measures to mitigate habitat fragmentation are realised during the construction phase of roads or railways. Work in all the countries concerned is undertaken in co-operation with the EIA. Many procedural aspects involved (described in detail earlier) are based upon the legislative requirement. The process itself contains possibilities for including de-fragmentation measures and the justification for realising measures is based on an EIA in many countries. In Spain, the EID contains the minimum mitigating measures required for each project and it is mandatory to carry these out. In the Netherlands, many fauna passages have also been constructed within the framework of retrospective maintenance; this programme is based on the official policy of the government (Piepers, 2001).

Existing guidelines relating to road design, management and maintenance sometimes pay attention to aspects of nature and the landscape. Such guidelines give a general summary of the possible solutions and seem to be the most suitable starting point for attaining the systematic treatment of the problems of fragmentation

7.6. MAINTENANCE ASPECTS

The maintenance aspects of transportation infrastructure and its surroundings has a long tradition in all European countries. However, maintenance was formerly carried out mainly to ensure traffic safety and prevent the deterioration of the infrastructure. This applied both to the technical installations of the infrastructure itself, and also to the verges of roads, railway lines and canals. Increasingly, the potential value for nature has been taken into consideration, which has resulted in a wide variety of recommendations. The emphasis given to verge management is reflected in the national State of the Art reports, where little is said on other issues regarding maintenance. Maintenance aspects, however, also play an important role in ensuring the functioning of measures installed to mitigate against habitat fragmentation. Although this has been increasingly recognised in most countries, maintenance has been identified as an issue where a lot of work still needs to be done. Often, maintenance aspects are not considered sufficiently early enough, *i.e.* when the infrastructure and the specific mitigation or compensation measures are being planned.

7.6.1. Verge management

7.6.1.1. Management strategies

Traffic safety and the technical function of the road or railway have always been the main aim of verge management. Trees are thus pruned and shrubs removed so as to ensure optical visibility along the road. Vegetation is managed to prevent erosion on steep slopes and ditches are cleared to facilitate effective drainage of the structure.

Although traffic safety and technical functions remain a priority, there has been a shift in many countries towards integrating biodiversity objectives into the verge management schemes. Some countries have adopted ecological principles for verge management. An example can be given from Switzerland, where priority is given to nature conservation aspects in the maintenance strategy (CH-SoA, 7.6). In The Netherlands, the ‘Directorate-General for Public Works and Water Management‘ bases its management of nature along the main roads on ecological principles (NL-SoA, 8). In France, the 'South of France Motorways' company has set an objective to maintain verges with the aim of protecting and conserving nature. This is achieved by reducing the mown area, performing mechanical interventions during periods which are least detrimental to fauna, and reducing the use of chemicals for weed and insect control. This ecologically adapted maintenance system is gaining ground in other French motorway companies, as well as the State services (F-SoA, 7.6).

The way maintenance plans are designed and implemented plays a key role. Well-performed maintenance operations founded on ecological principles are an efficient tool for promoting biodiversity, whilst poorly executed activitied can impoverish the environment.

Some countries have recognised a potential conflict in the goals of verge management. Increasing biodiversity, especially in a homogeneous landscape, can be considered beneficial, however, the road verge can be made too attractive to animals, which increases not only animal traffic mortality but also decreases traffic safety. This question has been raised in Switzerland (CH-SoA, 7.6), among other countries, and is particularly relevant for birds of prey.

Verges can be ecologically managed to be optimised either for their habitat value or corridor function. Most countries where verge maintenance is ecologically adapted seem to give priority to the habitat function of the verge (Figures 7.19 and 7.20). In some cases, however, management is primarily concerned with preventing the potentially negative aspects related to road verges, *e.g.* in Spain, where specific legislation requires measures to be geared at preventing the spread of fires that often originate from road users (C. Rosell, *pers. comm.*).

Figure 7.19 - Verges along roads are often rich in biodiversity and can promote wildlife movement. Prestekrage, Norway. (Photo by Inger Auestad)

Figure 7.20 - Verges of the new railway line along the north shore of lake of Neuchâtel (Switzerland) were seeded as dry grasslands and niches for reptiles were made. (Photo by Marguerite Trocmé)

7.6.1.2. Management activities

Trees and shrubs

Trees are pruned when necessary from a traffic-safety point of view *i.e.* to maintain visibility for the driver. In many regions, tree-linned roads are a conspicuous landscape feature of special importance because of their biological, cultural, historical and scenic values. Despite these values, traffic safety adds further special demands on the maintenance of tree-linned roads. In dry Mediterranean countries such as Spain, the choice of species planted on road and railway verges must take drought hardiness, soil erosion and the likelihood of forest fires into consideration (E-SoA, 7.6).

Grassy vegetation

Verge mowing is generally performed at least once annually, but fast growth of grass and herb vegetation will make repeated mowing necessary (UK-SoA, 7.6). In recent years, increasing emphasis has been given to the importance of the timing of mowing operations. Both plant seeding periods and the annual activity cycle of animals are to be considered when planning maintenance activities. It is often recommended that mowing be undertaken in July or later (but not past October) to allow seeds to be shed (CH-SoA, 7.6; UK-SoA, 7.6).

Removing the grass cuttings is an effective means of reducing the fertility of nutrient-rich soils and thereby enhancing the conditions for biodiversity to increase (CH-SoA, 7.6; N-SoA, 7.6; Sjölund *et al.*, 1999). This is common practice in The Netherlands and in Flanders (NL-SoA, 8; B-SoA, 7.6). To speed up nutrient depletion, mowing and subsequent grass removal can be repeated later in the autumn. Unless restricted by its heavy-metal content, grass cuttings can be used for purposes such as composting (as practiced in Switzerland, CH-SoA, 7.6).

Methods other than mowing to maintain grassy vegetation are rare. In France, trials have been undertaken on grazing with sheep and horses (F-SoA, 7.6). In Norway and Sweden, trials are being performed using mixes of seeds of local origin when new verges are established (N-SoA, 7.6; Sjölund *et al.*, 1999).

Chemical applications are still in use as part of road-verge maintenance in France, the United Kingdom and to some extent Denmark but herbicides as well as other pesticides are banned in road maintenance in Sweden and Switzerland. For railway verge maintenance, herbicides are still widely in use, *e.g.* in Norway and Sweden. Bringing the use of chemical pesticides to an end is an aim of the maintenance strategy in The Netherlands and in Flanders (B-SoA, 7.6; CH-SoA, 7.6; DK-SoA, 7.6; F-SoA, 7.6; N-SoA, 7.6; NL-SoA, 8; UK-SoA, 7.6; Folkeson, 2000).

Ditches

Ditches are cleared and deepened when necessary in order to retain their draining function. Removing the vegetation and its substrate can diminish the likelihood of threatened plant or animal species surviving there, however, saving at least patches of vegetation may facilitate re-establishment and may at the same time reduce the risk of soil erosion. In The Netherlands, ditch maintenance strategies consider not only the water management aspects but also the ecological functions (NL-SoA, 8).

7.6.2. Management of other surfaces

Fauna passages

Maintenance considerations should be thoroughly integrated in the planning and design phases of fauna passages and also by the road operator in the programming of their activities. Insufficient regard to the practical aspects of maintenance may create unexpected problems later on. Experience from the repair of a French wildlife overpass points to the importance of paying particular attention to the seal and drainage system of the structure, especially where the overpass is to be covered with vegetation (F-SoA, 7.6). The vegetation has to be maintained in a condition that is optimal for the target species and at the same time not detrimental to the technical functioning of the bridge. Badger tunnels and similar structures for mammals must be regularly inspected and kept free of obstructions (NL-SoA, 8; UK-SoA, 7.6).

Culverts and tunnels

To retain their flow capacity, water culverts are cleared of vegetation and debris. This is carried out regularly in some countries but in others only when needed. In northern Sweden, salt is occasionally used as a de-icing agent in culvert entrances to reduce the risk of flooding resulting from the culvert being clogged by ice (S-SoA, 7.6).

Fences

Any breach in a fence negates its effectiveness. Fences need to be inspected regularly and repaired when necessary to retain their function. The recommended inspection intervals differ between countries (NL-SoA, 8; UK-SoA, 7.6).

Waterways

Dutch waterway banks are maintained so as to integrate the infrastructure into the surrounding environment. The maintenance includes dredging mud, mowing vegetation and maintaining the function of fauna exits. Dredging and cleaning is often performed in the autumn when fish are inactive but still able to escape. Mowing grassy vegetation usually takes place once annually, in autumn. Maintenance problems include the cost of removing the mown grass and finding places suitable for the disposal of dredge spoils that are often polluted (NL-SoA, 8). In the United Kingdom, waterways are operated and maintained according to standards reflecting the intensity of use. To ensure maintenance compliance with environmental and recreational obligations, British Waterways issues and follows an Environmental Code of Practice and a Biodiversity Action Plan (UK-SoA, 7.6).

7.6.3. Responsibility and financing

The responsibility for the maintenance of roads, railway lines, canals and their associated features differs between European countries. In many countries, verges and other green areas of highway land are managed by the road-operator. Road-operators may be the state (as in Sweden, the Czech Republic, Spain and, for national roads, The Netherlands) or private companies (as in France). In Spain, motorways are maintained for the first 20 to 30 years after construction by the (private) motorway company in question but after that period, the maintenance responsibility is taken over by the Roads Administration. Other Spanish roads are maintained by the Ministry of Transport (CZ-SoA, 6.7; E-SoA, 7.6; F-SoA, 7.6; NL-SoA, 8; S-SoA, 7.6).

In many countries, the management is subject to competition and is performed either by a branch of the road administration or by a private company. This is the case in, *e.g.* France, the United Kingdom, Sweden and The Netherlands (Faith-Ell, 2000; F-SoA, 7.6; NL-SoA, 8; UK-SoA, 7.6). Environmental requirements are currently included in the procurement of road maintenance in the Swedish National Road Administration (Faith-Ell, 2000).

Railway verges are managed by the railway company itself in many countries, including The Netherlands and Sweden (NL-SoA, 8). Maintenance was opened up to open procurement in Sweden in 2001 (Banverket 2001). In The Netherlands, the Railways Infrastructure Management Board tries to organise the harmonisation of adjacent landuse by means of landscape plans drawn up with other interested parties (NL-SoA, 8). In France and in the United Kingdom, the maintenance of off-site areas is ensured by a nature conservation association (F-SoA, 7.6; UK-SoA, 7.6). In Switzerland, the maintenance of compensation areas can be handed over to cantonal authorities, environmental protection groups, specialised maintenance associations or the original landowner (CH-SoA, 7.6).

The responsibility for the management of the four Dutch wildlife overpasses (ecoducts) is shared between the road manager who cares for the technical functioning and a nature-conservation organisation which cares for the green space and the immediate surroundings. The experience from this dual responsibility is positive (NL-SoA, 8). In France, the management of fauna passages is often entrusted to County Hunting Federations, and biologists are seldom involved. Management and monitoring agreements may vary in duration from 1 to 10 years (F-SoA, 7.6).

In The Netherlands, the Directorate-General for Public Works and Water Management usually hands the maintenance of inland waterways over to specialised contractors (NL-SoA, 8).

Communication between the designer, contractor, manager and maintainer of green areas is often considered to be a crucial factor for effective management (F-SoA, 7.6; UK-SoA, 7.6). It is, for example, important to establish a common understanding of why a mitigation measure has to be managed in a certain way in order to reach the ecological goals set for it at the outset.

In the planning of measures, the cost of maintenance is an important issue to be considered. The expenditure of routine maintenance such as grass cutting has been estimated at 12 to 15% of the highway budget in the United Kingdom (Atkinson, 1997). According to French experience, the cost of maintenance of off-site compensation areas may vary considerably between seemingly similar measures. The cost of operating a French footpath over a motorway was found to exceed the cost of construction after 20 years (F-SoA, 7.6).

7.7. Evaluation and monitoring of the effectiveness of measures

7.7.1. What is effectiveness?

Almost in every new transportation infrastructure, a lot of time and money is spent on the design and implementation of measures with the aim of avoiding, mitigating and compensating barrier effect, fauna casualties, and other effects related to habitat fragmentation . Nevertheless, the evaluation of the effectiveness of these measures is often not considered to be a priority, although more recently the amount of attention paid to this subject is increasing significantly.

Analysing the effectiveness of the measures is a key element in mitigation schemes because it provides valuable information for the planning and design criteria of future infrastructure. Monitoring data provides a critical baseline against which the cost-effectiveness of measures can be determined. By utilising this information, unnecessary efforts in the implementation of measures that will not accomplish the fixed objectives can be avoided. The application of monitoring and evaluation schemes in the long run will make environmental prediction more efficient and reliable and it will improve the efficacy of ecological mitigation (Hollick, 1981).

But what is meant by effectiveness? And what are the criteria currently applied in Europe for measuring the degree of effectiveness of measures? To evaluate the effectiveness of measures, monitoring schemes must be implemented to determine whether or not the measures fulfil the purpose for which they were planned. Monitoring is defined as the regular examination and recording of phenomena and, in this case, measurable parameters for analysing whether the fragmentation of habitats caused by infrastructure development has been mitigated or not must be identified. However, a difficulty appears in the procedures applied at present in European countries because of the lack of common standards and clearly stated aims for the measures applied (see Section 7.7.2). The lack of standards, similar to those that exist for evaluating water or air quality, for example, makes the interpretation of results obtained from monitoring procedures highly subjective. As a result, it is often difficult to establish if the measures are really effective or not. Biological diversity indicators, in particular those focused on measuring the degree of habitat fragmentation, are required as a first step towards the development of standards that will allow for better interpretation of monitoring results. In turn this will permit more accurate evaluation of the effectiveness of measures.

In general, road and environment administrations within Europe still focus their evaluation on the monitoring of individual measures. This is most common for fauna passages, and less frequently to measure the utility of fences and other systems for reducing fauna casualties (see Table 7-5). Fauna passages (including all kinds of adapted culverts, under– and overpasses, green bridges, etc.) are considered effective when the target species for which they were designed uses them. However, there is often no information gathered about their demographic implications and their effectiveness in linking sub-populations. In most cases it is not possible to assess whether many different individuals are using the passage, or if there is a selective use, for example, by resident as opposed to dispersing individuals.

The same problem is observed in the evaluation of the effectiveness of fences. Inventories of road casualties usually provide data about the number of animals killed on roads, but no references are made to the population levels of these species or the effects the road has upon them. A new approach is needed, at least in extensive monitoring programmes that are geared towards obtaining general information about the effectiveness of a specific kind of measure, to gather information at a population level.

Table 7-5 - Objectives and parameters currently used in the monitoring of mitigation measures.

Measures	Objective	Parameters used
Fauna passages	To evaluate if the structure is correctly constructed and located	Number of species that are using the passage; Usage by the target species
Measures to avoid fauna casualties	To evaluate if the structure is correctly installed and located	Number of collisions recorded in the protected stretch; Percentage of casualty reduction (if the measure is applied in an existing infrastructure)
Restoration of affected areas (usually ponds or marshes)	To evaluate if the new habitat is being used by the target species	Number of species and composition of the new communities; Presence of the target species

Source: National State of the Art reports

Comprehensive monitoring programmes are being developed in many countries. In Spain (see Box 7.1) some recommendations have been produced based on the proposal of Noss (1990) but they are not yet applied. Such programmes enable effectiveness to be evaluated more robustly and clearly than individual, uncoordinated surveys. They also avoid the risk of accumulating a large amount of data that is difficult to interpret and will not lead to any immediate or useful conclusions (Landres *et al.*, 1988).

Box 7.1 - Recommended basis for monitoring programmes to evaluate the effectiveness of measures in Spain

The design of a monitoring programme to evaluate the effectiveness of the measures taken to prevent, mitigate and compensate the effects of an infrastructure on habitat fragmentation must include:

- An overall consideration of all the measures applied;
- A clear definition of the objectives of the measures;
- A choice of target species or habitats and formulation of specific hypothesis at the outset;
- The establishment of indicators and standards for measuring success of the measures;
- A protocol for monitoring, including a description of the methodology for recording information and the frequency of measurement. Methods must be clearly defined, systematic and as standardised as possible;
- A statement of the procedure for storing and analysing the information obtained from the monitoring and for evaluating the effectiveness of the measures based on the fixed criteria and standards;
- A description of the procedure for disseminating the information, ensuring accessibility to all stakeholders.

It is also fundamental to record sufficient information about the different variables that can influence the effectiveness of the measures, *e.g.* their dimensions, characteristics and landscape features. This will allow for a multivariate analysis of the information that not only helps to determine the effectiveness of a measure, but also what factors are responsible for that level of effectiveness.

7.7.2. Procedures and minimum requirements for the evaluation of measures

At present, few European countries apply an obligatory monitoring programme to all the mitigation measures constructed or installed as part of transportation infrastructure projects (see Table 7-6). In France there is a compulsory procedure for such monitoring and evaluation based on the Law on Guidelines of Domestic Transportation, March 1999 (F-SoA, 5.4.6). Similarly, in Portugal a new law, the Decret Law 69/2000, May 2000, has established the obligatory application of a procedure, as a part of the EIA process, for evaluation of mitigation measures associated with any new transportation infrastructure (Marcolino, 2001). In Spain, legislation (the Real Decret Law 1302/1986 modified by the Real Decret Law 9/2000) establishes the obligation to apply an Environmental Vigilance Plan when a new infrastructure project is finished, but this is not always carried out. A new procedure including a three year monitoring period has been proposed by the Ministry of Public Works for evaluating the mitigation measures constructed on all the new roads and railways within the State Network (E-SoA, 4.4).

Even without formal programmes, in many countries the evaluation of measures has become common practice. In Switzerland, for example, the monitoring of measures to verify their effectiveness has become a standard procedure. In France, it is usual to carry out monitoring, at least on the most important or innovative mitigation measures, and in The Netherlands systematic evaluation is applied on passages along waterways and also on many roads and railways. In Norway monitoring has become a priority, mainly because of collisions with large game species which pose a serious problem in terms of traffic safety. In many other countries the evaluation of the effectiveness of measures is only applied in exceptional cases, usually on fauna passages, due to the initiative of research centres, universities and less frequently, by administrations or public companies who are responsible for the construction and maintenance of measures.

Some European countries are also carrying out or developing general biodiversity monitoring programmes designed to evaluate changes in types of landuse and ecosystems. However, specific attention has not been given in these programmes regarding the evaluation of measures applied to avoid habitat fragmentation caused by transportation infrastructure.

A gap worth highlighting is the lack of systematic inventories of existing measures. This is a basic requirement for identifying what kind of measures are being applied, where these are located and what their objectives are. Compiling an inventory is the first step in defining what has been done and in deciding what type of measures need monitoring (either because they are widely used perhaps with uncertainties about their effectiveness, or for other reasons). Some countries have carried out exhaustive inventories of some measures *e.g.* in France a national inventory of fauna passages was produced in 1991 (and is currently being updated) (F-SoA, 7.7.1). A compilation of measures has also been elaborated in Scotland (UK-SoA, 7.7.2) and The Netherlands (NL-SoA, 8.3) and a so-called ‘Inventory of Wildlife Crossings’ is currently being compiled in Switzerland (CH-SoA, 7.3). Other countries do not report on the existence of such inventories, or they have only just begun to collect the data, some, for example Spain, as a task undertaken within the framework of the COST 341.

Table 7-6 - Standards and obligatory schemes in monitoring practice.

Country	Compulsory procedures?	Standards
Belgium	No	
Czech Republic	No	
Denmark	No	
Estonia	No	
France	Yes	Law on Guidelines of Domestic Transportation, March 1999
Hungary	No	
The Netherlands	No – monitoring is a usual practice. Systematic evaluation of fauna passages is being applied	
Norway	No – monitoring is currently a priority subject	
Portugal	Yes	Law DL 69/2000, May 2000
Spain	Yes	RDL 9/2000, October 2000
Sweden	No	
Switzerland	No – but verification of the effectiveness of measures is usual practice	
United Kingdom	No - such monitoring of applied measures is carried out as well as the monitoring of evaluation schemes, affected populations and sites.	

Source: National State of the Art reports
DL: Decret Law; RDL: Real Decret Law

The lack of evaluation of the measures applied to prevent, mitigate or compensate for the fragmentation of habitats caused by transportation infrastructure in different countries mirrors deficiencies in EU Directive (97/11/EC). This instrument includes no requirement for monitoring or evaluating measures and further review of, and amendment to, the Directive is necessary to take into account the value of, and need for, post-project monitoring.

7.7.3. Organisations involved in the evaluation of measures

Important differences are observed between European countries in terms of the organisations involved in the evaluation of measures. In some countries, such as France, The Netherlands and Switzerland, where the evaluation of measures is common or almost a standard procedure, monitoring and assessment is promoted or directly carried out by the public administrations responsible for the infrastructure. In other countries, where the evaluation of the effectiveness is only applied for certain infrastructure or specific measures, research centres, Non-Governmental Organisations (NGOs) or other entities are more often involved in this matter, financed by public administrations, private or public foundations or other organisations.

In countries like The Netherlands, Switzerland and the United Kingdom, conservation organisations and wildlife trusts are often involved in the maintenance and monitoring of measures, and volunteers are especially active in the monitoring of fauna casualties. In regions where hunting is an important and traditional activity (*e.g.* Hungary and France), hunters are also involved in the monitoring of measures. Usually, the co-operation of hunters is restricted to the recording of fauna casualties or the use of big-game passages. In some cases the data provided by the monitoring procedures carried out by volunteers is used to evaluate the effectiveness of measures. In some other cases, research organisations or technical departments of the administrations analysing the data carry out the recording and evaluation.

Awareness about the importance of maintenance and monitoring of measures and of co-operation between different parties working in this field is increasing progressively. But there is a need for legally binding management agreements for the long-term management and monitoring of measures and affected sites. Such agreements should include a clear statement of the measures taken for mitigation, their objectives and a maintenance and monitoring plan (Salveson, 1990). The existence of these agreements can ensure that monitoring activities are carried out which provide valuable data for the evaluation of the effectiveness of measures.

7.7.4. Overview of monitoring methods and ouline of principal results

Most of the results obtained so far from the monitoring of measures are related to the use of fauna passages and the detection of road casualties. Less attention is paid to the monitoring of the effectiveness of habitat restoration actions or other avoidance or compensatory measures concerning habitats and landscapes. Information contained in the National State of the Art reports about the methods applied and the most relevant results is summarised in the sections that follow. The complete list of literature references regarding monitoring experiences is extensive: it has not been included in full here, but may be consulted in Chapter 7 of the National State of the Art reports cited in the text.

7.7.4.1. Procedures

The procedures most commonly used in the monitoring of mitigation measures are outlined below, including in brackets the countries that report the use of these techniques in the National State of the Art reports:

Recording of road casualties

Recording techniques are used to determine accident black spots that highlight the existence of fences that have been improperly installed or maintained and also the need to install fences combined with crossing points.

Methods for recording the species that use wildlife passages

- Recording of footprints on sand or beds of marble powder (Czech Republic, Denmark, France, Hungary, The Netherlands, Portugal, Spain, Sweden, Switzerland and the United Kingdom). This consists of the use of a strip of very fine sand or marble powder located in the middle of the structure that will record the footprints of animals that cross it. It allows for the registering of footprints of all type of animals, including small mammals, but it has the disadvantage of being fairly sensitive to the weather and it cannot be used in wet passages.
- Recording of footprints on ink beds (The Netherlands). This is the same system as above but instead using a bed of paper saturated with oil and carbon powder placed in a aluminium plate in combination with a sheet of paper on either side where the marks of the animals' feet impregnated with ink are registered. The prints obtained are often of higher quality than the sand prints and they can be kept for later identification.

- Recording footprints in snow (Czech Republic, Hungary and Sweden). This method can be used in the monitoring of overpasses, particularly in northern countries, to estimate the abundance of animals near the passages. The limitation is that it can only be used to check the use of a passage during the wintertime.
- Hair traps (The Netherlands). Tubes with a two-sided piece of adhesive tape are installed in passages. The hairs of passing mammals are captured on the adhesive tape and can be identified by specialists.
- Infrared video surveillance (France, Denmark, The Netherlands, Spain, Switzerland and United Kingdom). Video cameras activated by the movement of animals through or over wildlife passages have the advantage of recording the behaviour of the animal. This allows one to observe if they show any hesitation at all before crossing them, and also if they have any difficulties in using the structures.
- Infrared photo cameras (France, The Netherlands, Spain, Switzerland). Cameras that are activated when an animal crosses an infrared beam located at the entrance to the passage (Figure 7.21). It produces colour images of the animals, and for some species, e.g. the genet or Iberian lynx (Robles and Pereira, 2001), it allows animals to be identified individually through analysis of the spots on their coats.
- Electronic counters and transponders (The Netherlands). Counters give poor information because they only register the passage of an animal of a determined height, and no record is provided about what species has crossed the structure. This system can be improved by capturing and marking animals with transponders, allowing the system to record the number of times that marked individuals have used the passage.

Figure 7.21 - Infrared camera systems are used to record movements of mammals through fauna passages. (Photo by Minuartia Estudis Ambientals)

Telemetry methods for analysis of animal behaviour during the use of mitigation measures

Commonly, telemetry is based on the capture and fitting of transmitters on individual animals. Telemetry is too expensive and time consuming to be considered as a routine method for the evaluation of the effectiveness of passages. Nevertheless, it has been applied in some specific research programmes *e.g.* the use of fauna passages by wild boar and red deer in France (Vassant *et al.*, 1993a, 1993b); by wolf in Spain (Blanco and Cortes, 1999); and also for the analysis of hedgehog behaviour in relation to roads in The Netherlands (Huijser, 2000). The marking of animals by other means has also been reported from Switzerland in relation to amphibians and reptiles (Grossenbacher, 1985; Ryser, 1988).

7.7.4.2. Results

The results from the evaluation of the effectiveness of measures provides valuable information and criteria which should be used in the design of new structures. For this reason it is important to have an overview of the results obtained from monitoring programmes throughout Europe and a record of the experiences of individual countries. Information contained in the reports and articles cited below have provided a basis for the recommendations relating to mitigation measures published in the COST 341 Handbook '*Wildlife and Traffic – A European Handbook for identifying conflicts and designing solutions*' (in preparation). However, it is only possible to provide meaningful information for the evaluation of two groups of mitigation measures: wildlife passages and devices used to avoid fauna casualties.

The evaluation carried out highlights the fact that certain inefficient systems are still commonly used and that this factor is one of the most significant problems still to be resolved. Nevertheless, results have also shown that no single system may be considered as a panacea, and often it is necessary to apply several systems in combination with one another to maximise their efficiency.

Measures aimed at reducing road casualities

An evaluation of the effectiveness of various devices designed to impede the access of animals to transportation infrastructures and to prevent road casualties is shown in Table 7-7. It is clearly established that only erecting fences or clearing vegetation from verges in combination with warning signals can be effective in diminishing the numbers of collisions with wild animals. Other methods based on acoustic, olfactory or visual effects that aim to prevent large mammals from accessing roads and railways are not so effective. Several monitoring experiences have shown that over time these devices are no longer a deterrent to the animals.

Table 7-7 - Evaluation of the effectiveness of devices used to impede the access of animals to transportation infrastructures and to diminishing accidents caused by collisions with animals.

Measures	Country (Reference)	Remarks on the results
Fences	France (CTGREF, 1978; Ballon, 1985; Carsignol, 1989; SETRA and MATE, 1993); Norway (Amundsen, 1997)	Controversial: effective for avoiding big-game collisions (not for small animals) but reinforces the barrier effect; They must be used to drive the animals to safe crossing places or wildlife passages: this combined solution can reduce 80-90% of the road casualties; Importance of a good choice of height and location.
Warning signs and speed reduction	France; Norway	Standard warning signs alone are not effective at reducing the speed of drivers; The number of accidents can only be reduced if drivers reduce speeds to below 40-50 km/h; Higher effectiveness is linked to special signs *e.g.* temporary signs, or combined with flashing lights or/and sensor technology.
Clearing vegetation on the verges	France; Norway (N–SoA, 7.3.3)	Good results: discourages foraging and also increases the visibility of the animal to the driver; Negative effects relate to the increase in the edge effects and habitat loss. This can be especially negative in protected areas; A reduction of 56% of moose casualties has been recorded in Norway when in a 20 m corridor each side of a railway line has been cleared of trees, shrubs and understory vegetation from a further 10 m zone.
Mirrors, reflectors	France; The Netherlands (De Molenaar and Henkens, 1998); Switzerland; Norway (Reeve *et al.,* 1989)	▪ In most countries it has been reported that they are not effective (NL, CH), but others still recommend them in combination with other measures (N); ▪ Some animals can adapt their behaviour and don't react to these devices when they become habituated to them; ▪ On-going research in Belgium.
Olfactory repellents	France	▪ Not enough information but it seems that it has only a temporary effect; ▪ Good maintenance is needed; ▪ Some unpublished studies remark that they can reduce significantly the collisions with ungulates but others do not show any change on the number of collisions.
Ultrasound	France	▪ Tested on the HSR/TGV: it was considered ineffective
Road lighting	France; Norway (De Molenaar and Jonkers, 2000)	Low effectiveness; Negative secondary effects on fauna populations; Ongoing research in The Netherlands about wider effects of illumination.
Managing of ungulate population	France (Désire *et al.*, 1997)	Good local results; It is also necessary to monitor populations.

Sources: National State of the Art reports and detailed references.

Effectiveness of fauna passages

The evaluation of the effectiveness of wildlife crossings in avoiding the fragmentation effect on animal populations is somewhat more complicated than the evaluation of road casualties. Some of the most relevant monitoring experiences come from France, Norway, The Netherlands, Spain and Switzerland. Studies in these countries have provided information about the criteria that influence the effectiveness of wildlife passages: a summary of these is given below (nb. the large number of bibliographic references on which they are based can be found in the individual National State of the Art report from the country concerned:

- The preferences of different taxonomic groups in relation to the design and size of the passage are unique: different species have been shown to have different requirements and for this reason, it is important to define the target species before designing the passage.
- For small animals, e.g. invertebrates, the presence of vegetation at the entrances and the existence of suitable refuges on the floor of the passage is very important. For medium-sized and large mammals, the effectiveness of a passage depends primarily on its location and dimensions.
- The effectiveness of passages increases when they are located along the natural migration routes of animals or in alignment with existing landscape structures that favour their movement, e.g. forest edges, riverbanks or hedgerows. Passages are less attractive when they are located on stretches with mixed profiles (i.e. large cuttings and embankments) or when they are poorly aligned with landscape features.
- The dimensions are important criteria for determining the effectiveness of passages intended for large and medium-sized mammals. In Switzerland, more intense usage of structures of at least 60 m wide has been observed. Other experiences in the same country and also in France and Spain have shown that wild carnivores and ungulates can use narrower structures. The minimum width is determined by the size and behaviour of the species (deer require the largest structures) and also by the openness of the structure. This parameter is measured as (width x height)/length. The longer a passage is, the wider it needs to be in order to be effective.
- The entrances to passages should be as attractive for wildlife as possible, offer refuge (and sometimes the possibility for foraging) and direct the animals to the entrances. The effectiveness of passages increases when they allow for a direct view of the vegetation on the opposite side of the structure and for this reason, animals more easily accept passages located at the same level as the surroundings.
- Most species are sensitive to disturbance caused by human activities, therefore, the effectiveness of passages increases when they are screened by vegetation or other structures to reduce the negative effects of light, noise, etc.
- Most species prefer to use dry passages and for this reason, natural substrate (i.e. soil and vegetation) can be used to enhance the use of crossing places and structures. The effectiveness of wildlife passages in combination with water can be increased by constructing a dry bank alongside the watercourse, which runs the length of the passage.
- The use of transversal structures not specifically constructed as fauna passages by wildlife has been tested in different countries. The results show that several carnivores such as the wolf, red fox, martens, badgers and the genet use non-specific structures e.g. large culverts and under- or overpasses where minor roads intersect the main infrastructure. Also, ungulates such as wild boar use these structures when they are located in the optimum place and when their dimensions are big enough.

  Swiss monitoring shows the brown hare was never observed using structures which had not been specifically built for wildlife however, in Spain, the same species has been shown to commonly use over- and underpasses constructed in association with the re-establishment of forestry roads. In any case, it should be highlighted that in the monitoring carried out in Switzerland, the frequency of use of large structures designed specifically for wildlife was found to be considerably higher than the use of non-specific engineering structures.

7.8. SUMMARY

To counteract the problem of habitat fragmentation due to transportation infrastructure, a wide range of measures have been implemented throughout Europe. Despite the differences between countries, the principles of dealing with the issues are very similar. It has been recognised that avoidance of valuable or vulnerable nature areas should always be the first objective. Where avoidance leads to the re-routing of an infrastructure project, the problem is simply translocated to another, preferably less sensitive area. If avoidance is impossible, which is often the case, mitigation measures can be applied. If neither avoidance nor mitigation is possible, compensatory measures can be employed as a 'last-resort' solution. As experience in many European countries has shown, only integrated solutions, where the three principles are considered together from an early planning stage onwards, are likely to be successful.

In most European countries the first mitigation measures were aimed at reducing the number of accidents between animals and vehicles in order to improve driver safety and consequentially reduce the impact on animal populations related to traffic-related mortality. Measures comprised, for example, physical barriers, the adaptation of habitats or elements of the transportation infrastructure itself, and measures to reduce the impact from vehicles. More recently, special attention has been given to the development of measures aimed at reducing habitat fragmentation or barrier effects, *e.g.* fauna passages (artificial crossing structures built specifically for wildlife), adapted culverts, viaducts, etc., and road surfaces modified to facilitate animal mobility. More and more frequently, measures are being designed with the aim of providing a complete connection which maintains the ecological function of habitats on either side of the transportation infrastructure.

Compensatory measures are intended to develop specified natural values as a substitute for values affected by an approved infrastructure development. Such measures are often surface-oriented (*i.e.* aim to achieve 'no net loss') *e.g.* through the creation of new habitats; the enhancement of habitats deteriorated by past development (such as the restoration of river beds); and the implementation of activities associated with the infrastructure development (such as the establishment of environmental education areas).

In recent years, the importance of the appropriate maintenance of measures has been recognised but at the same time, many countries have identified this as an area where a lot of work still needs to be done. Often, maintenance aspects are not considered sufficiently when the infrastructure and the specific mitigation or compensation measures are being planned.

Analysing the effectiveness of measures forms a key element in monitoring schemes. The resulting experience provides valuable feedback which can inform the planning of future infrastructure projects and thus helps increase the cost-effectiveness of measures. The importance of investigating the effectiveness of measures has only recently been recognised. The development of monitoring programmes is to some extent limited by the lack of standards. During recent years, however, monitoring activities are being more widely applied in many European countries and a wide range of methods have been developed. In addition, several larger-scale research projects have been carried out to test the effectiveness of measures (mainly concentrating on fauna passages to date).

Monitoring results from individual measures and wider research projects indicate that many measures are indeed effective in counteracting habitat fragmentation. As a result of monitoring, the design of fauna passages and other measures has been improved. In particular, the importance of the location and dimension of passages and of the use of appropriate natural vegetation as a design element have been recognised. However, there are still many questions which remain, and more research and practical experience is needed in this area.

Chapter 8. Safety and Economic Considerations

This chapter deals with a wide range of traffic safety and economic aspects. After considering the causes of traffic accidents due to collisions with wildlife, economic aspects such as the external costs of habitat fragmentation are examined. An overview of the different approaches to measuring costs and benefits, as well as the financing of the various measures of defragmentation is given.

8.1. TRAFFIC SAFETY IN RELATION TO FAUNA COLLISIONS

Traffic safety in relation to fauna collisions is an important human and animal welfare consideration in European countries, mostly in relation to road accidents and, to a much lesser extent, railways. The problem is difficult to assess at a European scale as road registration schemes for reporting traffic accidents involving animals differ widely. It is especially difficult to obtain an overview of road traffic accidents involving wildlife where personal injury is *not* involved. Despite the general lack of data, traffic accidents involving wildlife are thought to account for only a small proportion of total traffic accidents, which is one of the main reasons why this theme is not a high priority in most countries. For example, only 0.3% (29 out of 11,124) of accidents involving personal injury or death in the Netherlands involved animals. This contrasts sharply with the extreme case of Sweden where police records show that in some areas up to 60% of road traffic accidents involve wildlife. In most European countries, the proportion of traffic accidents caused by wildlife is small.

8.1.1. Causes of traffic accidents involving wildlife

Traffic density is clearly related to the incidence of wildlife accidents, but this is not always a simple relationship. The proximity of suitable habitat or migration routes is also of importance. This can be illustrated with an example from eastern Norway where the county of Hedmark, a densely forested area, has a low density of roads but a high rate of accidents involving deer species (N-SoA, 5.4.4).

Speed increases the force of impact in accidents involving wildlife and hence the degree of injury to passengers. In Spain, motorway accidents involving fauna collisions have more than double the fatality rate of accidents in minor roads. Speed also increases the probability of serious injury when cars try to take evasive action and avoid wildlife on roads. Crashes into other cars or trees are the most serious form of accidents caused by drivers trying to avoid birds and small mammals.

Borer, F. and Fry, G. (2002) Safety and Economic Considerations. 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. 175-182. Office for Official Publications of the European Communities, Luxembourg.

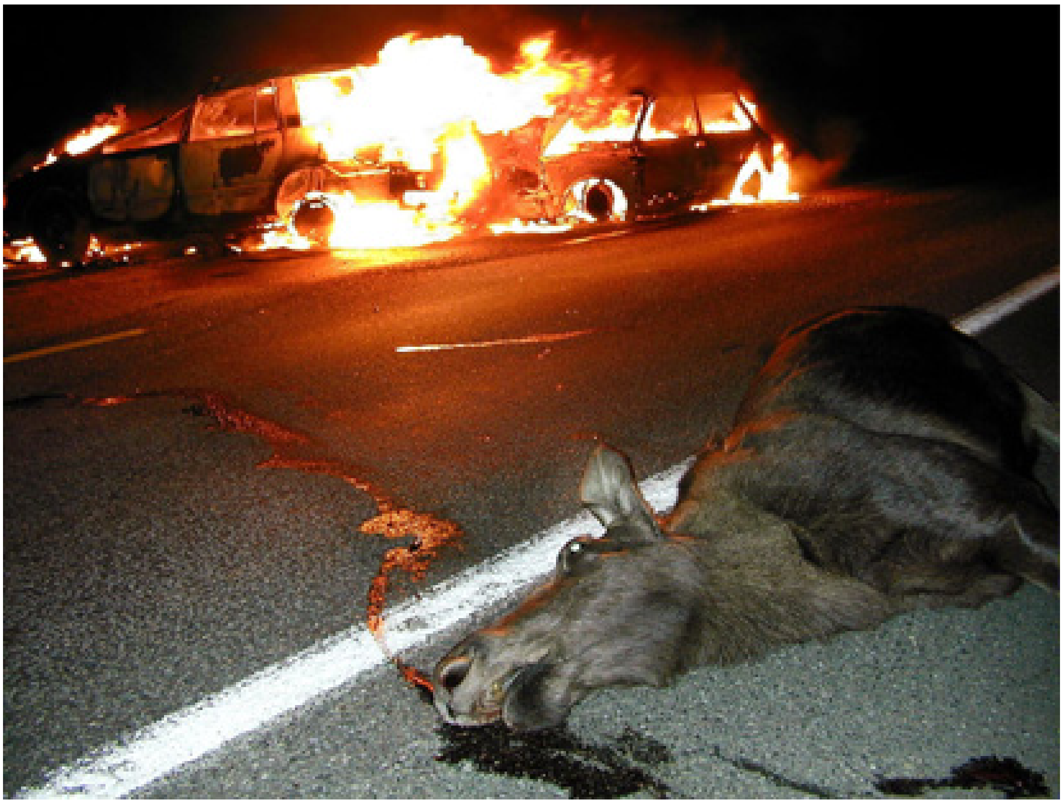

Figure 8.1 - Serious road accident involving a moose. (Photo by Helge Corneliussen)

Another important feature to consider is the strong relationship between the severity of road accidents and the size of the animal involved. Of particular concern are the large game animals such as red deer and moose, because of the relatively high proportion of road accidents that result in serious injuries to people. In Norway and Sweden, for example, approximately three times as many roe deer as moose are involved in collisions with cars, but the moose is a very large and heavy animal causing much more damage, greater than 10 times the injury rate caused by all other deer species together (see Figure 8.1). The large size of the moose with its high centre of gravity (height at shoulder up to 2 m and weighing up to 500 kg) can result in collisions where the body mass of the moose is above the bonnet height of a family car, such that the front windscreen and passenger area of the car take the full impact. Expanding populations of wild boar, *e.g.* in France, are also increasing the proportion of accidents involving injury to humans. Although wild boar relatively short in height, they are dense and can cause considerable material damage.

8.1.2. Avoiding accidents involving wildlife

Avoiding fragmentation effects during the planning of new road schemes would naturally reduce the number of fauna road casualties. The major techniques used to reduce accidents are presented in chapter 7.3.3. Although the best strategy to reduce accidents would be the siting of new roads away from important wildlife habitat and to avoid crossing migration routes of large species, in many cases this is not completely possible. Because of the presence of large species, certain countries have chosen to completely fence in their motorway system for safety reasons (CH-SoA, 5), adding heavy cost to road projects and accentuating fragmentation.

8.1.3. Monitoring collisions involving wildlife

One of the difficulties in addressing the scale of the problem, including human and financial costs of faunal casualties is the lack of central statistics in most countries. The way traffic accident reporting is carried out in different countries means it is very difficult to make comparisons. There is clearly a need to implement a systematic and uniform approach to monitoring road accidents involving fauna. This would enable us to gain an overview of the financial costs arising from death, injury, material damage, mitigation measures etc. A unified recording scheme would also identify trends in the European data as well as differences between countries and regions.

Accidents involving wild animals tend to have clear daily and seasonal patterns. These reflect foraging and migration behaviour and may be used to predict accident risk (see E-SoA, 6). Based on available statistics on traffic trends, certain factors that are likely to increase the problem of traffic safety can be identified:

- increasing road traffic density and speed;
- increased use of high-speed trains; and
- increasing distribution and abundance of large mammal species such as moose in Norway/Sweden and wild boar in France.

8.2. ECONOMIC CONSIDERATIONS

In the past, economic aspects in the area of nature and landscape conservation have been largely overlooked in Europe. However, with calls for the internalisation of external costs in the transport sector (EU, 1995; SVAG, 1997; ECMT, 1998; GVF, 2000) and increasing constraints on public spending, there is heightened interest in developing economic models and methods for evaluating nature and landscape and for optimising mitigation measures.

8.2.1. Social costs of accidents with wildlife

A previous COST Action (313) has reviewed approaches to the economic valuation of traffic accidents involving death and injury. However, compilation of an economic overview of the social costs of fauna-traffic accidents at a European level is impossible, partly because in many countries there are no central statistics concerning the number of road and railway traffic accidents involving wild fauna (United Kingdom, Hungary, Czech Republic, Spain, Cyprus, Denmark, etc.). Indicators and estimators offer the only opportunity to gain a rough picture of the situation in such countries. Elsewhere, in countries like Switzerland and The Netherlands, official statistics of reported accidents exist, but these figures do not reflect the total number of animals killed by traffic, since many accidents with animals are not reported. Data on railway accidents are even less accessible.

The estimated social costs of road accidents caused by wildlife is about 42,375 million Euro per year in Switzerland. These costs include material damage, human injuries and human fatalities taken from a Swiss standard that provides approximate values (CH-SoA, 6).

In Belgium, an insurance company making financial settlements for 3,962 reported traffic accidents involving animals paid 4.2 million Euro between 1992 and 1996, 90% of which was for material damage to vehicles. Since 1997, the majority of compensation claims are being refused by insurance companies and petitioners are referred to the towns where the collisions took place (B-SoA, 6).

In 1992, the cost of 21 incidents recorded with large fauna on the South East high-speed rail (HSR/TGV) line in France (Paris-Lyon) incurred an expense of 192,000 Euro. 44% of these costs were attributed to short stops, slowing down and remaining at a standstill; 31% related to reimbursement in travel coupons and reservation costs; and 25% was allocated for equipment repair (F-SoA, 6).

For one province in Spain, Alava, a detailed study was carried out on road traffic accidents involving two large game species: wild boar and roe deer. It was calculated that the mean economic cost per accident (regarding material damage only) was 1,135 Euro for accidents with wild boar, and 816 Euro for those involving roe deer. Extrapolating these figures gives a very approximate estimate of 862,179 Euro as the annual economic cost of material damage resulting from such accidents in Spain as a whole (E-SoA, 6.2).

In Sweden, accidents involving moose are estimated to cost between 8,325 and 21,853 Euro depending on the speed of the car, and from 1,560 to 3,122 Euro for accidents involving roe deer and reindeer (S-SoA, 6).

Further research about the wider financial implications of accidents with wildlife has to be undertaken across Europe. A range of cost implications relating to road traffic accidents have been identified: the cost of damage to vehicles; the call-out costs for vets, gamekeepers and the police to deal with injured or dead animals (especially deer); the call-out costs for ambulances and any subsequent human medical costs; and the costs of traffic delays. An understanding of these costs is important when assessing the ‘value for money’ of mitigation measures and the funds that should be made available for further research (UK-SoA, 6.2).

8.2.2. Calculating costs and benefits

Social Cost-Benefit Analysis (CBA) has been used in recent years in many European countries to assess transport investment options. CBA estimates cash values for elements such as changes in the level of congestion, timesavings, accidents, and, sometimes, environmental effects (see Ecoplan, 1998a,b). Such costs and benefits may then be compared with the capital costs of the investment. Other policy factors are also taken into account, but the CBA is often the core of the economic information given to policy-makers (ECMT, 2000).

CBA has been criticised for taking too narrow a view of ‘economic benefit’ and for not taking full account of environmental and social costs and benefits (Higman, 1995; Elbaz-Benchetrit, 1997; Cedermark and von Koch, 2000). The direct and indirect impacts of infrastructure development can be considerable, and are increasingly recognised as important considerations in proposed schemes. Studies have been made using various approaches in order to give a monetary value to the external effects of fragmentation. This is a very important aspect since the environmental impact of a project might otherwise be assumed to be zero (Boiteux, 1994). Despite the lack of standard methodology for valuing the wider external costs of fragmentation, it is much better to have a rough estimate of these effects rather than relying on CBA (which doesn’t counting the impact on the environment) when planning and constructing new transportation infrastructure.

In the United Kingdom, the Government has made a commitment to take forward work on environmental accounts as part of its Sustainable Development Strategy; to this end, a unit has been established in the Central Office for Statistics to develop them. These accounts will ultimately adjust measures of income for depletion of natural resources, and report physical quantities of pollutant emissions and expenditure on environmental protection. Environmental accounts identify the links between the economic and environmental impacts of different sectors of the economy. Indicators are able to highlight key environmental issues, such as the loss of biodiversity, but some indicators are difficult to associate with specific sectors of the economy and cannot easily be integrated into environmental accounts. The Government is therefore taking a joint approach in developing both a set of indicators and a system of accounts that will complement each other (UK-SoA, 9.2).

In Norway, the current Environmental Impact Assessment (EIA) process separates priced and non-priced consequences of infrastructure development. This represents a political acceptance that not all values can be given a price. Values that are not priced include aspects such as transport quality, ease of cycle use, recreation, nature, cultural heritage, aesthetics, 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, its quality and vulnerability. Fragmentation effects are increasingly used in the assessment of effects on nature (N-SoA, 9).

8.2.3. External costs of fragmentation

External costs are those that transport users inflict on others *e.g.* noise, air pollution, accidents, climate change, congestion, and infrastructure costs. With further improvement in data collection methods and economic modelling, fragmentation of human and animal communities, landuse, water pollution, and the aesthetic impacts of infrastructure and traffic could be quantified (EEA, 2000). Different approaches to calculating external costs are reviewed.

8.2.3.1. Anthropocentric approaches

Various studies have analysed the ”Willingness To Pay” (WTP) principle for different types of landscapes (see for example Hampicke, 1991; Nielsen, 1992; Blöchlinger und Jäggin, 1996), either by stated preference (questionnaire) or by measuring the expenditure of individuals. In a Swiss study on the costs and benefits of nature and landscape (Infraconsult 1999), a specific WTP per unit of m^2 for different types of landscapes has been extracted.

Although the WTP approach is quite well developed, there are a wide range of uncertainties to consider. Usually the surveys are not directly linked to transportation infrastructure and results are difficult to compare between countries since the initial state (*i.e.* scarcity of nature) is quite different. Thus this approach is most appropriate for measuring the additional costs and benefits of measures (or infrastructure projects) which directly improve the quality of nature.

8.2.3.2. Biocentric approaches

Another approach stems from the definition of the scarcity of nature defined by a natural scientist. By examining recent infrastructure projects it is clear that compensation and avoidance costs are rising due to the requirements imposed by the EIA process. Thus the average cost per km of new infrastructure is significantly higher than previously. A recent study in Germany (IWW *et al.,* 1998) has developed a new three-phased approach for considering these effects for the 'Bundesverkehrswegeplan':

- *Avoidance costs* (avoidance of nature and landscape effects) due to the choice of alternative alignments, especially for the protection of very important nature areas;
- *Compensation costs* for damage to nature and landscape. To value existing damage the costs of a reasonable set of compensation measures can be estimated (derived from recent infrastructure projects or from expert statements);
- *Repair costs* can be used in a similar way to compensation costs, especially for existing infrastructure, where the repair of measures would improve the situation. As above, specific costs per km of new environmentally optimised infrastructure can be used to measure the level of damage caused by the existing infrastructure (this holds true for nature and for water protection).

These costs represent virtual costs, since the depletion of resources has already taken place and in general cannot be reversed. This biocentric approach is also being recommended for a new study in Switzerland (Ökoskop, 1998; Ökoskop, 2000) to determine the impact of transport on air, water, climate, soil, fauna, landscape, noise and light. The area of habitat lost to transportation infrastructure will be estimated by analysing aerial photographs from the 1950s and 1990s. Virtual re-establishment costs will be used to express the transportation-related environmental damage in monetary terms. The main study is due to be completed in autumn 2002 (Nateco und Econcept AG, *in prep.*).

Looking at practice in various countries, it is evident that the biocentric approach using different cost elements is of practical relevance, it is easy to communicate and is thus more transparent than other methods of valuation. A biocentric approach could be recommended for assessing the likely levels of damage associated with transportation infrastructures. The WTP approach could be used to check the generated values. The level of differentiation depends very much on the availability of data relating to the transportation infrastructure and the level of intrusion it causes within the landscape.

The inter-linkages between environmental values and the transport sector are quite difficult to establish and sector-specific data is not available. Therefore the aggregation of national data has to follow a rather pragmatic approach (INFRAS/IWW, 2000), particularly in studies such as the Swiss example above.

8.2.4. Who finances measures?

In general, the financing of various mitigation and compensation measures follows the ‘polluter-pays’ principle. In the United Kingdom, mitigation measures are usually funded by the transport developer, either voluntarily or at the request of the planning authority to satisfy the requirements of the EIA. The priority of mitigation measures within a project depends on placing values on a range of environmental themes and interests including nature conservation, landscape, cultural heritage, visual quality, agriculture, education, recreation and community. The weighting given to these disciplines will vary with location and over time (UK-SoA, 9.3).

One important economic aspect of providing mitigation is the consideration of long-term maintenance costs. This is one area that has often been overlooked in the past, leading to deterioration of the structures and a decline in their efficiency. Best practice advocates that the long-term economic commitment towards maintenance needs to be secured at the outset of the project, with each of the involved parties fully aware of the financial implications of carrying out their parts of the contract. For costs of various maintenance operations related to verge management, fauna passages and compensation measures etc., see the French State of the Art Report (F-SoA, 7.6.).

In Denmark, investment in mitigation measures has been undertaken by the road authorities according to the ‘owner-pays’ principle. Rough calculations of prices of fauna passages indicate that it is much cheaper to make fauna and recreational passages when constructing new roads and railways than it is to decrease the barrier effects of existing transportation infrastructure (D-SoA, 9).

The same experience is true for The Netherlands, where the defragmentation of national trunk roads is financed by the Ministry of Transport, Public Works and Water Management. Initially, a separate budget was established for creating fauna passages on existing roads but subsequently the financing has been implemented in existing procedures. During construction of new national trunk roads, the cost of defragmentation (including both mitigating and compensating measures) is part of the overall project budget. Concerning waterways, bankside mitigation projects are carried out during canal widening or enhancement projects, often making it difficult to obtain a clear picture of the specific funds spent on each measure. The funds for removing physical barriers come from a restoration and configuration programme, financed by the same Ministry as the defragmentation measures (NL-SoA, 10.1).

In Spain, the costs of any measures which have to be implemented in relation to habitat fragmentation and infrastructure must be financed by the developer. This may be a private company, as is often the case with motorways or a semi-state or public company, as is usually the case in road and rail construction projects concerning public administration *e.g.* the State, Autonomous Governments or Provincial and Municipal administrations (E-SoA, 9).

In Switzerland, there is a clear legal requirement to take the interests of nature and the landscape into consideration in construction projects. Appropriate conservation measures are thus an integral part of any transportation infrastructure project and are financed as such. There are three types of conservation measures: the replacement and restoration measures; the ecological compensation measures; and the supplementary conservation measures. The last category go beyond legal requirements, are voluntary measures and must usually be financed by third parties (state funds, private foundations, contributions from environmental organisations or private enterprise, etc.) (CH-SoA, 9).

In Norway, road and railway projects are financed by the Ministry of Transport, including the provision of mitigation and compensation measures. The respective authorities for roads and railways are responsible for both infrastructure development and for EIAs associated with new developments and upgrading (N-SoA, 9).

In Hungary, all structures and measures associated with new linear infrastructure have to be financed by the investor, and the costs of establishing the environmental protecting structures form part of the investment budget (H-SoA, 9). The same is true for France, where the direct external costs are systematically borne by the project owner (F-SoA, 9).

8.3. SUMMARY

In recent years, more attention has been paid to economic aspects relating to nature and landscape features. Many countries are still a long way from adopting any sort of economic evaluation, but many studies have been carried out on quantifying environmental issues in connection with transportation infrastructure.

Economic aspects relating to wildlife accident prevention require further research and survey. There is clearly an urgent need to implement a systematic and uniform approach to monitoring road accidents involving fauna at a European level. This would enable the financial costs arising from death, injury, material damage, mitigation measures etc. to be established more accurately. A unified recording scheme would also help to identify trends across Europe and assess the efficacy of mitigation measures across different landscapes and biogeographic regions. The statistics currently available on traffic accidents already help to identify certain factors which are likely to increase the problem of traffic safety. These include: increasing road traffic density and speed; increased use of high-speed trains; increases in the distribution and abundance of large mammal species *e.g.* moose in Norway and Sweden and wild boar in France. Addressing such factors is future challenge for those concerned with wildlife accident prevention.

There is a common understanding in the EU and some non-member countries, that transport policy should be sustainable and efficient. One way of achieving this and promoting significant welfare gains is by reducing the external costs of transport. This requires the 'polluter-pays' principle to be applied to ensure that transport users pay all the costs they impose on others (EU, 1995; ECMT, 1998; ECMT, 2000). The Distance-related Heavy Vehicle Fee (HVF), successfully implemented in Switzerland at the beginning of 2001, is the first and only example in Europe that applies this concept (GVF, 2000). Other countries will be required to implement similar measures if a sustainable and efficient transport policy is to be realised.

It is fundamental that nature and landscape should be given monetary values to assist in the accurate economic assessment of transport investment options. More research is required in this field to create a standard methodology for valuing the wider external effects of fragmentation and to improve the baseline data used in determining the social costs of accidents involving wildlife. Only through this process will nature and landscape be given a 'monetary voice' when assessing the costs and benefits of measures to mitigate against habitat fragmentation.

Chapter 9. Policy Development and Future Trends

The fragmentation of natural habitats by transportation infrastructure is a problem that cannot be solved without an acknowledgement of the topic at policy level and without specific strategies and plans. This chapter examines global, European and national approaches to planning and queries whether any are integrated in terms of their consideration of habitat fragmentation. It also gives an overview of possible future policies, strategies and plans and discusses recently implemented policies whose effects are only just starting to show but will be important in the future.

Habitat fragmentation and future infrastructure development can be subject to different planning and policy instruments: it can either be part of general nature conservation planning or be included as a specific part of transportation planning. The text below therefore gives an overview of existing nature conservation strategies as well as parts of the transportation planning system that include habitat fragmentation. The first part of the chapter is focused on national strategies, policies and plans whilst the second part gives an overview at the European level.

9.1. NATIONAL POLICIES

Analysis of references in the National State of the Art reports on the subject of future policies and plans in the field of habitat fragmentation. Half of the reports don't mention visions of future policies and plans indicate that authorities in the COST 341 countries are now well aware of the problem of habitat fragmentation due to transportation infrastructure. A common approach is to tackle the problem through land-use planning and nature conservation policies. In some countries the significance of the problem has been recognised at such a level that it receives a special mention in their national transport policies. Some examples of where this has happened are given below.

Fragmentation is one of the 13 themes in the Flemish Environment and Nature Policy Plan (1997-2001) (B-SoA, 8.1.). A four-way strategy is suggested in the plan for reducing existing, and avoiding further, habitat fragmentation with the following priorities:

- Make the avoidance of additional fragmentation a priority.
- Facilitate a behavioural change in potential perpetrators (developers, planners etc).
- Reinforce ecological structures and deal with existing priority fragmentation problems.
- Fill in gaps in knowledge through appropriate research.

Damarad, T. and Van Straaten, D. (2002) Policy Development and Future Trends. 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. 183-187. Office for Official Publications of the European Communities, Luxembourg.

In the Netherlands, both the National Traffic and Transport and Nature Conservation Policy Plans (Ministerie van Verkeer en Waterstaat, 1990; Ministerie van Landbouw, Natuurbeheer en Visserij, 1990) give high priority to the development of the national ecological network, the avoidance of new infrastructure through it and to addressing problems at known bottlenecks. A substantial annual budget is allocated to these needs (NL-SoA, 9.2). For the secondary road network, the plan is to set up provincial and local authority defragmentation programmes. As far as the defragmentation of waterways is concerned, the Fourth Paper on Water Management (NW 4) aims to promote sustainable and resilient wetland ecosystems. The design of new inland waterways has evolved in line with this policy: wider, nature-friendly banks are now being constructed in Spaarnwoude region.

In Switzerland a statement ‘to minimise the biological barrier effect of existing or future transportation installations’ is included as a directive in the transport section of the Swiss Landscape Concept. As a result, a new programme to retrofit existing highways with fauna passages is underway (M. Trocmé, *pers. com.*) (CH-SoA, 8.2.).

The Spanish Strategy for the Conservation and Sustainable use of Biological Diversity (MIMAM, 1999) identifies transportation infrastructure as a specific cause to the problem of habitat fragmentation. This document is now under revision. Furthermore the problem of habitat fragmentation is addressed in some specific plans known as Planes de Ordenación de los Recursos Naturales (PORNS), drawn up to regulate the management of natural resources, as well as in recovery plans for threatened species (*e.g.* Plan for the Recovery of the Brown Bear). Some Autonomous Communities in Spain have recently drawn up their own strategies on biodiversity conservation for the next few years, and specific attention is indeed given to the theme of habitat fragmentation caused by transportation infrastructure (*e.g.* Navarra). However, in the transport sector, namely the Spanish Director Plan for Infrastructure (1993-2007) (MOPTMA, 1994), the problem does not receive a specific mention. (E-SoA, 8.2.)

The Italian General Plan for Transport (Ministry of Transport, 2000) recognises the goal of environmental sustainability and refers to the relationship between the infrastructure network and the national ecological network (parks, protected areas, ecological corridors for connectivity etc.) in biodiversity conservation terms (I-SoA).

Since 1996 in Sweden the issue of habitat fragmentation has been included in the planning structure as part of the Environmental Code. Specifically, fragmentation issues relating to strategic road and railway planning are dealt with using the section within the Environmental Code on EIA (S-SoA, 4.1).

In the United Kingdom the Integrated Transport White Paper ‘A New Deal for Transport: Better for Everyone’ (DETR, 1998) outlined a significant change in the priority for transport investment and development. A major component of this policy is concerned with how the environmental impact of transport should be dealt with, and in particular aims at: reducing the direct impact of transport on the built and natural environments; giving greater weight to the local environment (especially sensitive sites) in the appraisal of transport investment proposals through the use of the ‘New Approach to Appraisal’ (NATA). The Highways Agency (HA), the Government Agency responsible for maintaining, operating and improving the motorway and trunk road network in England works to support the Government’s integrated transport and landuse policies’. HA’s full role in the delivery of the Government's objectives for biodiversity are set out in the UK Biodiversity Action Plan (BAP), which is distilled further through the HA’s own BAP (the HABAP). In terms of defragmentation, the

HA is identified as a key stakeholder in several Species Action Plans (SAPs) *e.g.* for otters there is a requirement to limit accidental killing or injury where trunk roads cross their territory (UK-SoA, 8.2.).

Fragmentation is seen as a major policy issue by the Norwegian Ministry of Environment (N-SoA, 8.2.), and in Denmark research on fauna collisions, fauna passages and fragmentation is one of the specific political aims in the fields of infrastructure and traffic (DK-SoA, 8). The Czech Republic Transport Policy defines many measures to eliminate the environmental impacts of transport, but fragmentation is not directly mentioned (CZ-SoA, 7.1.). A similar situation is found in Estonia where the Estonian Act on Roads has been approved, but it does not contain anything about the avoidance of habitat fragmentation and the need for mitigation measures (EE-SoA). Several European countries have identified national ecological networks, and in The Netherlands, Hungary, Belgium, Switzerland and Estonia these ecological networks are used as tools to assess bottlenecks between nature and transportation infrastructure.

Many COST 341 countries, *e.g.* Sweden, Switzerland, the Czech Republic and the United Kingdom, recognise the strategic importance of research which aims to widen knowledge of the impact of highways on the natural environment, and consequently will help administrations to deal with habitat fragmentation. According to the National State of the Art Reports, the priority subjects where future efforts should be concentrated are:

- Development of technical manuals addressing the landscape and biodiversity implications of transport schemes (Norway, UK, Switzerland, The Netherlands, France, Spain);
- Costs and benefits of nature and landscape protection measures in the transport sector (Switzerland);
- Monitoring of existing wildlife crossings and evaluation of their effectiveness in order to identify optimum cost-effective design solutions to be applied in the future (Switzerland, the Czech Republic, The Netherlands); and
- Verge management, as a technique for enhancing biodiversity (The Netherlands).

9.2. EUROPEAN POLICIES

Three European institutions are taking the lead in developing and implementing policies which have a potentially significant impact on habitat fragmentation: the European Commission (EC); the Council of Europe (CoE); and the Organisation for Co-operation and Development (OECD) in Europe.

9.2.1. European Commission (EC)

Natura 2000 network

In the coming years, two processes will be important for determining the future development of the Natura 2000 ecological network. Within the current Member States, the process of designation of Natura 2000 sites (SPAs and SACs) is almost complete and it is expected that attention in these countries will shift from ‘identification and designation’ to ‘management and monitoring’ of the network of sites. Also, communicating the obligations and benefits arising from the Natura 2000 network to stakeholders *e.g.* regional and local authorities, land owners and financial sectors, will become more of a priority. Embedding Natura 2000 areas within regional development plans, spatial planning schemes and EIA processes will require special attention in the future in order to avoid conflicts between regional development and the adequate safeguarding of Natura 2000-sites.

As a result of the accession process, the Natura 2000 network will be extended towards Central and Eastern Europe and Cyprus. The EC has declared that accession countries must have finalised their list of proposed Natura 2000 sites before they will be accepted as full members. A quick, country-by-country extension of the Natura 2000 network is therefore likely to continue in the future. This process will lead to the addition of new species and biogeographical regions to the network and will subsequently require changes to the Annexes of both the Bird and Habitat Directives (Council Directives 79/409/EEC and 92/43/EEC respectively). However, it is not expected that this will have further consequences for the implementation of Natura 2000 in current Member states.

Strategic Environmental Assessment Directive

The long awaited Strategic Environmental Assessment (SEA) Directive (2001/42/EC) was adopted in June 2001 by the EC. The text of the directive (which can be found at http://europa.eu.int/comm/environment/eia/eia-legalcontext.htm) and Member States now have three years to integrate the new instrument into their national legislation.

The SEA Directive represents a key milestone: it represents one of the first comprehensive pieces of legislation which promotes the integration of the environment (including habitat fragmentation) in future planning and programming across a broad range of economic sectors (including transport). Specifically, it intends to fill the gap, which currently exists between project level EIA and the environmental integration of effort at a policy level.

In applying SEA as an instrument, the evaluation of different alternatives is one of the most important issues. Although EIA may be performed at different levels, alternatives are mostly considered at network level (*e.g.* providing a framework for environmentally-friendly use of infrastructure) and on corridor level (*e.g.* providing alternatives routings for infrastructure, reduction of traffic flows or encouragement of environmentally friendly modes of transport). Project level EIA gives more emphasis to mitigation measures (see Section 6.2.2.).

European countries are at different stages in implementing SEA in their legislation. Denmark, Sweden, Finland and The Netherlands all have an established history of SEA relating to transport which is already supported by national legal requirements. Flanders (Belgium), Ireland, Italy, the UK, some Spanish regions and France are countries which are moving towards a consistent application of SEA through varied means (*e.g.* pilot studies, proposed national legislation and/or existing regional legislation on SEA). Austria, Brussels and Wallonia (Belgium), Luxembourg, Portugal, Germany and Spain (at a national level) are countries which have chosen to postpone implementation of the Directive until it has been improved. However, all Member States must have transposed the new legislation within the next three years (Article 3, §2a) of Directive 2001/42/EC).

A proposal for a amending decision (No 1692/96/EC) on Community guidelines for the development of the Trans-European Transport (TEN-T) network advocates that SEA be applied to any future planned extensions to the TEN-T network

White Paper on European Transport Policy

In September 2001 the EC adopted the new White Paper on European Transport Policy for 2010, which aims to promote a transport policy that sacrifices neither economic growth in an enlarged Europe, nor freedom of movement. The essence of the challenge is not to restrict mobility, particularly since people increasingly view this as their right, but to make the transport system smarter and more environmentally-friendly. Highlighting the importance of sustainable development principles within the transport sector, this White paper gives priority to air quality, climate change and noise pollution problems, but does not explicitly highlight biodiversity or habitat fragmentation as issues of concern.

9.2.2. Council of Europe (CoE)

Pan-European Biological and Landscape Diversity Strategy

When the Pan-European Biological and Landscape Diversity Strategy (PEBLD) was endorsed in 1995, a five year action plan was outlined. In 2000, a new work programme was developed for 2001 to 2005 and, in comparison to previous years, the PEBLD Strategy is more focused on becoming a tool for implementing the Convention on Biological Diversity in Europe. The current work programme focuses on:

- Enhancing the implementation of the Convention on Biological Diversity in Europe through the PEBLDS process;
- Promoting and supporting specific European actions, initiatives and innovations; and
- Building the capacity of ‘Central and Eastern European Countries and the Newly Independent States’ (CEE/NIS) for the conservation and sustainable use of biodiversity (Council of Europe/UNEP, 2001).

Pan-European Ecological Network

The Pan-European Ecological Network remains one of the priority topics in the new work programme, but it is expected that the focus of activities in this framework will shift from the development of the concept to promoting its realisation on the ground and supporting cross border co-operation in this field.

Code of Practice

As part of the CoE’s activities to take forward the Pan European Biological and Landscape Diversity Strategy, a ‘Code of Practice for the Incorporation of Landscape and Biodiversity in the Planning of Linear Transport Infrastructure’ has been developed. The Code of Practice includes recommendations with regard to best practice in EIA, problems and opportunities for integrating the two fields, infrastructure development and maintenance and research. The Code is due to be endorsed in 2003 at the Ministerial Conference ‘An Environment for Europe’ in Kyiv (Kiev).

9.2.3. Organisation for Economic Cooperation and Development (OECD)

Finally, the OECD is preparing an environmental strategy document which highlights lines of action that affect transportation infrastructure. Outlined in March 2001 and entitled ‘A Guide for Environmentally Sustainable Transport’, the document has currently been written in very broad terms *i.e.* in such a way that it has not yet incorporated the Directives relating to the fragmentation of habitats and landscapes.

Chapter 10. Conclusions and Recommendations

10.1. FRAGMENTATION – A PRIORITY ISSUE

Since the development of agriculture during the Neolithic period, the originally highly wooded European landscape has been increasingly fragmented by changes in landuse related to human settlement.

Up until the beginning of the 20th century, fragmentation of natural habitats was mostly associated with agricultural diversification, resulting in the creation of new habitats and a general increase in biodiversity. However, by the 1950's, rapid intensification of agriculture, urbanisation and the development of high-capacity transport networks, had led to a transformation in the landscape. Together these changes resulted in habitat loss and fragmentation to such a degree that many sensitive or specialised species became rare or regionally extinct. At the beginning of the 21st century, the situation in many European countries is such that the list of threatened higher vertebrates is longer than the list of non-threatend species.

Throughout most of the 20th century, nature conservation policy was based upon the protection through designation of isolated pockets of natural habitat. However, as species began to disappear, even in national parks and nature reserves, it became clear that nature protection policy had to address a problem that went far beyond habitat loss. It became apparent that many nature reserves were too small to contain sustainable populations and too isolated from each other to permit the movement of individuals between them. Habitat fragmentation thus became a major concern for planners and conservationists worldwide.

The growing awareness that national and local nature protection efforts would be insufficient to prevent the continued decline in the populations of many species, instigated the first co-ordinated European transboundary efforts. In 1971 the Ramsar Convention was ratified, promoting the conservation of important wetland areas for migratory birds across Europe. Following this, the Berne Convention, on the conservation of European wildlife and natural habitats (1979), represented a further significant step in the co-ordination of European conservation efforts. More recently, the effort has intensified, and has resulted in the introduction of the 'Habitats Directive' (Council Directive 92/43/EEC (1992)) on the conservation of natural habitats and wild fauna and flora). This requires the designation of Special Areas of Conservation , which together with Special Protection Areas, designated under the 'Birds Directive', aim to create a coherent European ecological network, entitled Natura 2000. The Pan-European Biological and Landscape Diversity Strategy adopted in 1995 has reinforced Natura 2000, broadening it to promote the establishment of the Pan-European Ecological Network. The strategy represents a new approach by going beyond habitat conservation to focus more on increasing landscape connectivity.

Trocmé, M. (2002) General Conclusions and Recommendations. 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. 189-195. Office for Official Publications of the European Communities, Luxembourg.

10.2. FRAGMENTATION – A RECOGNISED PROBLEM

An overview of the COST 341 National State of the Art Reports (referred to as ‘the national reports’ in the rest of this Chapter) shows that the problem of fragmentation of natural habitats by transportation infrastructure has indeed become an important issue for conservation policy in all European countries.

In Belgium, Flanders is one of the regions where the issue has become most acute, with its high population density (438 hab/km^2), intensive agriculture and dense road network (4.8 km/km^2 in 2000). Here, 40 % of the badger (*Meles meles*) population is killed annually on roads (B-SoA, 4.2), putting the species at risk of local extinction. In Spain, with a population density of 78 hab/km^2 but low overall road density of 1.0 km/km^2, one of the main causes for the present decline in Iberian lynx (*Lynx pardinus*) is the isolating effects of roads on populations and the high mortality levels caused by road traffic accidents (E-SoA, 5.4.6).

It could be assumed that Sweden, with a population density of 19 hab/km^2, and a forest cover of 54 %, would be little affected by fragmentation. But it is apparent that even here the high traffic mortality rate for otters (64 % of all known causes of death) may be one of the factors preventing recovery of the the Swedish otter population from earlier local extinctions (S-SoA, 5.4.6). Indeed a recent inventory in the Uppland region of Sweden showed that 66 % of all road and railway bridges were badly adapted to the needs of otters, forcing them to walk across the transportation infrastructure (S-SoA, 5.4.5). Even Norway, with its low population density of 14 hab/km^2 and infrastructure density of 0.3 km/km^2, is confronted with nature conservation issues linked to habitat fragmentation. For example, as a direct result of infrastructure development in the Snohetta area, a sub-population of the wild reindeer (*Rangifer tarandus*) became isolated and left with an insufficient winter grazing area (N-SoA, 5.4.5).

The diverse infrastructure design standards across Europe do not seem to have a major influence on the intensity of the fragmentation effect. Traffic density appears to be a much more important factor: not only does it influence mortality directly but also causes disturbance effects in the surrounding habitat (NL-SoA, 5.3.2). The national reports emphasise that the dense network of secondary roads in some countries *e.g.* Sweden or Switzerland, also often contributes significantly towards fragmentation.

Sections 5.4 of the national reports review the variety of specific conservation problems linked to fragmentation due to transportation infrastructure. Although trends can be identified, it is not possible to establish a prioritised list of species most sensitive to fragmentation at the European level. The extent of the impact of fragmentation on individual species depends partly on the status of the species (*i.e.* whether it is threatened), its distribution and its ecology. Other factors can also play a role at national, regional and local levels. A general trend is, however, for large and wide-ranging species to suffer from fragmentation caused by infrastructure at the landscape scale, whilst locally, relatively sedentary habitat specialists are more sensitive to the loss and disturbance of their local habitat.

For example, even though the badger population is significantly impacted in The Netherlands and Belgium, in other countries, despite heavy traffic mortality, populations appear more resilient (UK-SoA, 5.4.4.2). On the other hand, all national reports mention mortality on roads as being a major cause of population decline for amphibians, leading to extinction at the local level. In the countries where otters are still found, this species is consistently mentioned as being extremely sensitive to fragmentation, with mortality on roads posing a conservation threat where populations are low. The toll is also high for certain endangered species, such as the Iberian lynx, which could be endangered by traffic at sub-population level (E-SoA, 5.4.6). Fragmentation due to transportation infrastructure also appears to be a limiting factor for hare populations in a number of countries (*e.g.* the Czech Republic and Denmark).

An Austrian study on the effects of transportation infrastructure on large carnivores in the Dinara Mountains has been supported by WWF Large Carnivore Initiative (see Box 4.2 in Section 4.2.2) (Zedrosser and Völk, 1999). The initiative points out that the development of infrastructure across certain key European ecological corridors, *e.g.* between the Alps and the Carpathians, or between the eastern Alps and the Dinaric Mountain range, could create barriers to the dispersal of species such as the brown bear. These barriers could prove fatal when considering the long-term future of large carnivores in the Alps (Zedrosser, 1996; Rauer and Gutleb, 1997) since relict populations may become confined to the west of the ranges therefore resulting in a European scale impact.

A further concern is that populations that have, in recent times, functioned as immigration sources on a continental level, may become more marginalised by fragmentation caused by the rapid expansion of transportation infrastructure in eastern Europe.

10.3. IMPLEMENTING A GLOBAL STRATEGY

Habitat fragmentation due transportation infrastructure has become a widely recognised problem. The possible responses to it range from the adoption of global action plans to the formulation of solutions on a case-by-case basis.

The basis for a global defragmentation strategy is the identification of locations where transportation infrastructure intercepts with ecological networks. This has yet to be achieved at a global (or even European) level, but valuable experience may be gained from countries which have identified ecological networks and located the conflict points (bottlenecks) within them *e.g.* Belgium, the Czech Republic, Estonia, Hungary, The Netherlands and Switzerland. After delimiting the bottlenecks, certain countries have integrated active defragmentation programmes into their national policies *e.g.* The Netherlands, Belgium and Switzerland. Some examples are highlighted in Table 10-1.

Table 10-1 - Examples of defragmentation policy in Europe.

Country	Defragmentation Policy
The Netherlands	The first country to have developed a formal national defragmentation programme, with an important annual budget located for the mitigation of existing bottlenecks. Local defragmentation programmes are also planned (NL-SoA, 5.3.8).
Belgium	Fragmentation is one of the 13 themes of the Flemish Environment and Nature policy Plan (1997-2001) (B-SoA, 8). The strategy rests on four pillars:i) Making the avoidance of additional fragmentation a priority; ii) Facilitating a behavioural change in potential perpetrators (developers, planners etc); iii) Reinforcing ecological structures and dealing with existing priority fragmentation problems; and iv) Filling in gaps in knowledge through appropriate research. A yearly budget has been adopted for defragmentation measures (Swillen, 2001).
Switzerland	The goal of minimising fragmentation due to existing or new transportation infrastructure has been officially recognized by Federal Government in the National Landscape Concept (CH-SoA, 8). A programme to mitigate existing bottlenecks along motorways is underway.
Spain	The problem of habitat fragmentation is increasingly referred to in official documents, but important regional differences appear in the implementation of policies (E-SoA, 8.2).

10.4. Specific strategies

To completely avoid any further habitat fragmentation from infrastructure, the only effective strategy would be to avoid building new infrastructure altogether. For various reasons this is seldom a practicable solution and the economic and social importance of a new linear infrastructure must be weighed against the interest of preserving an unfragmented area. In many cases, sensitive habitat can be avoided by the choice of an appropriate route for new transportation infrastructure, thus minimising the potential fragmentation impact. Generally avoidance strategies still receive too low a priority in transport planning.

Where avoidance is not practicable, a large range of mitigation measures can be implemented. For new infrastructure, the choice of mitigation measures is made during the Environmental Impact Assessment (EIA) process, with the goal of minimising the overall fragmentation effects of the project. Although the specific design of measures differs between countries (and even between projects within a country), common aims and principles are easily recognisable *e.g.* measures aimed at reducing mortality, and measures aimed at reducing the barrier effect. Throughout Europe, measures aimed at reducing disturbance effects on nature are still rare, despite the relative frequency of measures to address human disturbance impacts (*e.g.* noise barriers).

The role of verge management in defragmenting habitats has been receiving new attention recently. It has been recognised that through appropriate seeding and targeted management regimes, biodiversity can be enhanced and the verges can be used to create a new type of connectivity in the landscape. The Netherlands and Sweden, among others, have carried out a botanical inventory of their roadsides, identifying the potential to increase biodiversity and the positive use of the corridor effect. However whilst on the subject of verges, it should be highlighted that these linear habitats also have potentially negative aspects: they are often a source of invasive species that have the potential to disturb nearby natural ecosystems; they can become traps for certain animals *e.g.* birds of prey, whose habit of hunting along the open roadsides can result in high mortality rates due to collision with vehicles; and a large proportion of forest fires in Mediterranean areas originate along transportation infrastructure (20 % of roughly 20,000 fires annually in Spain (E-SoA, 4.3.2.5).

10.5. GAPS IN KNOWLEDGE

Most national reports make it clear that the planning of infrastructure involves the planning of landscapes. Indeed, without taking long term transformation of landscapes into account, mitigation measures and even avoidance strategies may fail to meet their goal. The dynamics of landscapes need to be better understood. For Strategic Environmental Assessment (SEA) of transportation development plans, especially the TEN-T, there is a deficit of robust indicators and well tested models to evaluate fragmentation.

Research

Despite a wealth of research which has been carried out to date, many questions concerning fragmentation remain, the most fundamental of which are:

- What are the thresholds relating to the barrier effects? How high a transportation network density is acceptable for a given ecosystem and its component habitats/species?
- How significant is traffic-related mortality for the sustainability of wildlife populations?
- How far from the road are disturbance effects significant for habitats and species?
- What density of fauna passages are required to effectively maintain habitat connectivity?
- How can the positive and negative corridor effects related to transportation infrastructure be balanced to benefit wildlife e.g. how can the risk of creating mortality traps be avoided?
- What are the effects of fragmentation at the habitat and ecosystem level?
- Which European habitats are most sensitive to, and threatened by, the fragmentation effects of current and future infrastructure?

Implementation

The approach to the fragmentation problem is often too scattered. The philosophy of defragmentation needs to be integrated in the planning and design process and be considered in all aspects of infrastructure operation and maintenance.

Once a project has been approved in principle, the wide array of possible mitigation measures has the potential to create confusion: the goals to be achieved by the mitigation measures are not always clearly specified at the outset and which type of measure is most effective in which situation is not always apparent. Basic questions such as the ideal density of wildlife passages remain unanswered. There is also a great diversity in the design of mitigation measures, especially concerning wildlife overpasses. This is often due to the wide range of target species and the different types of habitat to be connected, or is simply a reflection of the personal preferences and styles of individual engineers and landscape architects. None of the COST 341 countries had a complete register of fauna passages in existence, making the critical analysis of designs difficult. There are no overall statistics on the mitigation measures realised up to now.

Monitoring programmes to measure the effectiveness of mitigation measures (see Section 7.7) are implemented in some countries, but not in a systematic way. The data derived from these programmes often remains hidden in grey literature, meaning that the results cannot be utilised to inform new projects. Such feedback is vital for improving future designs of measures. Monitoring programmes also often lack a standardised approach meaning the results are difficult to compare between (and even within) countries.

Another chronic problem is the lack of appropriate maintenance of some mitigation measures, *e.g.* amphibian passages, which can significantly reduce the effectiveness of the measure. The cost of maintenance of mitigation measures needs to be incorporated in the overall infrastructure maintenance budget.

The implementation of compensatory measures, where mitigation is insufficient to completely alleviate environmental impacts, remains the weakest part in the approach to fragmentation. The main problem is that although it is possible to compensate for habitat loss, it is extremely difficult to compensate for the effects of fragmentation, which have an impact over a much larger area. Despite the obligation on EU countries made by the Habitats Directive (92/43/EEC) to compensate for any impact on the Natura 2000 network, compensation projects are often hindered by conflicts with other interests, non coercive legislation, and the lack of land or funding. Only two COST 341 countries, The Netherlands and Switzerland, have a ‘no-net-loss’ policy.

Overall, a holistic approach to the development of new transportation infrastructure is still lacking, even in those countries where mitigation measures are regularly implemented. EIA generally concentrates on the infrastructure at the project level and fails to address secondary developments that may follow. Secondary impacts that result from the construction of new infrastructure *e.g.* the intensification of agriculture due to the redistribution of land or urban development, can reduce or annul the effectiveness of even the best mitigation measures.

10.6. RECOMMENDATIONS

Compiling the experiences of all the participating countries, the following principles and recommendations can be made. These should act as guidelines for addressing future issues relating to the fragmentation of natural habitats by transportion infrastructure.

For planning:

- Habitat connectivity is a vital property of landscapes and is especially important when considering the ecological adaptation of infrastructure. Fragmentation should be addressed at all levels of transportation planning.
- Sustaining animal movements across the landscape by means of ecological networks should be a strategic goal in the environmental policy of the transport sector.
- Planning at the landscape scale involves both regional issues that relate to strategic evaluation, and local issues that determine the final action on the ground. A hierarchical approach can help to identify the most relevant problems and their solutions at each planning level.
- European and national nature protection legislation needs to be integrated in the planning process at the earliest possible stage.
- Only an interdisciplinary approach involving planners, economists, engineers, ecologists, landscape architects etc., can provide all the necessary tools for addressing fragmentation successfully. The approaches need to be integrated within the different levels of the transportation network.

- Effective models and indicators need to be developed to predict the impact of habitat fragmentation on wildlife. Impacts are non-linear: some effects may be compensated or buffered until a certain threshold is reached, but beyond this threshold, sudden and unforeseen changes in species' responses may occur.
- When planning and upgrading new infrastructure, the primary objective should be to avoid fragmentation. If this is impossible to achieve, a package of mitigation measures should be designed, and where residual impacts remain, compensatory measures should be employed as a last resort. Nature protection measures should be integrated at the beginning of the project and the choice of strategies and measures must consider the landscape context.
- Secondary effects of infrastructure development arising from increased access and associated developments should be part of the assessment process.
- Public involvement is also essential to broaden the basis of decision making and to ensure the success of the chosen solutions.

For design:

- Mitigation measures should not focus solely on the prestigious passages for large animals. Much can also be done, at relatively low cost, to increase the permeability of the existing and future transportation infrastructure, by adapting the design of engineering structures to benefit wildlife. Many existing wildlife traps could be addressed by adapting local road overpasses and underpasses to allow for (at least) infrequent use by animals. Engineering design should be reviewed for these functions by ecologists.
- Disturbance effects created by infrastructure need to be mitigated in order to avoid habitat degradation around the infrastructure.

For follow-up:

- Monitoring programmes to establish the effectiveness of mitigation measures are essential and need to become standardised. The cost of monitoring programmes should be included in the overall budget for new infrastructure schemes and the budget for their maintenance.
- The EIA Directive (97/11/EC) needs to be amended to take into account the fundamental requirement for post-project monitoring.
- Evaluation of the effectiveness of measures must be based on strategic monitoring programmes. The programmes should be designed to analyse the effectiveness of the whole mitigation package applied in an infrastructure project, rather than focusing the survey on one single measure, or type of measure. The definition of clear objectives for the monitoring programme is essential and specific questions must be formulated and measurable parameters (including key indicators) should be defined and reported against.
- Because of the complexity and widespread nature of the problem, an ongoing exchange of knowledge through Europe is vital. Co-operation between different countries is fundamental, not only to confirm which measures are the most cost-effective, but also what methods, measurable criteria and standards can be used to evaluate the effectiveness of these measures.
- Maintenance of measures needs to be integrated in infrastructure planning and design from the start and an appropriate budget needs to be assigned.

Chapter 11. References

Foreword

EEA (2001) *Environmental signals 2001*, Copenhagen 2001.

Gaffin, D. (1996) *In Place: Spatial and Social Order in a Faeroe Islands Community.* Waveland Press.

Chapter 1

CEC (2001) *Transeuropean networks: heading east with TINA.* Commission of the European Communities. Directorate-General for Energy and Transport. http://europa.eu.int/comm/transport/themes/network/english/tn_15_en.html [12-05-2001]

EEA (1998) *Spatial and ecological assessment of the TEN: demonstration of indicators and GIS methods.* European Environment Agency. Copenhagen. Denmark. 52 pp.

EEA (2000) *Are we moving in the right direction? Indicators on transport and environment integration in the EU.* Environmental Issue Series Nº12. European Environment Agency. Copenhagen. Denmark. pp. 136.

Teodoraşcu, D.M. (1997) Infra Eco Network Europe – An open European platform for cooperation and exchange of information in the field of habitat fragmentation caused by transportation infrastructure. In: Canters, K., Piepers, A. and Hendriks-Heersma, A. (Eds.) *Proceedings of the international conference on "Habitat fragmentation, infrastructure and the role of ecological engineering" Maastricht and The Hague 1995*, pp 442-450. Delft, The Netherlands: Ministry of Transport, Public Works and Water Management, Road and Hydraulic Engineering Division.

Chapter 2

Andersen, R. (1991) Habitat deterioration and the migratory behaviour of moose (*Alces-alces* L) in Norway. *Journal of Applied Ecology* **28**, 102-108.

Andrén, H. (1994) Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. *Oikos* **71**, 355-366.

Angelstam, P.K. (1992) Conservation of communities - The importance of edges, surroundings and landscape mosaic structure. In: Hansson, L. (Ed.) *Ecological principles of nature conservation*, 9-70. London: Elsevier Appl. Science.

Angelstam, P.K. (1997) Landscape analysis as a tool for the scientific management of biodiversity. *Ecol.Bull.* **46**, 140-170.

Baudry, J. and Burel, F. (1997) Agricultural landscape dynamics: implications for species movements. In: Cooper, A. and Power, J. (Eds.) *Species dispersal and land use processes. Proceedings of the sixth annual IALE (UK) conference.*, pp. 3-10. Belfast, UK: IALE (UK), Textflow services Ltd.

Baudry, J. and Merriam, G. (1988) Connectivity and connectedness: functional versus structural patterns in landscapes. In: Schreiber, K.F. (Ed.) *Connectivity in landscape ecology. Proceedings of the 2nd international seminar of the "International association for landscape ecology".* pp. 23-28. Münster, Germany.: Münstersche Geographische Arbeiten 29.

Bennett, A.F. (1990) Habitat corridors and the conservation of small mammals in a fragmented forest environment. *Landscape Ecology* **4**, 109-122.

Bennett, G. (1999) Maastricht II +5. *European Nature* 9-11.

Bennett, G. and Wolters, R. (1996) A European Ecological Network. In: Nowicki, P., Bennett, G., Middleton, D., Rientjes, S. and Wolters, R. (Eds.) *Perspectives on ecological networks*, pp. 11-17. European Centre for Nature Conservation, ECNC.

Bernes, C. and Grundsten, C. (1992) *The environment.* Stockholm: The National Atlas of Sweden.

Bissonette, J.A. (1997) Scale-sensitive ecological properties: historic context, current meaning. In: Bissonette, J.A. (Ed.) *Wildlife and Landscape ecology - Effects of pattern and scale.*. pp. 3-32. New York: Springer-Verlag.

Burel, F. (1992) Effect of landscape structure and dynamics on species diversity in hedgerow networks. *Landscape Ecology* **6**, 161-174.

Burgess, R.L. and Sharpe, D.M. (1981) *Forest island dynamics in man-dominated landscapes*. New York: Springer Verlag.

Dramstad, W.E., Olson, J.D. and Forman, R.T.T. (1996) *Landscape Ecological Principles in Landscape Architecture and Land-Use planning*. Washington, USA: Island Press.

Fahrig, L. and Merriam, G. (1994) Conservation in fragmented populations. *Conserv.Biol.* **8**, 50-59.

Fahrig, L., Pedlar, J.H., Pope, S.E., Taylor, P.D. and Wegener, J.F. (1995) Effect of road traffic on amphibian density. *Biol.Conserv.* **73**, 177-182.

Farina, A. (1998) *Principles and methods in landscape ecology*. London: Chapman & Hall.

Finder, R.A., Roseberry, J.L. and Woolf, A. (1999) Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. *Landscape and Urban Planning* **44**, 77-85.

Forman, R.T.T., and Alexander, L.E. (1998) Roads and their major ecological effects. *Annual Review of Ecology and Systematics* **29**, 207-231.

Forman, R.T.T. (1995) *Land mosaics: The ecology of landscapes and regions*. Cambridge: Cambridge University Press.

Forman, R.T.T. (1998) Road ecology: A solution for the giant embracing us. *Landscape Ecology* **13** , iii-v.

Fry, G.L. (1995) Landscape ecology of insect movement in arable ecosystems. In: Glen, D.M., Greaves, M.P. and Anderson, H.M. (Eds.) *Ecology and integrated farming systems.*. pp. 177-202. Bristol, UK: John Wiley & Sons Ltd.

Gaston, K.J. (1998) Biodiversity. In: Sutherland, W.J. (Ed.) *Conservation Science and Action*. pp. 1-19. Oxford, UK: Blackwell Science Ltd.

Golley, F.B. (1989) Landscape ecology and biological conservation. *Landscape Ecology* **2**, 201-202.

Groot Bruinderink, G.W.T.A. and Hazebroek, E. (1996) Ungulate traffic collisions in Europe. *Conserv.Biol.* **10**, 1059-1067.

Haila, Y. (1990) Towards an ecological definition of an island: a northwest European perspective. *J. Biogeography* **17**, 561-568.

Hanski, I. and Gilpin, M. (1991) Metapopulation dynamics: brief history and conceptual domain. *Biol.J.Linn.Soc.Lond.* **42**, 3-16.

Harris, L.D. (1984) The applicability of insular biogeography. In: Anonymous *The fragmented forest. Island biogeography theory and the preservation of biotic diversity*. pp. 71-92. Chicago and London: University of Chicago Press.

Hobbs, R.J. (1992) The role of corridors in conservation: solution or bandwagon? *TREE* **7**, 389-392.

Ihse, M. (1995) Swedish agricultural landscapes - patterns and changes during the last 50 years, studied by aerial photos. *Landscape and Urban Planning* **31**, 21-37.

Jedicke, E. (1994) *Biotopverbund - Grundlagen und Massnahmen einer neuen Naturschutzstrategi.e. 2. Auflage.* Stuttgart. Germany: Eugen Ulmer Verlag GmbH & Co.

Jongman, R.H.G. (1994) *An ecological main structure for the European Union*. Cook, E.A. and Van Lier, H.N. (Eds.) 6F. 309-326. Elsevier Science B.V.

Jongman, R.H.G. (1995) Ecological and landscape consequences of land use change in Europe: introduction. In: Jongman, R.H.G. (Ed.) *Ecological and landscape consequences of land use change in Europe. Proceedings of the first ECNC seminar on land use changes and its ecological consequences.*. pp. 9-16. Tilburg, NL: ECNC.

Jongman, R.H.G. (1999) Promising national and regional approaches. *European Nature* 19-22.

Jongman, R.H.G., Bunce, R.G.H. and Elena-Rosello, R. (1998) A European perspective on the definition of landscape character and biodiversity. In: Dover, J.W. and Bunce, R.G.H. (Eds.) *Key Concepts in Landscape Ecology. - Proceedings of the 1998 European Congress of the International Association for Landscape Ecology (IALE).* pp. 21-35. Garstang, UK: UK IALE, Colin Cross Printers Ltd.

Keller, V. and Pfister, H.P. (1997) Wildlife passages as a means of mitigating effects of habitat fragmentation by roads and railway lines. In: Canters, K., Piepers, A. and Hendriks-Heersma, A. (Eds.) *Proceedings of the international conference on "Habitat fragmentation, infrastructure and the role of ecological engineering" Maastricht and The Hague 1995*. Delft, The Netherlands: Ministry of Transport, Public Works and Water Management, Road and Hydraulic Engineering division.

Knauer, N. (1980) Möglichkeiten und Schwierigkeiten bei der Schaffung funktionsfähiger Naturschutzgebiete in der Agrarlandschaft. *Landwirtschaftliche Forschung* **37**, 105-116.

Kouki, J. and Löfman, S. (1999) Forest fragmentation: processes, concepts and implications for species. In: Dover, J.W. and Bunce, R.G.H. (Eds.) *Key concepts in Landscape ecology*. pp. 187-204. Garstang, UK: UK IALE, Colin Cross Printers.

Levins, R. (1969) Some demographic and genetic consequences of environmental heterogeneity for biological control. *Bulletin of the Entomological Society of America* **15**, 237-240.

Merriam, G. (1991) Corridors and connectivity: animal populations in heterogeneous environments. In: Saunders, D.A. and Hobbs, R.J. (Eds.) *Nature Conservation 2: The role of corridors.* pp. 142. Chipping Norton: Surrey Beatty & Sons.

Naveh, Z. and Lieberman, A. (1994) *Landscape Ecology - Theory and application. 2nd edition*. Berlin: Springer Verlag.

O'Neill, R.V., DeAngelis, D.L., Waide, J.B. and Allen, T.F.H. (1986) *A hierarchical concept of ecosystems*. Princeton: Princeton University press.

Opstal, A.J.F.M. (1999) *The architecture of the Pan European Ecological Network: Suggestions for concept and criteria.* Wageningen, NL: IKCN, Rapport Nr. 37.

Pfister, H.P. (1993) *Kriterien für die Planung wildspezifischer Massnahmen zur ökologischen Optimierung massiver Verkehrsträger.* Bonn-Bad Godesberg, Germany: Bundesministerium für Verkehr, Abteilung Strassenbau.

Prillevitz,F.C. (1997) Fragmentation, not forever. - In: Canters, K., Piepers, A. and Hendriks-Heersma, A. (Eds.) *Proceedings of the international conference on "Habitat fragmentation, infrastructure and the role of ecological engineering" Maastricht and The Hague 1995*. pp. 26-29. Delft, The Netherlands: Ministry of Transport, Public Works and Water Management, Road and Hydraulic Engineering division.

Pulliam, H.R. (1988) Source-sink, and population regulation. *Am.Nat.* **132**, 652-661.

Putman, R.J. (1997) Deer and road traffic accidents: Options for management. *Journal Of Environmental Management* **51**, 43-57.

Richards, J.F. (1990) Land transformation. In: Turner, B.L., Clark, W.C., Kates, R.W., Richards, J.F., Mathews, J.T. and Meyer, W.B. (Eds.) *The Earth as transformed by human action.* pp. 163-178. New York: Cambridge University Press.

Ruhle, C. and Looser, B. (1991) Results of marking-experiments with red deer (*Cervus elaphus*) in the Cantons of St-Gallen and Graubünden (Switzerland) and in the principality of Liechtenstein. *Z.Jagdwiss.* **37**, 13-23.

RVV (1996) *Miljökonsekvensbeskrivningar i praktiken. (EIA in practise)*. Stockholm: Riksrevisionsverket 1996:29.

Saunders, D.A. and Hobbs, R.J. (1991) The role of corridors in conservation: what do we know and where do we go? In: Saunders, D.A. and Hobbs, R.J. (Eds.) *Nature Conservation 2: The role of corridors*. pp. 421-427. Chipping Norton: Surrey Beatty & Sons.

Schaefer, M. and Tischler, W. (1983) *Wörterbuch der Ökologi.e. 2. Auflage.* Stuttgart: UTB, Gustav Fischer Verlag.

Seiler, A. and Eriksson, I.-M. (1997) New approaches for ecological consideration in Swedish road planning. In: Canters, K., Piepers, A. and Hendriks-Heersma, A. (Eds.) *Proceedings of the international conference on "Habitat fragmentation, infrastructure and the role of ecological engineering" Maastricht and The Hague 1995*. pp. 253-264. Delft, The Netherlands: Ministry of Transport, Public Works and Water Management, Road and Hydraulic Engineering division.

Senft, R.L., Coughenour, M.B. and Bailey, D.W. (1987) Large herbivore foraging and ecological hierarchies. *BioScience* **37**, 789-799.

Sjögren-Gulve, P. (1994) Distribution and extinction patterns within a northern metapopulation of the pool frog, *Rana lessonae*. *Ecology* **75**, 1357-1367.

Skånes, H. and Bunce, R.G.H. (1997) Directions of landscape change (1741-1993) in Virestad, Sweden - characterised by multivariate analysis. *Landscape and Urban Planning* **38**, 61-76.

Stanners, D. and Bourdeau, P. (1995) *Europe's Environment. The Dobris Assessment.* Copenhagen, Denmark: European Environmental Agency.

Sutherland, W.J. (1998) *Conservation Science and Action*. Oxford, UK: Blackwell Science Ltd.

Sweanor, P.Y. and Sandegren, F. (1989) Winter range philopatry of seasonally migratory moose. *J.Appl.Ecol.* **26**, 25-33.

Taylor, P.D., Fahrig, L., Henein, K. and Merriam, G. (1993) Connectivity is a vital element of landscape structure. *Oikos* **68**, 571-573.

Treweek, J.R., Thompson, S., Veitch, N. & Japp, C. (1993) Ecological assessment of proposed road developments: a review of environmental statements. *Journal of Environmental Planning & Management,* **36,** 295-307.

Urban, D.L., O'Neill, R.V. and Shugart, H.H.Jr. (1987) Landscape ecology. *BioScience* **37**, 119-127.

Van Selm, A.J. (1988) Ecological infrastructure: a conceptual framework for designing habitat networks. In: Schreiber, K.F. (Ed.) *Connectivity in landscape ecology. Proceedings of the 2nd international seminar of the "International association for landscape ecology"*. pp. 63-66. Münster: Münstersche Geographische Arbeiten 29.

Verkaar, H.J. (1988) The possible role of road verges and river dikes as corridors for the exchange of plant species between natural habitats. In: Schreiber,K.F. (Ed.) *Connectivity in landscape ecology. Proceedings of the 2nd international seminar of the "International association for landscape ecology"*. pp. 79-84. Münster, Germany: Münstersche Geographische Arbeiten 29.

Verkaar, H.J. and Bekker, G.J. (1991) The significance of migration to the ecological quality of civil engineering works and their surroundings. In: Van Bohemen, H.D., Buizer, D.A.G. and Littel, D. (Eds.) *Nature engineering and civil engineering works.* Wageningen, The Netherlands: Pudoc.

Wace, N.M. (1977) Assessment of dispersal of plants species - the car-borne flora in Canberra. *Proc.Ecol.Soc.Aust*. **10**, 167-186.

Watkinson, A.R. and Sutherland, W.J. (1995) Sinks, sources, and pseudo-sinks. *J.Anim.Ecol*. **64**, 126-130.

Whittaker, R.H., Levin, S.A. and Root, R.B. (1973) Niche, habitat and ecotope. *Am.Nat.* **107**, 321-338.

Wiens, J.A. (1989) Spatial scaling in ecology. *Functional Ecol.* **3**, 385-397.

Wilcox, B.A. and Murphy, D.D. (1985) Conservation strategy: the effects of fragmentation on extinction. *Am.Nat.* **125**, 879-887.

Chapter 3

Aaris-Sorensen, J. (1995) Road-kills of badgers (*Meles meles*) in Denmark. *Ann.Zool.Fenn.* **32**, 31-36.

Adams, L.W. and Geis, A.D. (1973) Effects of roads on small mammals. *J.Appl.Ecol.* **20**, 403-415.

Åhrén, T. and Larsson, P.O. (1999) Train collisions with reindeer (*Renpåkörningar*) – In Swedish. 46 pages. Report from Swedish National Rail Administration, Banverket Norra Regionen, Luleå, Sweden.

Andrews, A. (1990) Fragmentation of habitat by roads and utility corridors: A review. *Australian Zoologist* **26**, 130-141.

Angold, P.G. (1997) The impact of a road upon adjacent heathland vegetation: Effects on plant species composition. *Journal of Applied Ecology* **34**, 409-417.

Ashley, E.P. and Robinson, J.T. (1996) Road mortality of amphibians, reptiles and other wildlife on the long point causeway, Lake Erie, Ontario. *Can.Field Nat.* **110**, 403-412.

Auerbach, N.A., Walker, M.D. and Walker, D.A. (1997) Effects of roadside disturbance on substrate and vegetation properties in arctic tundra. *Ecological Applications* **7**, 218-235.

Auestad, I., Norderhaug, A. and Austad, I. (1999) Road verges - species-rich habitats. *Aspects of Applied Biology* **54**, 269-274.

Babisch, W., Ising, H., Gallacher, J.J., Sweetnam, P.M. and Elwood, P.C. (1999) Traffic noise and cardiovascular risk: The caerphilly and speedwell studies, third phase-10-year follow up. *Archives Of Environmental Health* **54**, 210-216.

Baur, A. and Baur, B. (1990) Are roads barriers to dispersal in land snail *Arianta arbustorum*? *Canadian Journal of Zoology-Revue Canadienne de Zoologie* **68**, 613-617.

Bauske, B. and Goetz, D. (1993) Effects on de-icing salts on heavy metal mobility. *Acta Hydrochimica et Hydrobiologica* **21**, 38-42.

Bekker, J.P. and Mostert, K. (1998) Kolonisatie van Zuid-Beveland door de rosse woelmuis *Clethrionomys glareolus*. *Lutra* **40**, 77-85.

Belant, J.L. (1995) Moose collisions with vehicles and trains in northeastern Minnesota. *Alces* **31**, 45-52.

Bennett, A.F. (1991) Roads, roadsides and wildlife conservation: a review. In: Saunders, D.A. and Hobbs, R.J. (Eds.) *Nature conservation 2: The role of corridors*. pp. 99-118. Chipping Norton: Surrey Beatty & Sons.

Bennett, G. (1997) Habitat fragmentation: The European dimension. In: Canters, K., Piepers, A. and Hendriks-Heersma, A. (Eds.) *Proceedings of the international conference on Habitat fragmentation and infrastructure in Maastricht and The Hague 1995*. pp. 61-69. Delft, The Netherlands: Ministry of Transport, Public Works and Water Management, Road and Hydraulic Engineering division.

Bergkvist, B., Folkeson, L. and Berggren, D. (1989) Fluxes of Cu, Zn, Pb, Cd, Cr, and Ni in temperate forest ecosystems - a literature review. *Water Air And Soil Pollution* **47**, 217-286.

Bergmann, H.H. (1974) Zur Phänologie und Ökologie des Strassentods der Vögel. *Vogelwelt* **95**, 1-21.

Bernard, J.-M., Lansiart, M., Kempf, C. and Tille, M. (Eds.) (1987) *Actes du colloques 'Route et fauna sauvage'. Strasbourg, Conseil de l'Europe, 5-7 Juin 1985*. Ministère de l'Equipement, du Longement, de l'Aménagement du Territoire et des Transports, et Ministère délégué chargé de l'Environnement, Colmar, France. 403 pp.

Berthoud, G. (1987) Impact d'une route sur une population de chevreuils. In: Bernard, J.-M., Lansiart, M., Kempf, C. and Tille, M. (Eds.) *Actes du colloques 'Route et fauna sauvage'. Strasbourg, 1985*, pp. 167-170. Colmar, France. Ministère de l'Equipement, du Longement, de l'Aménagement du Territoire et des Transports.

Blair, R.B. (1996) Land use and avian species diversity along an urban gradient. *Ecol.Appl.* **6**, 506-519.

Blake, D., Hutson, A.M., Racey, P.A., Rydell, J. and Speakman, J.R. (1994) Use of lamplit roads by foraging bats in southern England. *Journal Of Zoology* **234**, 453-462.

Blomqvist,G. (1998) *Impact of de-icing salt on roadside vegetation - a literature review.* VTI rapport 427A edn.. Linköping, Sweden: Swedish National Road and Transport Research Institute, VTI rapport 427A.

Buchanan, B.W. (1993) Effects of enhanced lightning on the behaviour of nocturnal frogs. *Animal Behaviour* **45**, 893-899.

Campbell, N.A. (1990) Biology (2nd Edition), Benjamin Cummings Publishers Inc.

Canters, K., Piepers, A. and Hendriks-Heersma, A. (1997) *Habitat fragmentation, infrastructure and the role of ecological engineering. - Proceedings of the international conference on Habitat fragmentation and infrastructure in Maastricht and the Hague*

1995. Delft, The Netherlands: Ministry of Transport, Public Works and Water Management, Road and Hydraulic Engineering division.

Clark, B.K., Clark, B.S., Johnson, L.A. and Haynie, M.T. (2001) Influence of roads on movements of small mammals. *Southwestern Naturalist* **46**, 338-344.

Clarke, G.B., White, P.C.L. and Harris, S. (1998) Effects of roads on badger *Meles meles* populations in south-west England. *Biol.Conserv.* **86**, 117-124.

Clevenger A. P. (1998) Highways and wildlife – An online bibliography. http://www.cmiae.org/biblio.html [October 2002]

Cuperus, R., Canters, K.J., de Haes, H.U. and Friedman, D.S. (1999) Guidelines for ecological compensation associated with highways. *Biol.Conserv.* **90**, 41-51.

Curatolo, J.A. and Murphy, S.M. (1986) The effect of pipelines, roads, and traffic on the movements of Caribou (*Rangifer tarandus*). *Can. Field Nat.* **100**, 218-224.

De Molenaar, J.G., Jonkers, D.A. and Sanders, M. (2000) *Wegverlichting en natuur III Lokale invloed van wegverlichting op een gruttopopulatie.* Dienst Weg- en Waterbouwkunde/Instituut voor Bos- en Natuuronderzoek, Delft/Wageningen.

Dehlinger, J. (1994) Amphibienschutz - Leitfaden für Schutzmassnahmen an Strassen. *Schriftereihe der Strassenbauverwaltung* Heft 4. Stuttgart, Germany: Verkehrsministerium Baden Württemberg.

Douglass, R.J. (1977) Effects of a winter road on small mammals. *J.Appl.Ecol.* **14**, 827-834.

DWW (1995) *Nature across motorways*. Bekker, H., Van den Hengel, B., Van Bohemen, H. D., and Van der Sluijs, J. (Eds.). Delft, The Netherlands: Rijkswaterstaat, Dienst Weg- en Waterbouwkunde.

Ellenberg, H., Müller, K. and Stottele, T. (1981) *Strassen-Ökologie: Auswirkungen von Autobahnen und Strassen auf Ökosysteme deutscher Landschaften.* Deutsche Strassenliga, Bonn.

Ernst, W.O. (1998) Invasion, dispersal and ecology of the South African neophyte Senecio inaequidens in The Netherlands: from wool alien to railway and road alien. *Acta Botanica Neerlandica* **47**, 131-151.

Evers, F.H. (1976) Zur Ausbreitung von Streusalzschäden im Innern von Waldbeständen. (in German). *Forstw.Cbl.* **95**, 251-264.

Evink, G.L., Garrett, P. and Zeigler, D. (Eds.) 1999. *Proceedings of the third International Conference on Wildlife and Transportation*. FL-ER-73-99. Florida Department of Transportation, Tallahassee, Florida. pp. 330.

Evink, G.L., Garrett, P., Zeigler, D. and Berry, J. (Eds.) 1996. *Highways and movement of wildlife: Improving habitat conditions and wildlife passageways across highway corridors. Proceedings of the Florida Department of Transportation / Federal Highway Administration transportation-related wildlife mortality seminar. Orlando April 30 - May 2, 1996*. Florida Department of Transportation, FHWA-PD-96-041. Tallahassee, Florida pp. 336.

Evink, G.L., Garrett, P., Zeigler, D. and Berry, J. (Eds.) (1998) *Proceedings of the International Conference on Wildlife Ecology and Transportation. Florida Department of Transportation*, FL-ER-69-98. Tallahassee, Florida. pp. 263.

Fahrig, L., Pedlar, J.H., Pope, S.E., Taylor, P.D. and Wegener, J.F. (1995) Effect of road traffic on amphibian density. *Biol.Conserv.* **73**, 177-182.

Feldhamer, G.A., Gates, J.E., Harman, D.M., Loranger, A.J. and Dixon, K.R. (1986) Effects of interstate highway fencing on white-tailed deer activity. *Journal of Wildlife Management* **50**, 497-503.

Finder, R.A., Roseberry, J.L. and Woolf, A. (1999) Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. *Landscape and Urban Planning* **44**, 77-85.

Findlay, C.S. and Bourdages, J. (2000) Response time of wetland biodiversity to road construction on adjacent lands. *Conservation Biology* **14**, 86-94.

Foppen, R. and Reijnen, R. (1994) The effects of car traffic on breeding bird populations in woodland. 2. Breeding dispersal of male willow warblers (*Phylloscopus trochilus*) in relation to the proximity of a highway. *J.Appl.Ecol.* **31**, 95-101.

Forbes, B.C. (1995) Tundra disturbance studies.3. Short-term effects of aeolian sand and dust, Yamal region, northwest Siberia. *Environmental Conservation* **22**, 335-344.

Forman, R.T.T. (1995) *Land mosaics: The ecology of landscapes and regions*. Cambridge: Cambridge University Press.

Forman, R.T.T. (1998) Road ecology: A solution for the giant embracing us. *Landscape Ecology* **13**, iii-v.

Forman, R.T.T. (2000) Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology* **14**, 31-35.

Forman, R.T.T. and Alexander, L.E. (1998) Roads and their major ecological effects. *Annual Review of Ecology and Systematics* **29**, 207-231.

Forman, R.T.T. and Deblinger, R.D. (2000) The ecological road-effect zone of a Massachusetts (USA) suburban highway. *Conservation Biology* **14**, 36-46.

Forman, R.T.T., Friedman, D.S., Fitzhenry, D., Martin, J.D., Chen, A.S. and Alexander, L.E. (1997) Ecological effects of roads: Towards three summary indices and an overview for North America. In: Canters, K., Piepers, A. and Hendriks-Heersma, A. (Eds.) *Proceedings of the international conference on 'Habitat fragmentation, infrastructure and the role of ecological engineering' Maastricht and the Hague 1995*. pp. 40-54. Delft, The Netherlands: Ministry of Transport, Public Works and Water Management, Road and Hydraulic Engineering division.

Frank, K.D. (1990) The impact of lighting on mots: an assessment, Journal of Lepidopterist's Society, 42, 63-93

Getz, L.L., Cole, F.R. and Gates, D.L. (1978) Interstate roadsides as dispersal routes for *Microtus pennsylvanicus*. *J.Mammal.* **59**, 208-212.

Gjessing, E., Lygren, E., Berglind, L., Gullbranden, T. and Skanne, R. (1984) Effect of highway runoff on lake water quality. *Science of the Total Environment* **33**, 247-257.

Glitzner, I., Beyerlein, P., Brugger, C., Egermann, F., Paill, W., Schlögel, B. and Tataruch, F. (1999) *Anlage- und betriebsbedingte Auswirkungen von Strassen auf die Tierwelt - Literaturstudie.* Graz, Austria: MA 22 Naturschutz und Landschaftspflege, Beiträge zum Umweltschutz, Heft 60/99.

Göransson, G., Karlsson, J. and Lindgren, A. (1978) *Influence of roads on the surrounding nature. II. Fauna*. Stockholm, Sweden: Swedish Environmental Protection Agency, SNV PM 1069.

Gratson, M.W. and Whitman, C.L. (2000) Road closures and density and success of elk hunters in Idaho. *Wildlife Society Bulletin* 28, 302-310.

Groot Bruinderink, G.W.T.A. and Hazebroek, E. (1996) Ungulate traffic collisions in Europe. *Conserv.Biol*. 10, 1059-1067.

Gundersen, H. and Andreassen, H.P. (1998) The risk of moose *Alces alces* collision: A predictive logistic model for moose-train accidents. *Wildlife Biology* -110.

Gundersen, H., Andreassen, H.P. and Storaas, T. (1998) Spatial and temporal correlates to Norwegian moose - train collisions. *Alces* **34**, 385-394.

Hamilton, R.S. and Harrison, R.M. (1991) *Highway pollution: Studies in environmental sciences*. Amsterdam: Elsevier.

Hansen, K. and Jensen, J. (1972) The vegetation on roadsides in Denmark. *Dansk Bot.Ark.* **28**, 1-61.

Hansen, L. (1982) Road kills in Denmark (in Danish with English abstract). *Dansk Ornitologisk Forenings Tidskrift* **76**, 97-110.

Hartwig, D. (1993) Auswertung der durch Wild verursachten Verkehrsunfälle nach der Statistik für Nordrhein-Westfalen. *Z.Jagdwiss.* **39**, 22-33.

Haugen, A.O. (1944) Highway mortality in southern Michigan. *J. Mammal*. **25**: 177-184.

Havlin, J. (1987) On the importance of railway lines for the avifauna in agro-coenoses. *Folia zool.* **36**, 345-358.

Helldin, J.O. and Seiler, A. (2001) Effects of roads on the abundance of birds in Swedish forest and farmland. *Submitted to J. Appl. Ecol.*

Hill, D. (1992) *The impact of noise and artificial light on waterfowl behaviour: a review and synthesis of available literature*. Tring, UK: British Trust for Ornithology.

Hill, D. et al. (1997) *Integrating habitats and species protection into transport and regional development policies: An initial study*. Ecoscope Applied Ecologists. North Yorkshire.

Holbrook, H.T. and Vaughan, M.R. (1985) Influence of roads on turkey mortality. *J.Wildl.Manage.* **49**, 611-614.

Holzang, O., Sieber, U., Heynen, D., von Lerber, F., Keller, V. and Pfister, H.P. (2000) *Wildtiere und Verkehr - eine kommentierte Bibliographie.* Sempach, Switzerland: Schweizerische Vogelwarte.

Huijser, M.P., Bergers, P.J.M. and Ter Braak, C.J. (1998) *Het voorkomen van doodgereden egels in relatie tot de samenstelling van het landschap*. Delft: Rijkswaterstaat Dienst Weg- en Waterbouwkunde.

Huijser, M.P., Van der Grift, E.A. and Bekker, G.J. (1999) Habitat fragmentation and infrastructure: A review of the proceedings of a European and a North American conference. *Lutra* **41**, 43-54.

Ihse, M. (1995) Swedish agricultural landscapes - patterns and changes during the last 50 years, studied by arial photos. *Landscape and Urban Planning* **31**, 21-37.

Illner, H. (1992) Effect of roads with heavy traffic on Grey partridge (*Perdix perdix*) density. *Gibier Faune Sauvage* **9**, 467-480.

Jalkotzky, M.G., Ross, P.I. and Nasserden, M.D. (1997) *The effects of linear development on wildlife: a review of selected scientific literature*. Prepared by the Arc Wildlife Services Ltd. 2201 - 34 St. S.W., Calgary, Alberta T3E 2W2, Canada (unpublished report, accessible from the author).

Jaren, V., Andersen, R., Ulleberg, M., Pedersen, P.-H. and Wiseth, B. (1991) Moose-train collisions: the effects of vegetation removal with a cost-benefit analysis. *Alces* **27**, 93-99.

Jedicke, E. (1994) *Biotopverbund - Grundlagen und Massnahmen einer neuen Naturschutzstrategie. 2. Auflage.* Stuttgart, Germany: Eugen Ulmer Verlag GmbH & Co.

Job, R.S. (1996) The influence of subjective reactions to noise on health effects of the noise. *Environment International* **22**, 93-104.

Jones, J.A., Swanson, F.J., Wemple, B.C. and Snyder, K.U. (2000) Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. *Conservation Biology* **14**, 76-85.

Jongman, R.H.G. (1994) *An ecological main structure for the European Union*. Cook, E.A. and Van Lier, H.N. (Eds.) 6F. 309-326. Elsevier Science B.V.

Joule, J. and Cameron, G.N. (1974) Field estimation of demographic parameters: influence of roads on *Sigmodon hispidus* population structure. *J.Mammal.* **55**, 309-318.

Keeley, B. and Tuttle, M. (1999) Bats in American bridges. In: Evink, G.L., Garrett, P. and Zeigler, D. (Eds.) *Proceedings of the third International Conference on Wildlife and Transportation.* pp. 167-172. Tallahassee, Florida. FL-ER-73-99. Florida Department of Transportation.

Klein, D.R. (1971) Reaction of reindeer to obstructions and disturbances. *Science* **173**, 393-398.

Kofler, H. and Schulz, W. (1987) Wildunfälle und Schutzmassnahmen in Österreich. In: Bernard, J.-M., Lansiart, M., Kempf, C. and Tille, M. (Eds.) *Actes du colloques 'Route et fauna sauvage'. Strasbourg, 1985*. pp. 93-102. Colmar, France. Ministère de l'Equipement, du Longement, de l'Aménagement du Territoire et des Transports.

Kolb, H.-H. (1984) Factors affecting the movement of dog foxes in Edinburgh. *J.Appl.Ecol.* **21**, 161-173.

Kozel, R.M. and Fleharty, E.D. (1979) Movements of rodents across roads. *Science* **24**, 239-248.

Kuhn, J. (1987) Strassentod der Erdkröte (*Bufo bufo*): Verlustquoten und Verkehrsaufkommen, Verhalten auf der Strasse. *Beih.Veröff.Naturschutz & Landschaftspflege in Baden-Württemberg* **41**, 175-186.

Kuitunen, M., Rossi, E. and Stenroos, A. (1998) Do highways influence density of land birds? *Environmental Management* **22**, 297-302.

Laursen, K. (1981) Birds on roadside verges and the effect of mowing on frequency and distribution. *Biol.Conserv.* **20**, 59-68.

Lavsund, S. and Sandegren, F. (1991) Moose-vehicle relations in Sweden: a review. Alces **27**: 118-126.

Lines, J.A., Lee, S.R. and Stiles, M.A. (1994) Noise in the countryside. *Journal Of Agricultural Engineering Research* **57**, 251-261.

Lode, T. (2000) Effect of a motorway on mortality and isolation of wildlife populations. *Ambio* **29**, 163-166.

Lofts, I. And Merton, N. (1968) Photoperiodic and physiological adaptations regulating avian breeding cycles and their ecological significance, Journal of the Zoological Society of London **155**, 327-394

Loney, B. and Hobbs, R.J. (1991) Management of vegetation corridors: maintenance, rehabilitation and establishment. In: Saunders, D.A. and Hobbs, R.J. (Eds.) *Nature conservation 2: The role of corridors*. pp. 299-311. Chipping Norton: Surrey Beatty & Sons.

Mader, H.J. (1984) Animal habitat isolation by roads and agricultural fields. *Biol.Conserv.* **29**, 81-96.

Mader, H.J. (1987a) Direkte und indirekte einflüsse des Strassennetzes auf die freilebende Tierwelt und auf die Populationsdynamik. In: Bernard, J.-M., Lansiart, M., Kempf, C. and Tille, M. (Eds.) *Actes du colloques 'Route et fauna sauvage'. Strasbourg. 1985*, pp. 19-

29. Colmar, France. Ministère de l'Equipement, du Longement, de l'Aménagement du Territoire et des Transports.

Mader, H.J. (1987b) Strassenränder, Verkehrsnebenflächen - Elemente eines Biotopverbundsystems? *Natur und Landschaft* **62**, 296-299.

Mader, H.J. (1988) The significance of paved agricultural roads as barriers to ground dwelling arthropods. In: Schreiber, K.F. (Ed.) *Connectivity in landscape ecology. Proceedings of the 2nd international seminar of the 'International association for landscape ecology'*. pp. 97-100. Münster, Germany: Münstersche Geographische Arbeiten 29.

Mader, H.J. and Pauritsch, G. (1981) Nachweis des Barriere-Effektes von verkehrsarmen Straßen und Feldwegen auf Kleinsäuger der Waldbiozönose durch Markierungs- und Umsetzversuche. *Natur und Landschaft* **56**, 451-454.

Mader, H.J., Krause, A. and Brandes, D. (1983) *Zur Tier und Pflanzenwelt an Verkehrswegen.* Sonderheft 4 der Dokumentation für Umweltschutz und Landschaftspflege. Bonn-Bad Godesberg, Germany: Bundesforschungsanstalt für Naturschutz und Landschaftsökologie.

Mader, H.J., Schell, C. and Kornacker, P. (1990) Linear barriers to arthropod movements in the landscape. *Biol.Conserv.* **54**, 209-222.

Madsen, A.B., Fyhn, H.W. and Prang, A. (1998) Traffic killed animals in landscape ecological planning and research. In: Danish: *Trafikdræbte dyr i landskabsøkologisk planlægning og forskning*. – DMU Rapport 228, Århus, DK.

Madsen, J. (1985) Impact of disturbance on field utilization of pink-footed geese in West Jutland, Denmark. *Biol.Conserv.* **33**, 53-64.

Melman, P.J.M. and Verkaar, H.J. (1991) Layout and management of herbaceous vegetation in road sides. In: Van Bohemen, H.D., Buizer, D.A.G. and Littel, D. (Eds.) *Nature engineering and civil engineering works*. pp. 62-78. Wageningen, The Netherlands: Pudoc.

Merriam, G., Kozakiewicz, M., Tsuchiya, E. and Hawley, K. (1989) Barriers as boundaries for metapopulations and demes of *Peromyscus leucopus* in farm landscapes. *Landscape Ecology* **2** , 227-235.

Meunier, F.D., Verheyden, C. and Jouventin, P. (1999) Bird communities of highway verges: Influence of adjacent habitat and roadside management. *Acta Oecologica-International Journal Of Ecology* **20**, 1-13.

Mladenoff, D.J., Sickley, T.A. and Wydeven, A.P. (1999) Predicting gray wolf landscape recolonization: Logistic regression models vs. new field data. *Ecological Applications* **9**, 37-44.

Müller, S. and Berthoud, G. (1997) *Fauna and traffic safety*. Lausanne, CH: LAVOC.

Newmark, W.D., Boshe, J.I., Sariko, H.I. and Makumbule, G.K. (1996) Effects of a highway on large mammals in Mikumi National Park, Tanzania. *African Journal Of Ecology* **34**, 15-31.

Niering, W.A. and Goodwin, R.H. (1974) Creation of relatively stable shrublands with herbicides: arresting 'succession' on right-of-way and pasture land. *Ecology* **55**, 784-795.

OECD (1994) *Environmental impact of roads*. Paris, France.: Road Transport research, Organisation for Economic Co-operation and development, OECD Scientific Expert Group.

Oxley, D.J., Fenton, M.B. and Carmody, G.R. (1974) The effects of roads on populations of small mammals. *J.Appl.Ecol.* **11**, 51-59.

Philcox, C.K., Grogan, A.L. and Macdonald, D.W. (1999) Patterns of otter *Lutra lutra* road mortality in Britain. *J.Appl.Ecol.* **36**, 748-762.

Pierre-Le Pense, A.-M. and Carsignol, J. (Eds.) (1999) *Actes des troisièmes rencontres 'Route et fauna sauvage'*. Ministère de l'Equipement, des Transports et du Longement et Ministère de l'Aménagement du Territoire et de l'Environnement. Paris, France. pp. 460.

Puglisi, M.J., Lindzey, J.S. and Bellis, E.D. (1974) Factors associated with highway mortality of white-tailed deer. *Journal of Wildlife Management* **38**, 799-807.

Putman, R.J. (1997) Deer and road traffic accidents: Options for management. *Journal Of Environmental Management* **51**, 43-57.

Räty, M. (1979) Effect of highway traffic on tetraonid densities. *Ornis Fenn.* **56**, 169-170.

Reck, H. and Kaule, G. (1993) *Strassen und Lebensräume: Ermittlung und Beurteilung strassenbedingter Auswirkungen auf Pflanzen, Tiere und ihre Lebensräume.* Bonn-Bad Godesberg, Germany. Bundesministerium für Verkehr, Abteilung Strassenbau.

Reh, W. and Seitz, A. (1990) The influence of land use on the genetic structure of populations of the common frog (*Rana temporaria*). *Biol.Conserv.* **54**, 239-249.

Reichelt, G. (1979) Landschaftsverlust durch Straßenbau. (*Loss of landscapes due to road construction*). *Natur und Landschaft* **54**, 335-338.

Reicholf, J. and Esser, J. (1981) Daten zur Mortalität des Igels (*Ericaneus europaeus*) verursacht durch den Strassenverkehr. *Z.Säugetierkd.* **46**, 216-222.

Reijnen, M.J.M.G. (1995) Disturbance by car traffic as a threat to breeding birds in the Netherlands. Proefschrift Universiteit Leiden.

Reijnen, R. and Foppen, R. (1994) The effects of car traffic on breeding bird populations in woodland. 1. Evidence of reduced habitat quality for willow warblers (Phylloscopus trochilus) breeding close to a highway. *J.Appl.Ecol.* **31**, 85-94.

Reijnen, R., Foppen, R., Ter Braak, C.J. and Thissen, J. (1995a) The effects of car traffic on breeding bird populations in woodland. 3. Reduction of density in relation to the proximity of main roads. *J.Appl.Ecol.* **32**, 187-202.

Reijnen, M., Veenbaas, G. and Foppen, R. (1995b) *Predicting the effects of motorway traffic on breeding bird populations*. Delft, The Netherlands. Road and Hydraulic Engineering Division and DLO-Institute for Forestry and Nature Research, P-DWW-95-736.

Reijnen, R., Foppen, R. and Veenbaas, G. (1997) Disturbance by traffic of breeding birds: Evaluation of the effect and considerations in planning and managing road corridors. *Biodiversity and Conservation* **6**, 567-581.

Richardson, J.H., Shore, R.F., Treweek, J.R. and Larkin, S.C. (1997) Are major roads a barrier to small mammals? *Journal Of Zoology* **243**, 840-846.

Rodríguez, A. and Delibes, M. (1992) Current range and status of the Iberian lynx *Lynx pardinus* Temminck, 1824 in Spain. *Biological Conservatio*n, **61**, 189-196.

Rodts, J., Holsbeek, L. and Muyldermons, S. (1998) *Dieren onder onze wielen.* Vubpress, Brussel: Koninklijk Belgisch Verbond voor de Bescherming van de Vogels. ISBN 90 5487 185 7 NUGI 829.

Romin, L.A. and Bissonette, J.A. (1996) Deer-vehicle collisions: Status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin* **24**, 276-283.

Rosell, C. and Velasco Rivas, J.M. (1999) *Manual on preventing and remedying the impact of roads on fauna*. Barcelona, Spain. Generalitat de Catalunya, Departement de Medi Ambient, Secretaria General.

Rost, G.R. and Bailey, J.A. (1979) Distribution of mule deer and elk in relation to roads. *J.Wildl.Manage.* **43**, 634-641.

Rydell, J. (1992) Exploitation of insects around streetlamps by bats in Sweden. *Functional Ecology* **6**, 744-750.

Santelmann, M.V. and Gorham, E. (1988) The influence of airborne road dust on the chemistry of Phagnum mosses. *Journal of Ecology* **76**, 1219-1231.

Sayer, M. and Schaefer, M. (1989) *Wert und Entwicklungsmöglichkeiten straßennaher Biotope für Tiere I.* Bonn-Bad Godesberg, Heft 569, Germany. Forschung, Straßenbau und Straßenverkehrstechnik. Bundesministerium für Verkehr, Abteilung Straßenbau.

Scanlon, P.F. (1987) Heavy metals in small mammals in roadside environments - implications for food chains. *Science of the Total Environment* **59**, 317-323.

Scanlon, P.F. (1991) Effects of highway pollutants upon terrestrial ecosystems. In: Hamilton, R.S. and Harrison, R.M. (Eds.) *Highway pollution. Studies in environmental sciences*. pp. 281-338. Amsterdam: Elsevier.

Schmidley, D.J. and Wilkins, K.T. (1977) *Composition of small mammal populations on highway right-of-way in east Texas.* Texas State Department of Highways and Public Transportation, Research Report 197-1F.

Schmidt, W. (1989) Plant dispersal by motor cars. *Vegetatio* **80**, 147-152.

Seiler, A. and Eriksson, I.-M. (1997) New approaches for ecological consideration in Swedish road planning. In: Canters, K., Piepers, A. and Hendriks-Heersma, A. (Eds.) *Proceedings of the international conference on 'Habitat fragmentation, infrastructure and the role of ecological engineering' Maastricht and the Hague 1995*. pp. 253-264. Delft, The Netherlands. Ministry of Transport, Public Works and Water Management, Road and Hydraulic Engineering division.

Shaw, *E.G.* (1996) Noise environments outdoors and the effects of community noise exposure. *Noise Control Engineering Journal* **44**, 109-119.

Sjölund, A., Eriksson, O., Persson, T. and Hammarqvist, J. (1999) *Vägkantsfloran*. Borlänge, Sweden. Swedish National Road Administration, Publ. 1999:40.

Spellerberg, I.F. (1998) Ecological effects of roads and traffic: a literature review. *Global Ecology And Biogeography Letters* **7**, 317-333.

Stansfeld, S.A., Sharp, D.S., Gallacher, J. and Babisch, W. (1993) Road traffic noise, noise sensitivity and psychological disorder. *Psychological Medicine* **23**, 977-985.

Steiof, K. (1996) Roadside vegetation - a death-trap for birds. (Verkehrsbegleitendes Grün als Todesfalle für Vögel). *Natur und Landschaft* **71**, 527-532.

Stoner, D. 1925. The toll of the automobile. - *Science* 61: 56-58.

Stubbe, M. (1993) Monitoring Fishotter - Grundlagen zum überregionalen Management einer bedrohten Säugetierart in Deutschland. In: Anonymous *Tiere im Konflikt 1, Fischotter Monitoring 1985 - 1991.* pp. 3-10. Halle-Wittenberg. Matin-Luther Universität.

Svensson, A.M. and Rydell, J. (1998) Mercury vapour lamps interfere with the bat defence of tympanate moths (*Operophtera* spp.*; Geometridae*). *Animal Behaviour* **55**, 223-226.

Sweden Statistics (1999) *Statistical Yearbook of Sweden*. Statistics Sweden, Stockholm.

Swihart, R.K. and Slade, N.A. (1984) Road crossing in *Sigmodon hispidus* and *Microtus ochrogaster*. *J.Mammal.* **65**, 357-360.

Thiel, R.T. (1985) Relationship between road densities and wolf habitat suitability in Wisconsin. *Am.Midl.Nat.* **113**, 404-407.

Trewhella, W.J. and Harris, S. (1990) The effect of railway lines on urban foxes (*Vulpes vulpes*) numbers and dispersal movements. *J.Zool.Lond.* **221**, 321-326.

Trombulak, S.C. and Frissell, C.A. (2000) Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* **14**, 18-30.

Tyser, R.W. and Worley, C.A. (1992) Alien flora in grasslands adjacent to road and trail corridors in Glacier National-park, Montana (USA). *Conservation Biology* **6**, 253-262.

Usher, M.B. (1988) Biological invasions of nature reserves. *Biol.Conserv.* **44**, 119-135.

Van Bohemen, H.D., Buizer, D.A.G. and Littel, D. (Eds.) (1991) *Nature engineering and civil engineering works*, pp. 62-78. Wageningen, The Netherlands: Pudoc.

Van den Tempel, R. (1993) *Vogelslachtoffers in het wegverkeer* (in Dutch with English summary). - Vogelbescherming Nederland, Ministerie van Verkeer en Waterstaat, Directoraat-Generaal Rijkswaterstaat. Delft.

Van der Grift, E.A. (1999) Mammals and railways: Impacts and management implications. *Lutra* **42**, 77-98.

Van der Sluijs, J. and Van Bohemen, H.D. (1991) Green elements of civil engineering works and their (potential) ecological importance. In: Van Bohemen, H.D., Buizer, D.A.G. and Littel, D. (Eds.) *Nature engineering and Civil Engineering Works*. pp. 21-32. Wageningen, The Netherlands: PUDOC.

Van der Zande, A.N., Ter Keurs, W.J. and Van der Weijden, W.J. (1980) The impact of roads on the densities of four bird species in an open field habitat - evidence of a long-distance effect. *Biol.Conserv.* **18**, 299-321.

Van der Zee, F.F., Wiertz, J., Ter Braak, C.J. and Van Apeldoorn, R.C. (1992) Landscape change as a possible cause of the badger *Meles meles* L. decline in the Netherlands. *Biol.Conserv.* **61**, 17-22.

Van Dyke, F.B., Brocke, R.H., Shaw, H.G., Ackerman, B.B., Hemker, T.P. and Lindzey, J.S. (1986) Reactions of mountain lions to logging and human activity. *Journal of Wildlife Management* **50**, 95-102.

Van Gelder, J.J. (1973) A quantitative approach to the mortality resulting from traffic in a population of *Bufo bufo*. *Oecologia* **13**, 93-95.

Van Gent, H.A. and Rietveld, P. (1993) Road transport and the environment in Europe. *Science of the Total Environment* **129**, 205-218.

Veen, J. (1973) De verstoring van weidevogelpopulaties. *Stedeb.en Volkshuisv.* **53**, 16-26.

Verkaar, H.J. and Bekker, G.J. (1991) The significance of migration to the ecological quality of civil engineering works and their surroundings. In: Van Bohemen, H.D., Buizer, D.A.G. and Littel, D. (Eds.) *Nature engineering and civil engineering works*, Wageningen, The Netherlands: Pudoc.

Vos, C.C. and Chardon, J.P. (1998) Effects of habitat fragmentation and road density on the distribution pattern of the moor frog *Rana arvalis*. *Journal of Applied Ecology* **35**, 44-56.

Wace, N.M. (1977) Assessment of dispersal of plants species - the car-borne flora in Canberra. *Proc.Ecol.Soc.Aust.* **10**, 167-186.

Warner, R.E. (1992) Nest ecology of grassland Passerines on road right-of-ways in central Illinois. *Biol.Conserv.* **59**, 1-7.

Warren, M.L. and Pardew, M.G. (1998) Road crossings as barriers to small-stream fish movement. *Transactions of the American Fisheries Society* **127**, 637-644.

Way, J.M. (1977) Roadside verges and conservation in Britain: a review. *Biol.Conserv.* **12**, 65-74.

Wildlands CPR (2001) Wildlands Center for preventing roads. http://www.wildlandscpr.org/ [October 2002]

Chapter 4

Bohn, U. (2000) *General Map of the Natural Vegetation of Europe*. Federal Agency for Nature Conservation, Bonn.

CE, UNEP and ECNC (1996) *The Pan-European Biological and Landscape Diversity Strategy - a vision for Europe's natural heritage*. ISBN 90-802482-4-x, Mart Spruijt BV, Amsterdam. pp. 50. http://www.strategyguide.org/fulltext.html

CEC (1996) *Council Decision 1692/96/EC on Community Guidelines for the Development of a Trans-European Transport Network*. Commission of the European Communities. Office for Official Publications of the European Communities. Luxembourg. 104 pp.

CEC (2000) *EU Transport in Figures 2000 – Statistical Pocket Book. Commission of the European Communities*. Directorate-General for Energy and Transport / Statistical Office of the European Communities. Office for Official Publications of the European Communities. Luxembourg. pp. 153.

CEC (2001a) *Transeuropean networks: a few budget figures – TEN-T funding and achievements*. Commission of the European Communities. Directorate-General for Energy and Transport. http://europa.eu.int/comm/transport/themes/network/english/tn_16_en.html [12-05-2001]

CEC (2001b) *Transeuropean networks: heading east with TINA*. Commission of the European Communities. Directorate-General for Energy and Transport. http://europa.eu.int/comm/transport/themes/network/english/tn_15_en.html [12-05-2001]

CEC (2001c) *Proposal for a Decision of the European Parliament and of the Council amending Decision No 1692/96/EC on Community guidelines for the development of the trans-European transport network, 2001*. Commission of the European Communities. http://europa.eu.int/comm/transport/library/tent_rev_en.pdf

DETR (1999) *Transport Statistics Great Britain 1999*. Department of the Environment, Transport and the Regions. http://www.transtat.detr.gov.uk/roadtraf/gor/gblen99.htm [3-11-2000]

EC (1999) *European Spatial Development Perspective*. Office for Official Publications of the European Communities, Luxembourg. 82 p.

EC (2000a) *Second annual survey on the implementation and enforcement of Community environmental law*. Working document of the Commission Services. Office for Official Publications of the EC. Luxembourg. 99 p. ISBN 92-828-9324-3.

EC (2000b) *Regular report from the Commission on progress of Slovakia towards accession.* http://www.europa.eu.int/comm/enlargement (March 2001)

EC (2000c) *Regular report from the Commission on progress of Estonia towards accession.* http://www.europa.eu.int/comm/enlargement. (March 2001)

EC (2000d) *Regular report from the Commission on progress of Lithuania towards accession*. http://www.europa.eu.int/comm/enlargement (March 2001)

EC (2000e) *Regular report from the Commission on progress of Slovenia towards accession.* http://www.europa.eu.int/comm/enlargement (March 2001)

EC (2000f*) Regular report from the Commission on progress of Latvia towards accession.* http://www.europa.eu.int/comm/enlargement (March 2001)

EEA (1998a) *Europe's Environment: the second assessment*. Office for Official Publications of the European Communities, Luxembourg & Elsevier Science Ltd, Oxford. pp. 293. ISBN 92-828-3351-8.

EEA (1998b) *Spatial and ecological assessment of the TEN: demonstration of indicators and GIS methods.* European Environment Agency. Copenhagen. Denmark. pp. 52.

EEA (2000) *Are we moving in the right direction? Indicators on transport and environment integration in the EU*. Environmental Issue Series Nº12. European Environment Agency. Copenhagen. Denmark. pp. 136.

Fisher, Ian and Waliczky, Zoltán (2001*) An assessment of the potential impact of the TINA network on Important Bird Areas (IBAs) in the accession countries – Final Report*. The Royal Society for the Protection of Birds. BirdLife International. pp. 76 (plus maps).

Foppen, R.P.B., Bouwma, I.M., Kalkhoven, J.R.T., Dirksen, J. and Opstal, S. van (1999) Corridors of the pan-European Ecological Network: concepts and examples. STRA_REP (99) 10.

Foppen, R.P.B., Bouwma, I.M., Kalkhoven, J.T.R., Dirksen , J. and Van Opstal, S. (2000) *Corridors of the Pan-European Ecological Network. Concepts and examples for terrestrial and freshwater vertebrates*. ECNC. Tilburg. pp. 56.

García, R. and Herrero, J. (1999) El bucardo en los Pirineos: Historia de una extinción. *Galemys*, **11** (1): 17-25.

IUCN (2000) *Red List of Threatened Species*. IUCN, Gland, Switzerland and Cambridge, UK. xviii + pp. 61. www.redlist.org.

Jongman, R.H.G.(Ed.) (1995) *Ecological and landscape consequences of land use change in Europe*. Proceedings of the first ECNC seminar on land use change and its ecological consequences. ECNC, Tilburg. pp. 410.

Mander, U., A. Printsmann and H. Palang (2001) *IALE European Conference 2001 Development of European Landscapes.* Volume I and II. Institute of Geography, University of Tartu, Tartu. pp. 804.

Mitchell-Jones, A.J., Amori, G., Bogdanowicz, W., Kryštufek, B., Reijnders, P.J.H., Spitzenberger, F., Stubbe, M., Thissen, J.B.M., Vohralík, V. and Zima, J. (1999) *The Atlas of European Mammals*. Poyser, T. and Poyser, A.D. London. pp. 484.

Mücher, C.A. (2000) *PELCOM, development of a consistent methodology to derive land cover information on a European scale from remote sensing for environmental modelling*. EC, DG X-II-D Science Research and Development, Brussel/Luxembourg. pp. 299.

Perzanowski, K. and Kozak, I. (1999) The Carpathian bison *Bison bonasus*: its past and future. *Biosphere Conservation* **2:** 75-81.

Petit, S., Wyatt, B., Firbank, L., Howard, D., Bunce, R., Hill, M., Swetnam, R., Bull, K., Morton, D., Cooper, J. and Foppen, R. (1998) *MIRABEL - Models for Integrated Review and Assessment of Biodiversity in European Landscapes.* Report of ITE (NERC), IBN-DLO and NINA to the European Environment Agency Topic Centre on Nature Conservation. Paris.

Rauer, G., and Gutleb, B. (1997) *The brown bear in Austria [Der Braunbär in Österreich]*. Ministry for Envionment, Youth and Family, Monographien, Band 88. Wien. pp. 64.

Skvortsov, O. (1995) *Prospects of the country and regions. Report for the "Highway Policy Seminar for the Countries of the Former Soviet Union*". Federal Highway Departement. Moscow.

Stanners, D. and Bourdeau, P. (1995) *Europe's environment. The Dobříš Assesment.* Office for official publications of the EC, Luxembourg. pp. 712.

TINA Secretariat (1999a) *Draft TINA final report: identification of the network components for a future Trans-European Transport Network in Bulgaria, Romania, Hungary, Slovenia, Slovak Republic, Czech Republic, Poland, Lithuania, Latvia, Estonia and Cyprus – Executive Summary*. Economic Commission for Europe. United Nations Economic and Social Council. Documents TRANS/WP.5/1999/7 (8 July 1999).

TINA Secretariat (1999b) *TINA Work: Maps*. The European Commission. TINA Secretariat. Vienna. Austria. http://www.tinasecretariat.at/maps.html [12-05-2001]

UNECE (1991) *Convention on Environmental Impact Assessment in a Transboundary Context.* United Nations Economic Commission for Europe. http://www.unece.org/env/eia/eia.htm

Williams, P.; Humphries, C. and Araujo, M. (1998) Mapping Europe's biodiversity. In: B.C.W. Delbaere (ed). *Facts & Figures on Europe's Biodiversity 1998-1999*.115 p. ECNC, Tilburg. pp. 12-15.

Zedrosser, A. and Völk, F. (1999) Large carnivores (bear, wolf, lynx) moose and trunk roads in Austria. In: 5 th IENE Meeting Budapest, Hungary, Report of the meeting. pp. 24-27.

Chapter 5

Abrahamsson, I. and Pettersson, L. (1997) *Vägkulvertar i Säveån - funktion med avseende på faunapassage*. Mölnlycke. Terra Limno Gruppen.

Babiloni, G. (1992) Informe provisional del seguimiento de la mortalidad de vertebrados en las carreteras de la provincia de Barcelona. In: *I Jornadas para el Estudio y Prevención de la Mortalidad de Vertebrados en Carreteras.* CODA, Madrid, pp. 127-135.

Baudvin (1996) Etude de la mortalité animale liée à l'autoroute ; convention " La Choue "/SAPRR, rapport interne SAPRR

Bekker, G.J. and Canters, K.J. (1997) The continuing story of badgers and their tunnels. *In: Canters, K.J., Piepers, A.A.G. and Hendriks-Heerma, D.(eds). Habitat Fragmentation and Infrastructure: Proceedings International Conference on Habitat Fragmentation, Infrastructure and the Role of Ecological Engineering.* Dienst Weg-en Waterbouwkunde, Delft.

Bergengren, J. (1999) *Vanbdringshinder and Spridningsbarriärer*, 1991: 1-110 Härnösand: Länsstyrelsen i Västernorrlands län, Miljöanalys and Naturvård.

Bergers, P.J.M. (1997) *Versnippering door railinfrastructuur; een verkennende studie*, IBN-rapport 262, Instituut voor Bos-en Natuuronderzoek, Wageningen.

Berthoud G. (1968) *Expertise sur l'impact écologique a pastériori du tracé autoroutier N1 Genève-Lausanne.* Bureau de construction des autoroutes. Etat de Vaud. pp. 52, 2 cartes.

Blanco, J.C. and Cortés, Y. (1999) *Estudio para la gestión del lobo en hábitats fragmentados por autovías.* Unpublished Report to Ministerio de Medio Ambiente and Junta de Castilla y León.

Blaustein, A.R. and Wake, D.B. (1990) Declining amphibian populations: a global phenomenon? *TREE* **5**, 203-204.

Bourquin, J.-D. & Meylan, A. (1982) *Les peuplements de micromammifères le long des autoroutes: Inventaire faunistique et examples d'occupation par Microtus arvalis (Pallas).* Revue Suisse de Zoologie **89**, 977-991.

Broekhuizen, S., Muskens, G.J.D.M. & Sandifort, K. (1994) *Invloed van sterfte door verkeer op de voortplanting bij dassen.* IBN-rapport 055. Instituut voor Bos- en Natuuronderzoek, Wageningen.

Bruun-Schmidt J. (1994) *Trafikdræbte dyr.* Specialerapport. Odense Universitet.

Bugter, R.J.F. (1993) *Versnippering van fauna-leefgebieden door rijks- en provinciale wegen in Limburg*. Rapport 93/1, Bureau Natuurbalans, Nijmegen.

Bureau Waardenburg BV (1993) *Natuur en verkeer op de Utrechtse heuvelrug, Visie op ontsnippering*. Culemborg.

CEMAGREF (1982) *Canaux, voies navigables et grand gibier.* Centre National du Machinisme Agricole, du Génie Rural et des Eaux et Forêts. Division Loisirs et Chasse, Nogent-sur-Vernisson, Note technique n° 49, pp. 48.

CETE de Lyon et INGEROUTE (1999) *Méthode d'évaluation stratégique des réseaux de transports, tests pour la mise en évidence des enjeux environnementaux et l'utilisation d'indicateurs d'évaluation.* Ministère de l'Aménagement du Territoire et de l'Environnement, rapport interne.

Cirera, M. (2000) Analysis of the effects of the construction and entering into service of a new road in the breeding area of a pair of Bonellis Eagle *(Hieraetus fasciatus*) using radio-tracking. In: *Natura 2000 and Transportation Infrastructure, 6th IENE Meeting, Sitges, Spain, 6th April 2000*.

Clarke, G.P., White, P.C.L. and Harris, S. (1998) Effects of roads on badger (*Meles meles*) populations in south-west England. *Biological Conservation*, **86**, 117-124.

Clevenger, A.P. and Purroy, F.J. (1990) Ecología y conservación del oso cantábrico, *Quercus*, **51**, 22-30.

Clevenger, A.P., Purroy, F.J. and Campos, M.A. (1997) Habitat assessment of a relict brown bear *(Ursus arctos)* population in northern Spain, *Biological Conservation*, **80**, 17-22.

Cortés, Y., Fernández-Salvador, R., García, F.J., Virgós, E. and Llorente, M. (1998) Changes in otter *(Lutra lutra)* distribution in Central Spain in the 1964-1995 period, *Biological Conservation*, **86**, 179-183.

Czajkowski M.A. et Thauront M. (1990) *Impact du trafic ferroviaire sur l'avifaune, étude bibliographique.* Ministère de l'Environnement. pp. 43.

Danmarks Statistik (1996) Vildtudbyttet i 1994/95. *Danmarks Statistik*, 1996:5

De Molenaar, J.G. and Jonkers, D.A. (1997) *Wegverlichting en natuur II Haalbaarheidsstudie aanvullend onderzoek*. IBN-rapport 336. Instituut voor Bos-en Natuuronderzoek, Wageningen.

De Molenaar, J.G., Jonkers, D.A. and Sanders, M. (2000) *Wegverlichting en natuur III Lokale invloed van wegverlichting op een gruttopopulatie.* Dienst Weg-en Waterbouwkunde/Instituut voor Bos- en Natuuronderzoek, Delft/Wageningen.

Direction des travaux publics du canton de Fribourg (1996), N1 Magazine, No 2 juillet 1996, 8pp.

Duel, H. (1992) *Modellen voor de beoordeling van oevers op hun geschiktheid als habitat of corridor voor fauna*. TNO/Dienst Weg- en Waterbouwkunde, Delft.

EEA (2000) *Land cover annual topic update 1999.* Topic report No. 4/2000, EEA, Copenhagen. pp. 245. http://www.eea.eu.int

EEA-ETC/CC (2001) (http://themes.eea.eu.int) (December 2001)

English Nature Research Report 60 (1993) Linear features: linear habitats and wildlife corridors. *English Nature*, Peterborough.

English Nature Research Report 89 (1994a) Habitat Fragmentation: species at risk. *English Nature*, Peterborough.

English Nature Research Report 94 (1994b) Are habitat corridors conduits for animals and plants in a fragmented landscape? A review of the scientific evidence. *English Nature*, Peterborough.

English Nature Research Report 95 (1994c) Habitat fragmentation and heathland species. *English Nature*, Peterborough.

English Nature (1994d) Roads and nature conservation: Guidance on impacts, mitigation and enhancement. *English Nature,* Peterborough.

English Nature Research Report 10 (1995) Rebuilding the English Countryside: habitat fragmentation and wildlife corridors as issues in practical conservation. *English Nature,* Peterborough.

English Nature Research Report 178 (1996) The significance of secondary effects from roads and road transport on nature conservation. *English Nature*, Peterborough.

Fahrig,L., Pedlar,J.H., Pope,S.E., Taylor,P.D. and Wegener,J.F. (1995) Effect of road traffic on amphibian density. *Biol.Conserv.* **73**, 177-182.

Fajardo, I., Pividal, V., Trigo, M. and Jiménez, M. (1998) Habitat selection, activity peaks and strategies to avoid road mortality by the little owl *(Athene noctua), Alauda*, **66**, 49-60.

Fernández, J.M. (1993) Colisiones entre vehículos y animales de caza mayor, Una aproximación al problema. In: *II Simposio Nacional sobre Carreteras y Medio Ambiente*, Asociación Técnica de Carreteras, Madrid. pp. 385-398.

Ferreras, P. (1993) Incidencia de las carreteras sobre las poblaciones de lince ibérico, *Quercu*s, **83**, 22-23.

Ferreras, P. (1994) *Patrones de dispersión del lince ibérico (Lynx pardina) en Doñana e implicaciones para su conservación.* Ph.D. Thesis, University of Madrid (UAM).

Ferreras, P., Aldama, J.J., Beltrán, J.F. and Delibes, M. (1992) Rates and causes of mortality in a fragmented population of Iberian lynx *(Felis pardina)* Temminck, 1824, *Biological Conservation*, **61**, 197-202.

Forman, R.T.T., Friedman, D.S., Fitzhenry, D., Martin, J.D., Chen, A.S. and Alexander, L.E. (1997) Ecological effects of roads: toward three summary indices and an overview for North America. In: Canters, K. (ed) *Habitat fragmentation and infrastructure.* Ministry of Transport, Public Works and Water Management. Delft, The Netherlands.

Gaona, P., Ferreras, P., and Delibes, M. (1998) Dynamics and viability of a metapopulation of the endangered Iberian lynx *(Lynx pardinus), Ecological Monograph*s, **68**, 349-370.

Gragera, F., Corbacho, M.A. and Ávalos, J. (1992) Informe provisional del seguimiento de la mortalidad de vertebrados en las carreteras de la provincia de Badajoz. In: *I Jornadas para el Estudio y Prevención de la Mortalidad de Vertebrados en Carretera*s, CODA, Madrid. pp. 136-144.

Grahn, B. and Öberg, A. (1996) *Rapport över vägtrummornas funktion i Västerbottens län.* Umeå: Skogsvårdsstyrelsen Västerbotten.

Grontmij (1995) *Infrastructuur & Water*. Zeist.

Gonseth, Y. (1992) La faune des Lépiodptères diurnes (Rhopalocera) des talus routiers et ferroviaires du Juar neuchâtelois. *Mitteilungen der Schweizerischen Entomologischen Gesellschaft* **65**, 413-430.

Göransson, G., Karlsson,J. and Lindgren, A. (1978) *Influence of roads on the surrounding nature II Fauna.* Stockholm, Sweden: Swedish Environmental Protection Agency, SNV PM 1069.

Hansen, L. (1982) *Trafikdræbte dyr i Danmark*. Dansk Ornitologisk forenings tidsskrift **76,** 97-110.

Harris, L.D. and Gallagher, P.B. (1989) *New initiatives for wildlife conservation. In: Preserving Communities and Corridors, Defenders of Wildlife.* Washington. 11-34.

Harwood, R., Hilbourne, S., *et al.* (1992) *Ever Increasing Circles: The impact and effectiveness of the M25 plan.* RSNC, The Wildlife Trusts Partnership.

Heinen, E. (1995) *Fauna uitstapplaatsen.* Stageverslag, Dienst Weg-en Waterbouwkunde, Delft.

Hels (1998) Effects of roads on amphibian populations. PhD Thesis, National Environmental Research Institute. Denmark. pp. 80.

Hernández, M. (1988) Road mortality of the little owl *(Athene noctua)* in Spain. *Journal of Raptor Research*, **22**, 81-84.

Hill and Hockin (1992) In: TEST, 1991. *Wrong Side of the Tracks? Impacts of Road and Rail Transport on the Environment: a basis for discussion*. TEST, London.

Hodson, N.L. (1962) Some notes on the causes of bird road casualties. *Bird Study*, **9**, 168-72.

Hodson, N.L. (1966) A survey of road mortality in mammals. *Journal of Zoology*, **148**, 76-79.

Huijser, M.P. and Bergers, P.J.M. (1997*) Egels en verkeer: effecten van wegen en verkeer op egelpopulaties.* Dienst Weg-en Waterbouwkunde, Delft.

IFEN, Institut Français de l'Environnement (1999) *L'environnement en France, La Découverte*, 96 - 98.

Kaae, B.C., Skov-Petersen, H. and Larsen, K.S. (1998) Større trafikanlæg som barrierer for rekreativ brug af landskabet, *Park- og Landskabsserien* nr. 17, Forskningscentret for Skov and Landskab, Hørsholm. pp. 165.

Kastdalen, L. (1999) Gardermoutbyggingen – evaluering av avb tende tiltak for elg. http://www.hihm.no/publiksjon/rapport/1999/26_1999.htm (November, 2002)

Kemper J.H. (1998) *Onderzoek naar de passeerbaarheid van sifons.* W-DWW-98-016, OVB, Nieuwegein.

Koster, A. (1991) *Spoorwegen, toevluchtsoord voor plant en dier*. KNNV, Utrecht.

Lagerkvist, G. (1998) *Viltstyrningsplan för väg 47/48 mellan Månseryd – Mullsjö*. Jönköping: Vägverket Konsult Sydöst.

Langton, T.E.S. (Ed.) (1989) *Amphibians and Roads. Proceedings of the toad tunnel conference*. Rendsburg, Federal Republic of Germany. ACO Polymer Products Ltd. 1989.

Lankester, K., Apeldoorn, R. van, Meelis, E. and Verboom, J. (1991) Management perspectives for populations of the eurasian badger *(Meles meles)* in a fragmented landscape. *Journal of Applied Ecology,* **28**, 561-573.

Lenders, A.J.W. (1996) Dispersie van watersalamanders tijdens de voorjaarstrek. *Natuurhistorisch maandblad,* **85(5)**, 94-100.

López Redondo, J. (1993a) Metodología y resultados del proyecto de seguimiento de la mortalidad de vertebrados en carreteras (P.M.V.C./C.O.D.A.) In: *II Simposio Nacional sobre Carreteras y Medio Ambiente*. Asociación Técnica de Carreteras, Madrid. pp. 319-334.

Mader, M. (1984) In: TEST, 1991. *Wrong Side of the Tracks? Impacts of Road and Rail Transport on the Environment: a basis for discussion*. TEST, London.

Madsen, A.B. (1993) *Fauna passages in connection with large roads systems II, Hedgehogs, bats, birds and research of effects*. Danmarks Miljøundersøgelser, Faglig rapport fra DMU nr. **82**, 54.

Madsen, A.B.; Fyhn, H.W. and Prang, A. (1998) *Trafikdræbte dyr i landskabsøkologisk planlægning og forsknin.* Damnarks Miljøundersøgelser, Faglig rapport fra DMU, nr. **228**, 42.

Markham, D. (1996) *The significance of secondary effects from roads and road transportation on nature conservation*. Research Report 178, English Nature.

Martínez, C. (1994) Habitat selection by the little bustard *(Tetrax tetrax)* in cultivated areas of central Spain. *Biological Conservation*, **67**, 125-128.

Meunier F.D., Gauriat C., Verheyden C. et Jouventin P. (1998) Végétation des dependences vertes autoroutières : influences d'un mode de gestion extensif et du milieu traversé. *Rev. Ecol. (Terre Vie)* **53**, 97-121.

Müri, H. (1999) Veränderungen im Dispersal von Rehen in einer stark fragmentierten Landschaft. *Zeitschrift für Ökologie und Naturschutz,* **8 (1)**, 41-51.

Muselet D. (1987) *Etude du comportement de l'avifaune lors de la traversée des voies autoroutières, cas de l'autoroute A10 au nord d'Orléans, Loiret.* Actes du colloque routes et faune sauvage 5-7 juin 1985. SETRA, 245-258.

Naves, J. (1996) Biología del oso pardo cantábrico. In: García-Perea, R., Baquero, R.A., Fernández-Salvador, R. and Gisbert, J. (Eds)., *Carnívoros: evolución, ecología y conservación*. CSIC, Museo Nacional de Ciencias Naturales, SECEM. Madrid. pp. 217-239.

Neal, E. and Cheeseman, C. (1996) Badgers. Poyser, London.

ONC-Ministère de l'Aménagement du Territoire et de l'Environnement (1998) *Infrastructures vertes : inventaire des espaces de libre circulation du Cerf élaphe (Cervus elaphus) en France.* Rapport pp. 55 (+ annexes).

Palomares, F. (1997) *Modelo de hábitat en los corredores utilizados para la dispersión por el lince ibérico, y finalización y unificación de la base de datos del inventario de fincas con presencia de la especie en Cádiz y Granada.* Unpublished report to the Consejería de Medio Ambiente, Junta de Andalucía.

Palomares, F., Rodríguez, A., Laffitte, R. and Delibes, M. (1991) The status and distribution of the Iberian lynx *(Felis pardina)* (Temminck) in Coto Doñana area, SW Spain. *Biological Conservation*, **57**, 159-169.

Pettersson, R. (1997) *Viltstyrningsplan för E4 förbi Örkeljunga.* Örebro: Tyréns Infrakonsult AB.

Pery, M., García Petit, J. and Aymerick, P. (1998) Seneci del cap (Senecio inaequidens), una planta invasora. *Catalunya Rural i Agraria* **60**, 21-23.

Pons J.M. (1994) *Estimation de la mortalité aviaire estivale sur le réseau ferroviaire du T.G.V. Nord*. pp. 11.

Pontón, O. (1997) Mortandad de vertebrados. *Galemy*s, **9**, 9-10.

Puky, M., Bako, B. and Krolopp, A. (1990) Migration Characters of Brown Toad (*Bufo bufo*). *Opuscula Zoologica* XLVI: 99-104. Budapest.

Randrup, T.B. and Pedersen, L.B. (1996) *Vejsalt, træer og buske.* Vejdirektoratet. Rapport nr. 64. pp. 69.

Reicholf, J. and Esser, J. (1981) Daten zur Mortalität des Igels (*Ericaneus europaeus*) verursacht durch den Strassenverkehr. *Z.Säugetierkd.* **46**, 216-222.

Reh, W. and Seitz, A. (1990) The influence of land use on the genetic structure of populations of the common frog (*Rana temporaria*). *Biol.Conserv.* **54**, 239-249.

Reijnen, M.J.S.M., Veenbaas, G. and Foppen, R.F.B. (1992) *Het voorspellen van het effect van snelverkeer op broedvogelpopulaties*. Dienst weg-en Waterbouwkunde/Instituut voor Bos- en Natuuronderzoek, Delft/Wageningen.

Reijnen, R., Foppen, R. and Meeuwsen, H. (1996) The effects of traffic on the density of breeding birds in dutch agricultural grasslands. *Biological Conservation*, **75**, 255-260.

Reijnen, R., Foppen, R., Braak, C. ter and Thissen, J. (1995) The effects of car traffic on breeding bird populations in woodland. III: The reduction of density in relation to the proximity of main roads. *Journal of Applied Ecology*, **32**, 187-202.

Reolid, J.M. and Zamora, J.F. (1992) Informe provisional del seguimiento de la mortalidad de vertebrados en las carreteras de Albacete. In: *I Jornadas para el Estudio y Prevención de la Mortalidad de Vertebrados en Carretera*s. CODA, Madrid, pp. 118-122.

Richardson, J.H., Shore, R.F., Treweek, J.R. and Larkin, S.B.C. (1997) Are major roads barriers to small mammals? *Journal of Zoology*. London. pp. 1-13.

Rodríguez, A. (1997) *Fragmentación de poblaciones y conservación de carnivoros.* Ph.D. Thesis, University of Madrid (UCM).

Rodríguez, A. and Delibes, M. (1990) *El lince ibérico* (Lynx pardina) *en España. Distribución y problemas de conservación*. ICONA, Madrid.

Rodríguez, A. & Delibes, M. (1992) Current range and status of the Iberian lynx Felis pardina Temminck, 1824 in Spain. *Biological Conservation,* **61**, 189-196.

Rodts, J., Holsbeek, L. and Muyldermons, S. (1998) *Dieren onder onze wielen.* Vubpress, Brussel: Koninklijk Belgisch Verbond voor de Bescherming van de Vogels. ISBN 90 5487 185 7 NUGI 829.

Rosell, C. and Velasco, J.M. (1995) *Mesures preventives i correctores dels impactes de les infraestructures viàries sobre la fauna: Projecte de recerca guanyador del Concurs de Projectes sobre Prevenció i Correcció de l'impacte mediambiental de les grans construccions i obre públiques a Catalunya i a les Balears*. A collaboration with the University of Barcelona, Fundació la Caixa. Pp. 211. Unpublished report.

Rosell, C. and Velasco, J.M. (1999) *Manual de prevenció i correcció dels impactes de les infraestructures viàrieas sobre la fauna.* Documents dels Quaderns de medi ambient, Núm. 4, Generalitat de Catalunya, Departament de Medi Ambient.

Ryser, J. (1988) Amphibien und Verkehr, Teil 2: Amphibienrettungsmassnahmen an Strassen in der Schweiz – gegenwärtiger Stand, Erfahrungen und Bedeutung für den Artenschutz. pp. 10. KARCH, Bernastr. 15, 3005 Bern.

Salvig, J.C. (1991) *Faunapassager i forbindelse med større vejanlæg*. Danmarks Miljøundersøgelser, Faglig rapport fra DMU nr. 28.

Salvig, J.C., Andersen, U.V. and Therkelsen, J. (1997) *Veje og jernbaner som spredningsbarrierer.* Rapport udarbejdet af COWI for Skov- og Naturstyrelsen, Vejdirektoratet og DSB.

Secrett and Cliff Hodges (1986) In: TEST, 1991. *Wrong Side of the Tracks*? Impacts of Road and Rail Transport on the Environment: a basis for discussion. TEST, London.

Seiler, A. (1999a) Uppföljningsstude Höga Kusten: E4ans barriäreffekt på älg. In: Iuell, B. (Ed.), *Proceedings of the Nordic Conference on roads, road traffic and habitat fragmentation*. pp. 57-60. Oslo. Statens Vegvesen.

Seiler,A. (1999b) Ecoways - Rapport av pilotstudien 1998. pp. 52. Riddarhyttan: Grimsö Wildlife Research Station, SLU.

http://www.grimso.slu.se/research/infrastructure/index.htm.

Seiler, A., Cederlund, G., Jernelid, H., Grängstedt, P. and Ringaby, E. (2001) *Highway E4 and moose in the High Coast Area - Final report*. Riddarhyttan. Grimsö Wildlife Research Station, SLU (in prep.).

Seiler, A. and Folkeson, L. (1996) *Förslag till program för MKB-uppföljning av ny RV-31. Riddarhyttan.* Grimsö Wildlife research Station and VTI.

Seiler, A., Helldin, J.O. and Jernelid, H. (2000) *Highway 31 - Final report of the baseline study*. Riddarhyttan. Grimsö Wildlife Research Station, SLU (in press).

SETRA (1998b) *Collisions véhicules-grands mammifères sauvages - Evolutions des inventaires de 1984-1986 et 1993-1994.* Note d'information n° 60. SETRA, Bagneux.

Sjögren-Gulve, P. (1994) Distribution and extinction patterns within a northern metapopulation od the pool frog, Rana lessonea. *Ecology* **75**, 1357-1367.

Skov-og Naturstyrelsen (1996) *Forvaltningsplan for Odder,* Lutra lutra *i Danmark.*

SNRA (2000) *Uttrar och vägar.* Borlänge: Vägverket. vagverket.butiken@vv.se.

Spansk, Ö. (1997) *Vägtrummor – vandringshinder*. Luleå: Vägverket.

Svensson, S. (1998) Birds kills on roads: is this mortality factor seriously underestimated? *Ornis Svecica,* **8**, 183-187.

TEST (1991) *Wrong Side of the Tracks? Impacts of Road and Rail Transport on the Environment: a basis for discussion.* TEST, London.

Thomsen, K. (1992) *Projekt vildtregistrering. Rapport udarbejdet for Falck*. Danmark.

Traverso, J.M. and Álvarez, A. (2000) Mortalidad de vertebrados en el Canal de las Dehesas. *Quercus*, **167**, 28-30.

Treweek, J.R. (1999) *Ecological Impact Assessment.* Blackwell Sciences Limited, Oxford.

UNA (1993/95) *UVB-Bericht(e) zur AlpTransit im Kandertal – Sachbereich Flora/Fauna.* UNA, Atelier für Naturschutz und Umweltfragen, Mühlenplatz 3, 3011 Bern.

Van der Sluis, T. and Vos, C.C. (1996) *Amfibieën en verkeerswegen; een patroonanalyse in Gelderland en Noord-Brabant*. DWW-Versnipperingsreeks deel 28, Dienst Weg-en Waterbouwkunde/Instituut voor Bos- en Natuuronderzoek, Delft/Wageningen.

Van den Tempel, R. (1993*) Vogelslachtoffers in het wegverkeer*. Technisch rapport nr. 11, Vogelbescherming Nederland, Zeist.

Van der Zande, A.N., Ter Keurs, W.J. and Van der Weijden, W.J. (1980) The impact of roads on the densities of four bird spesies in an open field habitat - evidence of a long-distance effect. *Biol.Conserv.* **18**, 299-321.

Van der Zee, F.F., Wiertz, J., ter Braak, C.J.F. and Apeldoorn, R.C. van (1992) Landscape change as a possible cause of the badger Meles meles L. decline in the Netherlands. *Biol. Cons.,* **61**, 17-22.

Van Gelder, J.J. (1973) A quantitative approach to the mortality resulting from traffic in a population of *Bufo bufo*. *Oecologia* **13**, 93-95.

Vlaamse Milieumaatschappij, 1994. *Leren om te keren. Milieu- en Natuurrapport.* Leuven/Apeldoorn.

Van Leeuwen, B.H. (1982) Protection of migrating common toad (Bufo bufo) against car traffic in the Netherlands. *Environmental Conservation* **9 (1)**, 34.

Van Nieuwenhuizen, W. and Apeldoorn, R.C. (1995) *Mammal use of fauna passages on national road A1 at Oldenzaal.* DWW-Versnipperingsreeks deel 20A, Dienst Weg-en Waterbouwkunde, Delft.

Verboom, J., Lankester, K. & Metz, J.A.J. (1991) Linking local and regional dynamics in stochastic metapopulation models. *Biol.J.Linnean Soc.* **42**, 39-55.

Vestjens, W.J.M. (1973) Wildlife mortality on a road in New South Wales. *Emu* **73**, 107-112.

Vos, C.C. (1997) Effects of road density; a case study of the moor frog. In: Canters, K.J., Piepers, A.A.G. and Hendriks-Heerma, D. (Eds.) *'Habitat fragmentation and Infrastructure, Proceedings 18-21 September 1995, Maastricht and The Hague'*. Dienst Weg-en Waterbouwkunde, Delft.

Vos, C.C. & Chardon, J.P. (1998) *Effects of habitat fragmentation and road density on the distribution pattern of the moor frog Rana arvalis. Journal of Applied Ecology* **35**, 44-56.

Wallentinus, Hans-Georg (2000) *Vägars effekter på fågelliv och klövvilt. Miljökonsekvenser av byggande och användning av E3/E18 i Vallentuna kommun*. ISSN 1403-1361, ISBN 91-576-5975-3. SLU, Institutionen för Landskapsplanering Ultuna, Uppsala.

Wasson J. G. (1998) Impacts écologiques de la chenalisation des rivières. CEMAGREF - Editions. *Série Gestion des Milieux Aquatiques* **14**, pp. 160.

Wiegand, T., Naves, J., Stephan, T., and Fernández, A. (1998) Assessing the risk of extinction for the brown bear *(Ursus arcto*s) in the Cordillera Cantabrica, Spain, *Ecological Applications*, **68**, 539-570.

Wirth, T., Oggier, P. & Baur, B. (1999) Effects of road width on dispersal and genetic population structure in the land snail Helicella itala. *Zeitschrift für Ökologie und Naturschutz* **8**, 23-29.

Chapter 6

Botequilha Leitão, A. and Ahern, J. (2002) Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and Urban Planning* **59** (2002), 65-93

Buchwald, K. and Engelhardt, W. (Eds.) (1980) Handbuch für Planung und Schutz der Umwelt, Die Bewertung und Planung der Umwelt. BLV Verlagsgesellschaft, München, Wien, Zürich.

Cuperus, R. and Canters, K.J. (1997) Maten en mate van versnippering; versnippering van ecosystemen in vervoerregio's. Centrum voor Milieukunde/Dienst Weg- en Waterbouwkunde, Leiden/Delft.

EEA (1998) *Spatial and ecological assessment of the TEN: demonstration of indicators and GIS methods.* European Environment Agency. Copenhagen. Denmark. pp. 52.

EEA (2000) *Are we moving in the right direction? Indicators on transport and environment integration in the EU*. TERM 2000. Environmental issues series no 12. Copenhagen. ISBN 92-9167-206-8. pp. 136.

European Commission (1999) *European Spatial Development Perspective: Towards Balanced and Sustainable Development of the Territory of the European Union.* Office for official Publications of the European Communities, Luxembourg. pp. 82.

Hammershøj, M. and Madsen, A.B. (1998) *Fragmentierung og korridorer i landskabet. En litteraturudredning*. Danmarks Miljøundersøgelser, faglig rapport fra DMU nr. 232. pp. 107.

Hehl-Lange, S. (2000) *GIS- gestützte Analyse und 3D-Visualisierung der Funktionen naturnaher Lebensraumtypen und die sie beeinflussenden Wirkungen ausgewählter Landnutzungen.* Dissertation ETH Zürich, Institut für Orts-Regional-und Landesplanung.

Hels (1998) *Effects of roads on amphibian populations.* PhD Thesis, National Environmental Research Institute, Denmark. pp. 80.

Hinsberg, A. van, Dijkstra, H.L., Hinssen, P.J.W., Kramer, K., Leus, F.M.R., Reiling, R., Reijnen, M.J.S.M., Tol, M.W.M. and Wiertz, J. (1999) *Stroomlijning NatuurPlanBureau modellen*. Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven.

Infra Eco Network Europe (1999) *Report of the meeting. Presentations of the participants. 5th IENE meeting Budapest, Hungary, 14-17 April 1999*. pp. 82.

Jaeger, J. (2001) *Quantifizierung und Bewertung der Landschaftserzerschneidung*. Arbeitsbericht nr. 167, ISBN 3-934629-12-1, ISSN 0945-9553, Stuttgart.

Jongman, R.H.G. and Kristiansen, I. (2000) *National and regional approaches for ecological networks in Europe*. Council of Europe Publishing. Nature and Environment, nº110. pp. 86.

Jongman, R.H.G. (2002) Homogenisation and fragmentation of the European landscape: ecological consequences and solutions. *Landscape and Urban Planning* **58** (2002) 211-221.

Kaae, B.C., Skov-Petersen, H. and Larsen, K.S. (1998) Større trafikanlæg som barrierer for rekreativ brug af landskabet, *Park- og Landskabsserien* nr. 17, Forskningscentret for Skov and Landskab, Hørsholm. Pp. 165.

Ministerie van Verkeer en Waterstaat (1999) *Beleidseffectrapportage 1998*. Den Haag. pp. 160.

Norwegian Public Roads Administration (1994) *Handbook 192 Roads and Nature.* ISBN 82-7207-417-6 (English)

Oñate, JJ., Pereira D, Suárez F., Rodríguez J.J. and Cachón J. (2002) *Evaluación Ambiental Estratégica.: la evaluación de políticas, planes y programas*. Ed. Mundi-Prensa, Madrid.

Rijksplanologische Dienst (1999) *Ruimtelijke Perspectieven in Europa.* Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, Den Haag. nr. 990193/b/9-99. pp. 224.

Seiler, A (1999) *Ecoways Rapport av pilotstudien 1998.* Riddarhyttan: Grimsö Wildlife Research Station. pp. 52.

SGW (Schweizerische Gesellschaft für Wildtierbiologie) (1999) *Wildtierkorridore Schweiz - Räumlich eingeschränkte, überregional wichtige Verbindungen für terrestrische Wildtiere im ökologischen Vernetzungssystem der Schweiz*. Swiss Ornithological Station, 6204 Sempach. pp. 71.

Chapter 7

Amundsen (1997) *Innsatsplan mot viltpåkjørsler*. Høringsutkast. TTS 16 1997. Statens vegvesen.

Atkinson, K. (Ed.) (1997) *Highway Maintenance Handbook* (2nd edn.). Thomas Telford Publications. London.

Ballon P. (1985) *Bilan technique des aménagements réalisés en France pour réduire les impacts des grandes infrastructures linéaires sur les ongulés gibiers.* Actes du XVII ème Congrès de l'Union Internationale des Biologistes du Gibier, 679-689.

Banverket (2001) *Miljöbaskrav vid upphandling av tjänster och varor* (Basic environmental requirements in the procurement of services and goods) (In Swedish). Regulation BVF 814.1, Head Office, Banverket, Borlänge, Sweden.

Bekker, G.J and Canters, K.J (1997) The continuing story of badgers and their tunnels. In: Canters, K.J, Piepers, A.A.G and Hendriks-Heerma, D. (Eds.) *Habitat Fragmentation & Infrastructure. Proceedings of the International Conference on Habitat Fragmentation, Infrastructure and the role of ecological engineering*. Dienst Weg- en Waterbouwkunde, Delft.

Bernard, J.-M., Lansiart, M., Kempf, C. and Tille, M. (Eds.) (1987) *Actes du colloques 'Route et fauna sauvage'. Strasbourg, Conseil de l'Europe, 5-7 Juin 1985*. Ministère de l'Equipement, du Longement, de l'Aménagement du Territoire et des Transports, et Ministère délégué chargé de l'Environnement, Colmar, France. pp. 403.

Blanco, J.C. and Cortés, Y. (1999) *Estudio para la gestión del lobo en hábitats fragmentados por autovías.* Unpublished Report to Ministerio de Medio Ambiente and Junta de Castilla y León.

Carsignol J. (1989) Dix années d'observations des collisions véhicules – grands mammifères gibiers sur l'autoroute A 4 en Alsace-Lorraine et sur le réseau routier du département de la Moselle. Bulletin Mensuel de l'Office National de la Chasse **135**, 32-37.

Clevenger A. P. (1998) *Highways and wildlife – An online bibliography.* http://www.cmiae.org/biblio.html [October 2002]

CTGREF (1978) *Autoroute et grand gibier.* Note technique 42. Groupement technique forestier. Ministère de l'Agriculture. Paris.

De Molenaar, J.G. & Henkens, R.J.H.G. (1998) *Effektiviteit van wildspiegels: een literatuurstudie.* Instituut voor Bos- en Natuuronderzoek, Wageningen.

De Molenaar, J.G. and Jonkers, D.A. (2000) *Verlichting rijksverkeerswegen Utrechtse Heuvelrug. Een evaluatie van de faunistische aspecten van een proef met hoofdverlichting en orientatieverlichting*. *Alterra-rapport* 110, ISSN 1566-7197, Wageningen.

Désiré G., Mouron D. et Sanaa M. (1997) *Recensement des collisions véhicules – grands mammifères sauvages. Evolution entre les inventaires de 1984-1986 et 1993-1994.* Congrès de l'Union Internationale des Biologistes du Gibier.

Faith-Ell, C. (2000) *Environmental management of road maintenance--with emphasis on "Green procurement".* Royal Institute of Technology, Department of Civil and Environmental Engineering, Division of Land and Water Resources, Royal Institute of Technology, Stockholm. TRITA-AMI-LIC 2061. Licentiate thesis. Stockholm. pp. 93.

Fangarezzi, C., Piani, C., Selmi, E. and Dinetti, M. (1999) Incidenti di avifauna contro pannelli trasparenti prima e dopo interventi di mitigazione. *Avocetta* **23**, 186.

Folkeson, L. (Ed.) (2000) *Pollution from roads and vehicles and dispersal to the local environment: Monitoring of 14 case studies*. POLMIT (Pollution of Groundwater and Soil by Road and Traffic Sources: Dispersal Mechanisms, Pathways and Mitigation Measures). RO-97-SC.1027. – EC Transport RTD Programme of the 4th Framework Programme. Draft report, Deliverable D3.

Grossenbacher, K. (1985) *Amphibien und Verkehr*. Koordinationsstelle für Amphibien- und Reptilienschutz in der Schweiz (KARCH), Bern. pp. 22. Address: KARCH, Bernastr. 5, CH-3005 Bern, Switzerland.

Hollick, M. (1981) The role of quantitative decision-making methods in environmental inpact assessment. *Journal of Environmental Management* **12**, 65-78.

Huijser, M.P. (2000) *Life on the edge. Hedgehog traffic victims and mitigation strategies in an anthropogenic landscape.* PhD Thesis. Wageningen University. Wageningen. The Netherlands. pp. 165.

Kägi, B.; Stalder, A. and Thommen, M. (2002) *Wiederherstellung und Ersatz im Natur- und Landschaftsschutz.* Bundesamt für Umwelt, Wald und Landschaf, Leitfaden Nr 11, Bern.

Kistler, R. (1998) *Wissenschaftliche Begleitung der Wildwarnanlage Calstrom WWA-12-S Schlussbericht*. Infodienst Wildbiologie & Ökologie, Zürich. 67 pp. Address: Infodienst Wildbiologie und Ökologie, Strickhofstr. 39, CH-8057 Zürich, Switzerland.

Landres, P.B., Verner, J. and Thomas, J.W. (1988) Ecological uses of vertebrate indicator species: a critique. *Conservation Biology* **2(4)**, 316-328.

Marcolino, A. (2001) *Monitorizaçao*. Seminario técnico Medidas de minimizaçao associadas a infraestructuras rodoviárias e ferroviárias – Desfragmentaçao de sistemas naturais. Alfragide, 26 março 2001. In Press.

Müller, S. and Berthoud, G. (1997) *Fauna/traffic safety - Manual for civil engineers*. EPFL, Lausanne. 119 S.

Muselet, D. (1985) Etudes du comportement de l'avifaune lors de la traversée de voes autoroutières, autoroute A10 au Nord d'Orléans, Loiret. In: Bernard, J.-M., Lansiart, M., Kempf, C. and Tille, M. (Eds.): *Routes et Faune Sauvage. Actes du Colloque au Conseil de l'Europe, Strassbourg, 5-7 Juin 1985*. F-92223 Bagneux. 406.

Noss, R.F. (1990) Indicators for monitoring biodiversity: A hierarchical approach, *Conservation Biology* **4(4)**, 355-364.

Oord, J.G. (1995) *Handreiking maatregelen voor de fauna langs weg en water, Rijkswaterstaat.* Dienst Weg- en Waterbouwkunde & Dienst Landinrichting en Beheer Landbouwgronden, Delft, Utrecht. pp. 278.

Piepers, A.A.G. (Ed.) (2001) *Infrastructure and nature; fragmentation and defragmentation. Dutch State of the Art Report for COST activity 341.* Road and Hydraulic Engineering Division Defragmentation Series, part 39a. Road and Hydraulic Engineering Division, Delft, The Netherlands. pp. 184

Pfister, H. P., Keller, V., Reck, H. and Georgii, B. (1997) *Bio-ökologische Wirksamkeit von Grünbrücken über Verkehrswege*. Forschung, Strassenbau und Verkehrstechnik 756. Bundesministerium für Verkehr, Bonn. pp. 590.

Reeve, A.F. and Anderson, S.H. (1993) Ineffectiveness of Swareflex Reflectors at reducing deer-vehicle collisions. *Wildlife Society Bulletin* **21,** 127-132.

Robles, F. and Pereira, P. (2001) *Resultados del seguimento del uso de los pasos para fauna por parte de mamiferos carnivoros en el Parque Nacional de Doñana.* Dirección General para la conservación de la Naturaleza, Ministerio de Medio Ambiente. Unpublished report. pp. 13.

Rosell, C., Parpal, J., Campeny, R., Jové, S., Pasquina, A. & Velasco, J.M. (1997) Mitigation of barrier effect of linear infrastructure to wildlife. *In: Canters, K. (Ed). Habitat fragmentation and infrastructure.* Ministry of Transport, Public Works and Water Management, Delft, The Netherlands. pp. 367-372.

Ryser, J. (1988) *Amphibien und Verkehr, Teil 2. Koordinationsstelle für Amphibien- und Reptilienschutz in der Schweiz (KARCH).* Bern. pp. 24. Address: KARCH, Bernastr. 5, CH-3005 Bern, Switzerland.

Salveson, D. (1990) *Wetlands: mitigating and regulating development impacts, Urban Land Institute.* Washington DC.

Schmid, H. and Sierro, A. (2000) Untersuchungen zur Verhütung von Vogelkollisionen an transparenten Lärmschutzwänden. [A field trial of measures to prevent bird strikes on transparent noise protection walls]. *Natur und Landschaft* **75**, 426-430.

SETRA and MATE (1993) *Passages pour la grande faune, Guide technique*. Service d'Etudes Techniques des Routes et Autoroutes, Bagneux. pp. 121.

Sjölund, A., Eriksson, O., Persson, T. and Hammarqvist, J. (1999) *Vägkantsfloran.* Vägverket Publ 1999:40. Borlänge, Sweden. pp. 175.

Van der Linden, P.J.H. (1997). A wall of tree-stumps as a fauna-corridor. *In: Canters, K.J., Piepers, A.A.G. & Hendriks-Heerma, D. (eds). Habitat Fragmentation & Infrastructure.* Proceedings of the international conference on habitat fragmentation, infrastructure and the role of ecological engineering. Dienst Weg- en Waterbouwkunde, Delft. pp. 409-417.

Vassant, J. Brandt, S. and Jullien, J.M. (1993a) Influence du passage de l'autoroute A5 sur les populations cerf et sanglier du Massif Arc-en Barrois. 1re partie: Cas de la population de cerf. *Bulletin de l'Office National de la Chassa* **183**, 15-25.

Vassant, J. Brandt, S. and Jullien, J.M. (1993) Influence du passage de l'autoroute A5 sur les populations cerf et sanglier du Massif Arc-en Barrois. 2e et derniere partie: Cas de la population de sanglier. Bulletin de l'Office National de la Chassa, 184, 24-33.

Veenbaas, G. & Brandjes, G.J. (1999) Use of fauna passages along waterways under highways. Proceedings of the third international conference on wildlife ecology and transportation. September 13-16, 1999, Missoula, Montana, USA.

Völk,F., Glitzner I. and Wöss M. (2001) *Kostenreduktion bei Grünbrücken durch deren rationellen Einsatz: Kriterien-Indikatoren-Mindesstandards.* Strassenforschung, Heft 513, Bundesministerium für Verkehr, Innovation und Technologie, Wien. pp. 97.

Chapter 8

Blöchlinger, H., and Jäggin, B. (1996) *Der Wert der Artenvielfalt im Jura*. Forschungsbericht zuhanden der Stiftung Mensch-Gesellschaft-Umwelt (MGU) der Universität Basel.

Boiteux, M. (1994) *Transports: pour un meilleur choix des investissements*. Commissariat général du Plan (Eds.), Groupe présidé par M. Boiteux. La documentation Française. Paris. pp. 132.

Cedermark, H. and Von Koch, A. (2000) *Intrangseffekter i natur- och kultlurmiljö.* Fallstudier. Vägverket Publikation 2000:24. Borlänge.

EEA, European Environment Agency (2000) *Are we moving in the right direction?* Indicators on transport and environment integration in the EU. TERM 2000. Environmental issues No 12. Copenhagen. pp. 136.

ECMT, European Conference of Ministers of Transport (2000) *Sustainable Transport*. Report on Assessing the Benefits of Transport. ECMT/CS(2000)9. Paris. pp. 56.

ECMT, European Conference of Ministers of Transport (1998) *Efficient Transport for Europe*. Policies for Internalisation of External Costs. ECMT/OECD Publications Service. Paris. pp. 261.

Ecoplan (1998a) *Externalitäten im Verkehr – methodische Grundlagen*. Schlussbericht. GVF-Auftrag Nr. 281a. Bern/Altdorf. pp. 104.

Ecoplan (1998b) *Externalitäten im Verkehr: Leitfaden für die Verkehrsplanung*. GVF-Auftrag Nr. 281b. Bern/Altdorf. pp. 57.

Elbaz-Benchetrit, V. (1997) *Autoroutes: impacts sur l'économie et l'environnement*. Presse de l'ENPC. pp. 116.

EU (1995) *Green Book on Fair and Efficient Pricing in Transport*. Brussels. pp.60.

GVF (2000) GVF-Bericht 1/2000: *Fair and efficient*. The Distance-related Heavy Vehicle Fee (HVF) in Switzerland. Eidg. Drucksachen- und Materialzentrale (EDMZ), 3003 Bern, Form. 801.580e. pp. 24.

Hampicke, U. (1991) *Naturschutz - Ökonomi.e.* UTB für Wissenschaft, Ulmer, Stuttgart.

Higman, R. (1995) *Fighting Road Schemes*, Friends of the Earth, England, Wales and Northern Ireland.

Infraconsult AG (1999) *Kosten und Nutzen im Natur- und Landschaftsschutz*. Eidg. Drucksachen- und Materialzentrale (EDMZ), 3003 Bern. pp. 376.

INFRAS/IWW (2000) *External Costs of Transport*. Accident, Environmental and Congestion Costs in Western Europe. INFRAS, Zurich and IWW, Karlsruhe. pp. 305.

IWW *et al.* (1998) *Entwicklung eines Verfahrens zur Aufstellung umweltorientierter Fernverkehrskonzepte als Beitrag zur Bundesverkehrswegeplanung*. Umweltbundesamt Karlsruhe.

Nateco (former Ökoskop) und econcept AG (in prep.) *Externe Kosten des Verkehrs im Bereich Natur und Landschaft.* Hauptstud *i.e.* GVF-Auftrag Nr. 348.2. Gelterkinden/Zürich/Bern.

Nielsen, C. (1992) *Der Wert stadtnaher Wälder als Erholungsraum*. Eine ökonomische Analyse am Beispiel Lugano. Dissertation der rechts- und staatswissenschaftlichen Fakultät der Universität Zürich. Rüegger, Zürich.

Ökoskop (1998) *Externe Kosten des Verkehrs im Bereich Natur und Landschaft*. Vorstud*i.e.* GVF-Auftrag Nr. 322. Gelterkinden/Bern. pp. 41.

Ökoskop (2000) *Externe Kosten des Verkehrs im Bereich Natur und Landschaft.* Forschungsbericht Phase II. GVF-Auftrag Nr. 348. Gelterkinden/Bern. Pp. 39.

SVAG, Schwerverkehrsabgabegesetz (1997) *Bundesgesetz über eine leistungsabhängige Schwerverkehrsabgabe*. Bundesblatt BBl 1997 IV 1614. Bern.

Chapter 9

Council of Europe/UNEP (2001) *Pan-European Biological and Landscape Diversity Strategy*. http://www.strategyguide.org/ (July 2002)

DETR (1998) *A New Deal for Transport: Better for Everyone*. Department of the Environment, transport and the Regions, HMSO, London.

MIMAM (1999) *Estrategia Española para la Conservación y el Uso Sostenible de la Diversidad Biológica*. Ministerio de Medio Ambiente, Secretaría General de Medio Ambiente, Dirección General de Conservación de la Naturaleza. pp. 160.

Ministerie van Verkeer en Waterstaat (1990) *National Traffic and Transport Plan*. SDU Uitgeverij, Den Haag.

Ministerie van Landbouw, Natuurbeheer en Visserij (1990) *Nature Conservation Policy Plan*. SDU Uitgeverij, Den Haag.

Ministry of Transport (2000) *Il Nuovo Piano Generale dei Trasporti, indirizzi e linee guida* (PGT, General Plan for Transport). Ministero dei Trasporti e della Navigazione. July 2000.

MOPTMA (1994) *Plan Director de Infraestructuras 1993 - 2007*. 2nd Edition. Ministerio de Obras Públicas, Transportes y Medio Ambiente. Document approved by agreement of the Council of Ministers of 4th March 1994. pp. 427.

Chapter 10

Rauer, G. and Gutleb B. (1997) *Der Braunbär in Österreich. Umweltbundesamt*. Monographien Bd. 88 Wien. pp. 1-64.

Swillen, H., Piet, B. and Moelants, M. (2001) *De-fragmentation motorways.* IENE ”Open Day”, 27 April 2001. Brussels.

Zedrosser, A. (1996) *Der Wolf in Österreich*. WWF-Studie 25, Wien. pp. 1-34.

Zedrosser, A. and Völk, F. (1999*) Large carnivores (bear, wolf, lynx, moose and trunk roads in Austria*. 5 th IENE meeting Budapest, Hungary, 14-17 April 1999. pp. 24-26

Annex I. COST 341 Memorandum of Understanding

Memorandum of Understanding

for the implementation of a European Concerted Research Action designated as COST Action 341

"Habitat fragmentation due to transportation infrastructure"

The Signatories to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the Technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST400/94 "Rules and Procedures for Implementing COST Actions", the contents of which are fully known to the Signatories.

2. The main objective of the Action is to promote a safe and sustainable pan-European transportation infrastructure through recommending measures and planning procedures in order to conserve biodiversity and reduce vehicular accidents and fauna casualties.

3. The overall cost of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at ECU 3 million at 1997 prices.

4. The Memorandum of Understanding will take effect on being signed by at least 5 Signatories.

5. The Memorandum of Understanding will remain in force for a period of 4,5 years, unless the duration of the Action is modified according to the provisions of Chapter 6 of the document referred to in Point 1 above.

TECHNICAL ANNEX

COST Action 341

Habitat fragmentation due to transportation infrastructure

A. BACKGROUND

Recently more attention has been paid to the causes that lead to decreasing biodiversity. Besides the reduction in surface of large natural areas habitat fragmentation (= splitting of natural ecosystems into smaller and more isolated units thus endangering the survival of animal and plant species and communities) plays here an important role. This negative phenomenon threatens the biodiversity on a European scale. One of the main causes of habitat fragmentation, besides agriculture and urbanization, is the construction and use of linear transportation infrastructure (roads, railways, waterways). By good planning, disturbance of natural areas can be avoided. By using mitigation and compensation measures the fragmentation effects can be reduced.

The existing networks of transportation infrastructure in Europe have already produced substantial fragmentation of the natural landscape. More European countries have become aware of the need to develop national programmes of research on effects of infrastructure on biodiversity and implementation of measures that could minimize the impacts. The results of the programmes will be used, on the one hand, to adapt the existing transportation routes to ecological requirements so as to ensure the maintenance of viable population levels of affected species and, on the other hand, to integrate fragmentation aspects within the planning procedures when new infrastructure is planned and constructed. The results of research and consequently the solutions offered could be used when implementing the planned Trans-European Networks (TENs).

A preliminary overview on the current situation of habitat fragmentation due to infrastructure has been undertaken in 12 European countries. The conclusions of this first assessment can be summarized as follows:

- the amount of research carried out so far (when applicable) is not enough to offer sufficient scientific background so as to give comprehensive solutions to the problem;
- measures to mitigate and/or compensate the losses and disturbances generated by fragmentation are very rarely implemented and/or planned;
- great differences exist among European countries regarding the scientific background and know-how, affected species and landscape, awareness and development.

The representatives of 12 European nations present at the meeting of the European Expert Group Infra Eco Network Europe (IENE) held in Romania, 9-11 October 1996 have stressed the need for cooperation and exchange of information in the field of habitat fragmentation caused by infrastructure at European level. The participants have recognized that concerted action is urgently required.

First of all a comprehensive detailed inventory of the current situation at European level of habitat fragmentation caused by construction and use of the transportation networks is needed. All information will be gathered into a "European state-of-the-art report on habitat fragmentation due to infrastructure".

Secondly, a "European Handbook on habitat fragmentation due to linear transportation infrastructure" will be produced that will include: guidelines, methods, indicators, technical design for, and examples of, measures. A short version of the handbook is desirable for decision-makers.

Simultaneously with the above two products, a "Database on-line" will be developed. This will contain: a list of European experts in the field of infrastructure and habitat fragmentation, data on existing literature, keywords list and list of reference to allow common language on European level. For a rapid access and exchange of information, the World Wide Web will be used. The database will be hosted by the Road and Hydraulic Engineering Division in the Netherlands, as part of an already developed home site of the Infra Eco Network Europe. Its URL address is: http://www.minvenw.nl/projects/iene.
Although the degree of fragmentation of nature is not as high as in Europe where the density of infrastructural works is the highest in the world, in the United States research is carried out and mitigation measures are implemented. Recommendations to take measures to diminish the impact of infrastructure on the natural heritage have also been drawn up in Japan.

B. OBJECTIVES AND BENEFITS

The main objective of the Action is to promote a safe and sustainable pan-European transportation infrastructure through recommending measures and planning procedures in order to conserve biodiversity and reduce vehicular accidents and fauna casualties.

Further on, the secondary objectives of the proposed Action are defined as follows:
- to enhance the level of knowledge in the field of habitat fragmentation and infrastructure;
- to improve cooperation and exchange of information among experts working in transportation and environmental sectors at national and European level;
- to influence the sectoral policy decision-makers;
- to improve mitigation and compensation measures at European level;
- to stimulate national strategies on environment and transportation;
- to promote international and multidisciplinary research and monitoring;
- to improve awareness on habitat fragmentation due to infrastructure.

These goals will further enhance the realization of national and international agreed objectives to conserve biodiversity at the ecosystem/habitat, species and genetic levels. The objectives of the proposed Action will improve the implementation of several international agreements:
- The Convention on Biological Diversity (Rio, 1992);
- The Convention on the Conservation of European Wildlife and Natural Habitats (Bern, 1979);
- The Pan-European Biological and Landscape Diversity Strategy – strategy 1996-2016 for the "Transportation" sector;
- Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (1992);
- The EECONET Declaration (Maastricht, 1993).

The proposed Action is expected to bring via its products the following benefits:

- reducing the stress produced by infrastructure on the European biological heritage by implementation of a scientifically-based uniform set of measures so as to decrease the existent habitat fragmentation and to prevent future damage;
- saving time and money by learning from mistakes and by avoiding overlapping research;
- enhancement of road safety;
- implementation of measures will allow producers around Europe to enlarge and diversify their production (ecoducts, tunnels, fences). That means consequently more work opportunities;
- European integration in the field of planning procedures and technical requirements for implementation of mitigation and compensation measures. This information could be used for transboundary European infrastructure projects;
- an immediate application of the results of the proposed Action could be used as scientific and technical support to the implementation of the Trans-European transport network (TEN). As stipulated in Article 5 of the Community guidelines for the TEN (Decision 1692/96/EC), integration of environmental concerns is one of the key priorities in the design and development of the TEN. In addition, the proposed Action can contribute to the development of methods for impact assessment. The TEN community guidelines stipulate explicitly the need for such methods (Article 8(2)).

C. SCIENTIFIC PROGRAMME

The proposed "European state-of-the-art report on habitat fragmentation due to infrastructure" will contain the following information:
- recognition of the problem,
- legislative framework,
- institutional development,
- scientific background and available sources,
- solutions and implementation of measures,
- cooperation between transportation and environmental sectors,
- Environmental Impact Assessment and Strategic Impact Assessment,
- national strategies and proposed actions,
- relevant case studies.

In the first stage, the research will be carried out separately by each participating country. It is desirable that every country is represented by institutions from both sectors, transportation and environment, in order to rise the quality of the survey. The following activities have to be carried out:
- literature survey,
- public relations,
- gathering information,
- writing final report.

In the second stage, the information given by the national overviews will be analysed and compiled in order to draw a single European Report. This final "European state of the art report" will give information on: the dimension of habitat fragmentation due to infrastructure (both qualitatively and quantitatively), existent knowledge and new research areas, various approaches to solve conflicts and results. The CORINE database hosted by the European Environmental Agency will be consulted in order to get updated geographical information especially on biotops and protected areas.

The "European Handbook on Habitat Fragmentation due to Linear Transportation Infrastructure" will contain:

- guidelines for the maximum amount of habitat fragmentation that is allowed (comparable to *e.g.* limit values for pollution);
- methods to define priorities when tackling intersections between infrastructure networks and nature;
- indicators for "fragmentation" of habitats;
- technical description and design specifications of successful mitigation and compensation measures;
- requirements for the design of various measures;
- methods for the evaluation and monitoring of the effectiveness of measures;
- guidelines for the maintenance of measures;
- overview on European case studies and recommendations on methodological aspects of a monetary evaluation of external effects due to traffic-related habitat fragmentation and impacts on biodiversity;
- recommendations on behalf of Eurostat, European Environmental Agency and the national statistical authorities describing the type and the structure of data needed for a continuous survey of traffic-related habitat fragmentation and impacts on biodiversity and their external costs;
- keys for planners to help them with planning procedures;
- relevant case studies and developed projects.

The results of COST Action 332 (Transport and Land Use Policies) will be taken into consideration when describing and making recommendations to improve the coordination between transport planning and nature management policies.

A short version of the handbook will be produced for decision-makers.

The "On-line database" will comprise:

- list of European experts in the field of infrastructure and habitat fragmentation;
- database on existing literature and video;
- keyword list and list of reference to allow common language on European level.

The above products can be used by: European Union, central governments, governmental agencies, infrastructure construction companies, consultancy companies, research institutes, education institutions, non-governmental organizations.

D. ORGANIZATION AND TIMETABLE

In different stages of the Action, Working Groups of experts will be designated by the MC in order to fulfil the proposed objectives. The proposed COST Action will be carried out in 5 phases, as follows (Figure 1):

Phase 1: The first meeting of the MC will be organized within a period of maximum six months after the formal start of the Action. The aim of the first meeting of the MC is:

- to prepare a detailed plan of action, containing:
- tasks of the Working Groups;
- detailed content of the proposed products;
- timetable of reporting results;
- to elect a Chairperson and a Vice Chairperson;
- to appoint the Working Groups.

Within three months after the meeting of the MC, the Working Groups will start working for the implementation of the Action. The MC will continuously monitor and adapt the working plan.
Duration: 9 months.

Phase 2: Preparation of the National Surveys on habitat fragmentation due to infrastructure. On a national level Working Groups of experts are nominated (one Group in each participating country). They will deliver the current situation in the field in every participant country.
In this phase two workshops and a meeting of the MC will be organized.
Duration: 12 months

Phase 3: An Editorial Group will be formed that has the task to analyse the national reports and to compile the information in order to prepare the final "European state-of-the-art report on habitat fragmentation due to infrastructure".
One meeting of the MC is planned to take place within this phase.
Duration: 6 months

Phase 4: A number of international Working Groups will be formed in order to prepare the "European Handbook on Habitat Fragmentation due to Linear Transportation Infrastructure" and the database. Each of these Groups will be responsible for the preparation of a specific part of the Handbook and database. The tasks might be given according the content of the proposed Handbook. For example: an Expert Working Group might be responsible for the chapter: Mitigation and Compensation Measures and another with the preparation of the List of Terms of Reference. The number of Working Groups will be defined by the MC within the planning procedure (Phase 1).
Two Expert Working Group meetings and one of the MC are planned during this phase.
Duration: 18 months

Phase 5: The final preparation of the Handbook will be the task of an Editorial Board (this might be the same as for Phase 3). A coordination meeting of the MC will take place in this stage of the Action.
Duration: 9 months

The total estimated duration of the Action is 4,5 years. The first product (the European state-of-the-art report) will be delivered after 2 years and the European Handbook and database after the next 2,5 years.

E. ECONOMIC DIMENSION

The following COST countries and the European Commission have actively participated in the preparation of the Action or otherwise indicated their interest: Austria, Belgium, Czech Republic, Estonia, Finland, France, Hungary, Italy, Netherlands, Romania, Spain, Sweden, Switzerland and the United Kingdom.
Furthermore, the Moscow State University has indicated its interest to participate in the proposed COST Action.

The estimated total cost of the project, assuming participation of 14 countries would be about ECU 3 million at 1997 prices.

Annex II. Directory of COST 341 Management Committee Members

Mr. Dick VAN STRAATEN	Belgium
Mr. Johan PEYMEN	Belgium
Ms. Anna CARAMONDANI	Cyprus
Mr. Jirí DUFEK	Czech Republic
Mr. Vaclav HLAVAC	Czech Republic
Mr. Niels TØRSLØV	Denmark
Ms. Barbara le Maire WANDALL	Denmark
Ms. Virginie BILLON/ Ms. Delphine CHEVALIER	France
Ms. Muriel MASTRILLI	France
Ms. Ágnes SIMONYI	Hungary
Ms. Ildiko VARGA	Hungary
Mr. Gerardus J. BEKKER	The Netherlands
Mr. Hans (J.G.) DE VRIES	The Netherlands
Mr. Bjørn IUELL	Norway
Mr. Gary FRY	Norway
Ms. M. Helena FARRALL	Portugal
Mr Billy FLYNN	Republic of Ireland
Mr. Eugene J. O'BRIEN	Republic of Ireland
Mr. George BURNEI	Romania
Mr. Razvan NOVASELIV	Romania
Ms. Carme ROSELL	Spain
Ms. Georgina ALVAREZ	Spain
Mr. Andreas SEILER	Sweden
Mr. Lennart FOLKESON	Sweden
Ms. Marguerite TROCMÉ	Switzerland
Ms. Franziska BORER	Switzerland
Ms. Penelope ANGOLD/Ms. Claire HICKS	United Kingdom
Mr Anthony SANGWINE	United Kingdom
Ms. Irene M. BOUWMA	European Centre for Nature Conservation (ECNC)
Ms. Tatsiana DAMARAD	European Centre for Nature Conservation (ECNC)
Mr. Magnus CARLE	COST Secretariat
Mr. Philippe STALINS	COST Secretariat

Annex III. Glossary

Explanations of terms adopted from dictionaries, reference books and textbooks and modified where appropriate. Many explanations, especially those pertaining to landscape ecology, are to be understood in the context of this book.

Term	**Meaning**
Agricultural underpass	Underground passageway or tunnel for agricultural use, often also permitting the passage of wildlife.
Amphibian fencing	A continuous structure erected alongside infrastructure, designed to prevent amphibians from crossing or direct them to a specific crossing point.
Amphibian tunnel	An enclosed passage or channel constructed for the sole purpose of conveying amphibians from one side of an infrastructure barrier to the other.
Anthropogenic	Generated and maintained, or at least strongly influenced by human activities.
Avoidance measures	Measures such as project abandonment or infrastructure re-routing employed in order to avoid unacceptable environmental impacts. See also 'Mitigation'.
Balancing pond	Artificial waterbody fed by storm drains and surface runoff, where pollutants from the road can settle out or filter through reeds before being released into the wider ecosystem.
Barrier effect	The combined effect of traffic mortality, physical hindrances and avoidance, which together reduce the likelihood and success of species crossing infrastructure.
Berm	Horizontal ledge in an earth bank or cutting constructed to ensure the stability of a steep slope.
Biodiversity	*See* Biological diversity.
Biological diversity	The variability among living organisms including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part. It includes diversity within and between species and within and between ecosystems as well the processes linking ecosystems and species.
Biota	All organisms in a community or area.
Biotope	The area inhabited by a distinct community of plants and animals. Biotope is commonly used among central European ecologists as the denominator of distinct land units and vegetation patches identified from an anthropocentric perspective. Elsewhere, biotope is often confused with and exchanged by the term 'Habitat'.
Bottleneck	Defined area (*e.g.* habitat corridor or patch) which, due to the presence of transportation infrastructure or other landuse, has become of crucial importance to animal migration or dispersal.
Brash	Woody vegetative cuttings (often left in a mass or pile, or randomly scattered across infrastructure verges).
Buffer zone	Vegetated strips of land that are intended to protect sensitive receptors *e.g.* protected sites, from impacts such as pollution or disturbance from infrastructure.
By-pass	Highway section following a route that passes around a congested or vulnerable area.
Catchment area	Geographical area from which all precipitation flows to a single stream or set of streams (may also be termed a drainage basin, or watershed).
Cattle creep	*See* Agricultural underpass.
Central reservation	The median strip running down the centre of a dual carriageway or motorway (sometimes vegetated), which separates traffic flowing in opposite directions.
Clippings	Cuttings from herbaceous vegetation.
Community (biotic)	Assemblage of interacting species living in a given location at a given time.
Compensatory measure	Measure or action taken to address a residual adverse ecological effect which cannot be satisfactorily mitigated. *See* also 'Mitigation'.
Connectivity	The state of structural landscape features being connected, enabling access between places via a continuous route of passage.
Consequence	*See* Impact.
Corridor	Tract of land or water connecting two or more areas. *See* also 'Wildlife corridor'.

Term	**Meaning**
Crossing	Designated or recognised place for people or fauna to cross from one side of something to the other *e.g.* pedestrian, cattle or deer crossings over infrastructure.
Crossroads	The place of intersection of two or more roads.
Culvert	Buried pipe or lined channel structure, that allows for a watercourse and/or road drainage to pass under infrastructure.
Curb	*See* Kerb.
Cutting	V-shaped cut out of the land enabling transportation infrastructure to pass at a level below the surrounding land surface.
Deer fencing	Continuous structure erected alongside infrastructure and designed to prevent deer from crossing or to direct them to a specific crossing point.
Dike	A wall built to prevent the sea or a river from flooding an area, or a channel dug to take water away from an area.
Dispersal	The process or result of the spreading of organisms from one place to another.
Drainage	The system of drains, pipes and channels devised to remove excess water (surface or subsurface) from an infrastructure surface.
Drover's track	Track used for the driving of herds.
Dual carriageway	Road with two lanes of traffic moving in opposite directions on either side of a central reservation (*see above)*.
Dyke	*See* Dike.
Ecoduct	*See* 'Wildlife overpass' *or* 'Landscape bridge'.
Ecological corridor	Landscape structures of various size, shape and vegetative cover that maintain, establish or re-establish natural landscape connectivity. Hedgerows or verges are examples of ecological corridors (natural and artificial) that can act as interconnecting routes permitting the movement of species across a landscape hence increasing the overall extent of habitat available to individuals.
Ecological infrastructure	The interconnected pattern of ecological corridors (*see above*) serving as a conduit for species moving across the landscape.
Ecological network	System of ecological corridors (*see above*), habitat core areas and their buffer zones which provide a (minimal) network of habitat needed for the successful protection of biological diversity at the landscape level.
Ecosystem	Dynamic complex of plant, animal and micro-organism communities and their non-living environment, interacting as a functional unit.
Ecotone	Transitional zone between two habitats.
Ecotope	Distinct area with a recognisable set of characteristics relating to the soil, vegetation or water conditions. The ecotope represents the smallest land unit that makes up the landscape mosaic.
Edge (effect)	The portion of an ecosystem near its perimeter, where influences of the surroundings prevent the development of interior environmental conditions.
Effect	*See* 'Impact'.
Embankment	Artificial bank (made of packed earth or gravel) such as a mound or dike, constructed above the natural ground surface in a linear form and designed to carry a roadway or railway across a lower lying area.
Endemic species	A species confined to a particular region and thought to have originated there.
Environmental Impact Assessment (EIA); Environmental Assessment (EA)	A method and a process by which information about environmental effects is collected, assessed and used to inform decision-making. *See also* 'Strategic Environmental Assessment'.
Fauna	Animal species.
Fauna-exit	Measure installed to prevent animals from becoming trapped by fences along infrastructure *e.g.* badger gate, or built in the sheet piling of a canal to enable animals to exit *e.g.* Amphibian ramp.
Fauna passage	Measure installed to enable animals to cross over or under a road, railway or canal without coming into contact with the traffic.
Filter effect	Infrastructure acts as a filter by inhibiting the movement of certain species or individuals. The scale of the effect varies between species and may even vary between sexes or age categories.
Flora	Plant or bacterial life.

Term	Meaning
Forestry road	(Narrow) road built mainly for forestry purposes which may or may not have public access.
Fragmentation	The breaking up of a habitat, ecosystem or land-use unit into smaller parcels.
Game	Animals hunted for sport and food.
Game fencing	*See* 'Deer fencing.
Gradient	The (rate of) change of a parameter between one area or region to another.
Guide fencing	Fencing built to lead wild animals to a dedicated crossing point.
Guard-rail	*See* 'Safety fence'.
Gutter	Paved channel designed to carry runoff from the edge of infrastructure into the drainage system (*see above).*
Habitat	The place or type of site where an organism or population naturally occurs - including a mosaic of components required for the survival of the species.
Habitat attrition	Habitat destruction due to progressive urbanisation.
Habitat fragmentation	Dissection and reduction of the habitat area available to a given species - caused directly by habitat loss (*e.g.* due to land-take) or indirectly by habitat isolation (*e.g.* due to barriers increasing distances between neighbouring habitat patches).
Halophyte	Terrestrial plant living in a salty environment.
Hard shoulder	*See* 'Shoulder'.
Hedgerow	A close row of woody species (bushes or trees) serving as a boundary feature between open areas (often used in combination with, or as an alternative to, a fence).
Herbicide	A chemical application which kills weeds.
Highway	*See* .Road'.
Impact	The immediate response of, *e.g.*, an organism, species or property to an external factor. This response may have an effect on the species or condition that may result in wider consequences to the population or species community over a longer time scale.
Indicator	Quantitative variable, usually with a target value representing an objective, which symbolises environmental or other impacts of transportation infrastructure.
Indicator species	Species indicative of (a) some environmental or historical influence (*e.g.* lichens can be atmospheric pollution indicators, and woodland ground-flora can be indicative of ancient woodland), or (b) a community or habitat type (*e.g.* some species can be used to classify invertebrate communities, or are indicative of particular habitats).
Infrastructure	The system of communications and services within an area.
Invertebrate	Animals lacking a vertebral column, or backbone
Junction	*See* 'Crossroads'.
Kerb	Edging (usually concrete) built along infrastructure to form part of the gutter (*see above)*.
Keystone species	A species that plays a pivotal role in an ecosystem and upon which a large part of the community depends for survival.
Land cover	Combination of landuse and vegetation cover.
Landform	Natural feature on the surface of the earth.
Landscape	The total spatial and visual entity of human living space integrating the geological, biological and human-made environment. A 'heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout' and create a specific, recognisable pattern. Includes (a) the integration of man with nature, (b) the mosaic structure, and (c) the functional linkage between the entities in the mosaic.
Landscape bridge	Large wildlife overpass or ecoduct used to connect habitats over an infrastructure barrier.
Landscape diversity	The numerous relations existing in a given period between individuals or a society and a topographically defined territory, the appearance of which is the result of the action, over time, of both natural and human factors.
Landscape element	Each of the relatively homogeneous units, or spatial elements, recognised at the scale of a landscape mosaic.
Landscaping	To modify the original landscape by altering the plant cover – this may include building earthworks to form new landscape structures.

Term	**Meaning**
Land-take	Land used for highway schemes (*in the context of this report)*.
Land unit	The smallest functional element of the landscape. *See* also 'Ecotope', 'Habitat' and 'Biotope'.
Land-use planning	Activity aimed at predetermining the future temporal and spatial usage of land and water by society.
Linear transportation infrastructure	Road, railway or navigable inland waterway.
Major road	Road which is assigned permanent traffic priority over other roads.
Matrix	In landscape ecology theory, the background ecosystem or land-use type in a mosaic, characterised by extensive cover, high connectivity and/or major control over dynamics.
Metapopulation	A set of local populations within an area, where typically migration from one local population to at least some other patches is possible to sustain local population numbers. The metapopulation may have a higher persistence than the single local populations.
Migration	The regular, usually seasonal, movement of all or part of an animal population to and from a given area.
Mitigation	Action to reduce the severity of, or eliminate, an adverse impact.
Mode	Form of transport (*e.g.* road, rail, air, shipping, pipeline, bicycle etc).
Monitoring	Combination of observation and measurement employed to quantify the performance of a plan, measure or action against a set of predetermined indicators, criteria or policy objectives.
Mosaic	The pattern of patches, corridors and matrices, (*in this case, within a landscape)* each composed of small, similar aggregated objects.
Motorway	Major arterial highway that features: two or more traffic lanes of traffic moving in each direction, separated by a 'central reservation' (*see* above); controlled entries and exits; and alignment eliminating steep grades, sharp curves, and other hazards (*e.g.* grade crossings) and inconveniences to driving.
Multimodal	Pertaining to more than one 'mode' of transport (*see above*).
Network	Interconnected system of movement corridors (*in this context*).
Noise barrier	Measure installed to reduce the dispersal of traffic noise in a certain sensitive area (*e.g.* wall, fence, screen).
Overpass	Structure (including its approaches) which allows one infrastructure element to pass above another (or other type of obstacle).
Pedestrian underpass	Tunnel under an infrastructure link designed for use by pedestrians.
Pesticide	Any chemical application to kill insects, rodents, weeds, fungi or other living organisms which are harmful to plants, animals or foodstuffs.
Population	Functional group of individuals that interbreed within a given, often arbitrarily chosen, area.
Pipe	Cylindrical water tight structure sunk into the ground to provide a passage (from one side of the infrastructure to another)
Re-afforestation	Re-establishment of forest by the planting of trees (may have commercial or ecological functions).
Region	A geographical area (usually larger than 100 km^2) embracing several landscapes or ecosystems that share some qualitative criteria *e.g.* topography, fauna, vegetation, climate etc. Examples include bio-geographic and socio-economic regions.
Regrading	The process of converting an existing landscape surface into a designed form by undertaking earthworks *e.g.* cutting, filling or smoothing operations.
Restoration	The process of returning something to an earlier condition or position. Ecological restoration involves a series of measures and activities undertaken to return a degraded ecosystem to its former state.
Riparian forest	Forest situated by a riverbank or other body of water.
Road	Concrete or tarmac public way for vehicles, humans and animals.
Road corridor	Linear surface used by vehicles plus any associated (usually vegetated) verges. Includes the area of land immediately influenced by the road in terms of noise, visual, hydrological and atmospheric impact (normally within 50 to 100 m of the edge of the infrastructure).

Term	Meaning
Road network	The interconnected system of roads serving an area.
Roundabout	Junction where three or more roads join and traffic flows in one direction around a central island of land which is often vegetated.
Safety barrier	A vehicle-resistant barrier installed alongside, or on the central reserve of, infrastructure intended to prevent errant vehicles from leaving the designated corridor and thus limit consequential damage. 'Safety fence' (*see below*) is one example of a safety barrier.
Safety fence	Continuous structure (of varied material) erected alongside infrastructure designed to prevent errant vehicles from leaving the designated corridor and limit consequential damage. May also be termed 'Guard-rail'.
Scale	In landscape ecology, the spatial and temporal dimensions of objects, pattern and processes.
Service road	Subsidiary road connecting a more major road with adjacent buildings or facing properties. Normally not a thoroughfare.
Sheet piling	Waterway bank erosion protection (wooden, iron or concrete planks sunk vertically between the edge of the water and the embankment).
Shoulder	The linear paved strip at the side of a 'motorway' which vehicles are allowed to use during emergencies, and which is used by maintenance vehicles to access works.
Single carriageway	Road in which a single lane of traffic is flowing in each direction, with no barrier or median strip dividing them.
Single track	Road that is only as wide as a single vehicle, and thus does not permit the flow of two-way traffic.
Sink	*See* 'source'.
Site	A defined place, point or locality in the landscape.
Slope protection	Activity or measure aimed at preventing soil erosion on slopes (*e.g.* by covering the ground with vegetation, stones, concrete or asphalt).
Source – sink habitats and populations	Source habitats are areas where populations of a given species can reach a positive balance between births and deaths and thus act as a source of emigrating individuals. Sink habitats, on the other hand, have a non-sustaining birth-death ratio and are dependent on immigration from source populations.
Spatial planning	*See* 'land-use planning'.
Stepping stone	Ecologically suitable patch where an organism temporarily stops while moving along a heterogeneous route.
Strategic Environmental Assessment (SEA)	The application of the principles of Environmental Impact Assessment (*see above*) to policies, plans and programmes at a regional, national and international level.
Surface-water drainage	System devised to remove water from the surface of the ground (or infrastructure) (see also 'drainage').
Target species	A species that is the subject of a conservation action or the focus of a study.
Taxon (pl. taxa)	Category in the Linnean classification of living organisms.
Terrestrial	Pertaining to land or earth.
Top soil	The top layer of soil that supports vegetation.
Underpass	Structure, including its approaches, which allows one route to pass under another route or obstacle.
Verge	The strip of land (often vegetated) beyond the infrastructure surface itself, but within the infrastructure corridor.
Vertebrate	Any animal characterised by a vertebral column, or backbone.
Viaduct	Long elevated bridge, supported on pillars, which carries infrastructure over a valley or other similar low-level landscape area.
Waterway	A navigable body of water.
Weir	Construction in a river or canal designed to hold the water upstream at a certain level.
Wetland	Land or area containing high levels of soil moisture or completely submerged in water for either part or the whole of the year.
Wildlife	Wild animals, plants and bacteria collectively.
Wildlife corridor	Linear-shaped area or feature of value to wildlife – particularly for facilitating movement across a landscape.

Term	Meaning
Wildlife crossing point	Designated place for wildlife to cross infrastructure safely *e.g.* using a specially-designed overpass, underpass etc.
Wildlife fence	Fence designed and erected specifically to prevent animals from gaining access onto infrastructure.
Wildlife overpass	Construction built over infrastructure in order to connect the habitats on either side. The surface is, at least partly, covered with soil or other natural material that allows the establishment of vegetation.
Willingness To Pay (WTP)	A term used in economics to quantify the maximum amount of consumption possibilities that an individual is prepared to sacrifice in order to consume a particular good. In many research projects, such as valuation of various environmental assets, the purpose is to estimate WTP in terms of money.

Annex IV. List of Abbreviations

(A)ADT	(Annual) Average Daily Traffic (*i.e.* vehicles/day).
A	Austria
avg	Average
B	Belgium
BAP	Biodiversity Action Plan (UK)
CBA	Cost-Benefit Analysis
CDV	Transport Research Centre (CZ)
CEC	Commission of the European Communities
CEE	Central and Eastern Europe
CEMAGREF	'Centre National du Machinisme Agricole, du Génie Rural, des Eaux et des Forêts' (F)
CETE	'Centre d'Etudes Techniques de l'Equipement' (F)
CH	Switzerland
CNRS	'Centre National de la Recherche Scientifique' (F)
CoE	Council of Europe
COST	European Co-operation in the Field of Scientific and Technical Research
cRN	Country Road Network
CY	Cyprus
CZ	Czech Republic
DAD	Daily Average Density
dbA	Decibels
DETR	Department of the Environment, Transport and the Regions (UK)
DK	Denmark
DWW	Road and Hydraulic Engineering Institute (NL)
E	Spain
EE	Estonia
EC	European Commission
ECMT	European Conference of Ministers of Transport
ECNC	European Centre for Nature Conservation
EEA	European Environment Agency
EEC	European Economic Commission
EIA	Environmental Impact Assessment
EID	Environmental Impact Declaration
ESDP	European Spatial Development Perspective
EU	European Union
EVV	Traffic and Transport Evaluation (NL)
F	France
GIS	Geographical Information System
GVF	Dienst für Gesamtverkehrsfragen General Sekretariat Department for Energy, Transport, Environement and Communication (CH)
H	Hungary
HA	Highway Agency (UK)
HSR / TGV	High Speed Rail / Train à Grande Vitesse
HVF	Heavy Vehicle Fee
I	Italy

IBA	Important Bird Area
IENE	Infra Eco Network Europe
IFEN	'Institut Français de l'Environnement' (F)
INRA	'Institut National de la Recherche Agronomique' (F)
IRL	Republic of Ireland
IUCN	International Union for Conservation of Nature and Natural Resources
IWW	Wirtschaftspolitik und Wirtschaftsforschung. Universität Karlsruhe (CH)
MATE	'Ministère de l'Aménagement du Territoire et de l'Environnement' (F)
MIMAM	'Ministerio de Medio Ambiente' (E)
MOPTMA	'Ministerio de Obras Públicas, Transportes y Medio Ambiente' (E)
MRN	Main Road Network
N	Norway
NATA	New Approach to Appraisal (UK)
NGOs	Non-Governmental Organisations
NIS	Newly Independent States
NL	The Netherlands
NW 4	Fourth Paper on Water Management (NL)
OECD	Organisation for Economic Cooperation and Development
ONC	Office National de la Chasse
p.a.	*Per annum*
P	Portugal
PEBLDS	Pan-European Biological and Landscape Diversity Strategy
PORNS	Planes de Ordenación de los Recursos Naturales (E)
RO	Romania
S	Sweden
SAC	Special Areas of Conservation
SAP	Species Action Plan (UK)
SEA	Strategic Environmental Assessment
SETRA	'Service d'Etudes Techniques des Routes et Autoroutes' (F)
SLU	Sveriges Lantbruksuniversitet (Swedish University of Agricultural Sciences)
SNH	Scotish National Heritage
SNRA	Swedish National Road Administration
SoA	National State of the Art Report on Habitat Fragmentation due to Transportation Infrastructure
SPA	Special Protection Areas
SRN	Secondary Road Network
SSSI	Sites of Special Scientific Interest (UK)
SVAG	'Schwerverkehrsabgabegesetz' (CH)
TEN-T	Trans-European Transport Network
TERM	Transport and Environment Reporting Mechanism
TINA	Transport Infrastructure Needs Assessment
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environmental Programme
VLINA	Flemish Incentive Programme for Nature Development (B)
WTP	Willingness To Pay
WWF	World Wide Fund for Nature

Annex V. Inventory of Fauna Overpasses

List of wildlife overpasses in European countries participating in COST 341 and/or IENE (incomplete).
Only structures with a width of <1000 m built for wildlife. Information provided by COST/IENE representatives in the different countries or from National State of the Art Reports.

Country	Name of overpass	Region	Type of road/railway line crossed	Code/no of road/railway line-	Width (at narrowest point)	Combined with road/agricultural track	Year of construction
Austria	Einhausung Königsberg	Niederösterreich	motorway	A 2	165 m	No	1999
	Unterflurtrasse Kreuzergegend	Kärnten	motorway	A 2	600 m	Agricultural road, agricultural track	1999
	Unterflurtrasse Bettlerkreuz	Kärnten	motorway	A 2	350 m	Agricultural road, local road	1999
	Unterflurtrasse Haidach	Kärnten	motorway	A 2	450 m	Main road, local road	1999
	Unterflurtrasse Reigersdorf	Kärnten	motorway	A 2	300 m	Agricultural road	1999
	Unterflurtrasse Farchern Ost	Kärnten	motorway	A 2	230 m	Agricultural road	1999
	Unterflurtrasse Farchern West	Kärnten	motorway	A 2	140 m	No	1999
	Wildüberführung Parndorf TÜPL	Burgenland	motorway	A4	25 m	Agricultural road	1991
	Grünbrücke Parndorf	Burgenland	motorway	A 4	100 m	Agricultural road	1993
	Grünbrücke Neusiedl	Burgenland	motorway	A 4	100 m	Agricultural road	1993
	Grünbrücke Weiden	Burgenland	motorway	A 4	100 m	Agricultural road	1993
	Grünbrücke Gols	Burgenland	motorway	A 4	100 m	Agricultural road	1993
	Grünbrücke Zurndorf	Burgenland	motorway	A 4	100 m	Agricultural track	1993
	Grünbrücke Mönchhof	Burgenland	motorway	A 4	100 m	Agricultural road	1993
	Wartberg 1	Oberösterreich	motorway	A 9	525 m	Local road	1990
	Wartberg 2	Oberösterreich	motorway	A 9	205 m	Local road	1990
	Wartberg 3	Oberösterreich	motorway	A 9	255 m	Forest road	1990
	Mötz-Schlenzmure	Tirol	motorway	A 12	240 m	Forest road	1986
	Grünbrücke bei Vils	Tirol	main road	B 314	25 m	No	1999
	3 game overpasses	Burgenland	express road	S 31	30 – 50 m	Agricultural road	2001 ?

Country	Name of overpass	Region	Type of road/railway line crossed	Code/no of road/railway line-	Width (at narrowest point)	Combined with road/agricultural track	Year of construction
	5 game overpasses	Niederösterreich	4-lane motorway	B 301	15 – 70 m	Agricultural road	2001 ?
Belgium	Rulles	Wallonia	motorway	E 411	8	no	1988
	Mannay	Wallonia	motorway	E 25	10	no	1983
	Mannay	Wallonia	motorway	E 42	?		?
	St. Hubert (5)	Wallonia	4-lane road	N 89	3	water	1978
Cyprus	No overpasses						
Czech Republic	Lipnik	Olomouc	motorway	R35	80 m	no	1997
Denmark	Flauenskjold faunapassage	Northern Jutland	motorway	E45	20 m	no	1999
Estonia	No overpasses						
France	Forêt de la Hardt (lieu-dit Grunhutte)	Alsace (Haut-Rhin)	4-lane motorway	A 36	8 m (45 m at ends)	Forest road	1981
	Forêt de la Hardt	Alsace (Haut-Rhin)	4-lane motorway	A 36	8 m (45 m at ends)	no	
	Forêt de la Hardt	Alsace (Haut-Rhin)	4-lane motorway	A 36	12 m (45 m at ends)	no	
	Forêt de la Hardt	Alsace (Haut-Rhin)	4-lane motorway	A 36	8 m (45 m at ends)	no	
	Lieu-dit: Bouchon-Magdeleine	Champagne - Ardenne	4-lane motorway	A 26	7.5 m	Agricultural road	
	Lieu-dit: Les Grandes Brûlées	Champagne - Ardenne	4-lane motorway	A 26	7.5 m	Agricultural road	
	Val Marnais Massif forestier de Châteauvillain – Arc en Barrois	Champagne - Ardenne	4-lane motorway	A 5	8 m	Forest road	1988
	Beau Jarron Massif forestier de Châteauvillain – Arc en Barrois	Champagne - Ardenne	4-lane motorway	A 5	8 m	no	1988
	Forêt d' Ermenonville	Paris	High-speed railway line	TGV Nord	80 m	no	
	Forêt de Hardelot	Nord-Pas-deCalais	Motorway	A 16	800 m	no	
	Forêt d'Eu	Normandie	Motorway	A 28	100 m		
	Piedmont des Vosges	Alsace (Bas-Rhin)	Motorway	A 35	20 m	no	
	Unknown number of similar bridges				mainly 8-15 m wide		
Germany	Schwarzgraben	Baden-Württemberg	3-lane fast road	B31neu	50 m	Local road	1992/95
	Weiherholz	Baden-Württemberg	3-lane fast road	B31neu	80 m	No	1993/95
	Negelhof	Baden-	3-lane fast	B31neu	20 m	Agricultural	1993/95

Country	Name of overpass	Region	Type of road/railway line crossed	Code/no of road/railway line-	Width (at narrowest point)	Combined with road/agricultural track	Year of construction
		Württemberg	road			road	
	Hirschweg	Baden-Württemberg	3-lane fast road	B31neu	80 m	Forest road	1993/95
	Nesselwangen	Baden-Württemberg	3-lane fast road	B31neu	29 m	Forest road	1993/95
	Würtembergle	Baden-Württemberg	3-lane fast road	B33	35 m	Agricultural road	1989
	Hohereute	Baden-Württemberg	3-lane fast road	B33	35 m	Agricultural road	1989
	Oberderdingen	Baden-Württemberg	High-speed railway	ICE	10 m	Forest road	1991
	Aichelberg	Baden-Württemberg	Motorway	A8		Forest road	
	Wildwechsel-brücke Barzig	Brandenburg	Motorway	A13	8.5 m		
	Gebrazhofen	Baden-Württemberg	Motorway	BAB?	50 m		
	Teisendorf	Bayern	Main road	B304	24 m	Forest road	2000
	Augsburg	Bayern	Main road	B17	24 m	Agricultural road with green strip	
	Birkenau/Reisen	Hessen	Main road	B38a	50 m		
	Pinnower See	Mecklenburg-Vorpommern	Motorway	BAB241	38 m	No?	2000
		Mecklenburg-Vorpommern	Motorway	BAB241	107 m		
	Near Wismar (1)	Mecklenburg-Vorpommern	Motorway	A20	45 m (80 m at ends)	No	
	Near Wismar (2)	Mecklenburg-Vorpommern	Motorway	A20	45 m (80 m at ends)	No	
	Near Rostock	Mecklenburg-Vorpommern	Motorway	A20	38 m		2000
	Kleinflöthe	Niedersachsen	Motorway	A395	10 m	No	
	Möser	Sachsen-Anhalt	Motorway	A2	40 m (80 m at ends)		In con-struction
	Herfatz	Baden-Württemberg	Motorway	A96	440 m		
	Near Pöcking	Bayern	Main road	B2	140 m	Agricultural road	
	Grosser Busch	Nordrhein-Westfalen	Main road	B224	275 m		
	Strümp	Nordrhein-Westfalen	Motorway	A44	640 m		
	Rheinschlinge	Nordrhein-Westfalen	Motorway	A44	870 m		
Hungary	No name 151+75 km	Moson Plain	motorway	M 1	20 m	no	1995
	No name	Moson Plain	motorway	M 1	20 m	no	1995

Country	Name of overpass	Region	Type of road/railway line crossed	Code/no of road/railway line-	Width (at narrowest point)	Combined with road/agricultural track	Year of construction
	147+55 km						
The Nether-lands	Woeste Hoeve		4-lane motor-way plus road	A 50	50 m	no	1988
	Terlet		4-lane motor-way plus road	A 50	50 m	no	1988
	Boerskotten		4-lane motorway	A 1	17 m	no	1992
	Kootwijk		4-lane motorway	A 1	30 m (80 at ends)	no	1998
	Noordelijke Randweg	Den Haag	4-lane motorway	A 14	14 m	Cycle track Riding track	2000
Norway		Aust-Agder	2-lane motorway	E18	17 m	(very) local road	1997
		Akershus	4-lane m.w. + highspeed railway	Rv 174 + Gardermo-banen	45 m	Local road	1996
		Møre og Romsdal		E39			1994 1997
		Oppland	2-lane county-road	Rv 35	40m	Forest road	1997
		Østfold	3-lane m.w.	E6	90 m	Local road	1999
	Additionally several very narrow overpasses						
Poland	Opole 4? bridges	?	4-lane motorway	?	< 10 m	Forest road	c. 2001
Portugal	No overpasses						
Slovenia							1 planned
Spain	Sahagún-San Mamés (León-Burgos)	Castilla León	4 lane motorway	A-231	15	no	2001
	Estivadas-Alto de Allariz (Rías Bajas motorway)	Galicia	4 lane motorway	A-52	25	no	1998
	León-Benavente (La Plata motorway)	Castilla-León	4 lane motorway	N-630	12 (30 at entrances)	no	In con-struction
	León-Benavente (La Plata motorway)	Castilla-León	4 lane motorway	N-630	20 (35 at entrances)	no	In con-struction
	Plasencia-Cañaveral (La Plata motorway	Extremadura	4 lane motorway	N-630	20	no	Planned
	Alforja-Vilaplana	Catalunya	2 lane road	TP-7013	10	Unpaved agricultural road	2000
	Mombuey-Requejo (Rías Bajas motorway)	Galicia	4 lane motorway	A-52	10 (12 at entrances)	Unpaved agricultural track	1998
	Mombuey-	Galicia	4 lane	A-52	10 (12 at	Unpaved	1998

Country	Name of overpass	Region	Type of road/railway line crossed	Code/no of road/railway line-	Width (at narrowest point)	Combined with road/agricultural track	Year of construction
	Requejo (Rías Bajas motorway)		motorway		entrances)	agricultural track	
Sweden	Uddevalla	Bohuslän	4-lane motorway	E 6	17 m (21 at ends)	Agricultural road	2000
Switzer-land	Fuchswies	Thurgau	4-lane motorway	A 7	200 m	Forest road	1992
	Aspiholz	Thurgau	4-lane motorway	A 7	140 m	Forest road	1992
	Loterbuck	Zürich	4-lane motorway	A 4	100 m	Forest road	1996
	Kaiserbuck	Zürich	4-lane motorway	A 4	140 m	Road plus Agricultural road	1996
	Henggart / Rütibuck	Zürich	4-lane motorway	A 4	50 m	?	2000
	Grauholz	Bern	6-lane motorway	A 1	28 m	No	1993/94
	Brienzwiler	Bern	2-lane fast road	A 8	22 m	No	1993/94
	Lyss	Bern	4-lane motorway	A 6	3.4 m	With track	1984/85
	La Lance	Vaud	4-lane motorway	A 5	50 m	Local road?	2001?
	Klosterwald	St. Gallen	?	?	?	?	?
	Chèvrefu	Fribourg	4-lane motorway	A 1	100 m	No	2001
	Hirschensprung - Rüthi	St. Gallen	4-lane motorway	A 13	50 m	no	1999
	Stöck	Bern	4-lane motorway	A 5	80 m	no	2001
	Chandossel	Fribourg	4-lane motorway	A 1	*ca.* 12 m	Local road	1998?
	La Raisse	Vaud	4-lane motorway	A 5	25 m	Local road	
	Chaltenboden Schindellegi	Schwyz	2-lane road plus cycle track	A 8	40 m	no	2000
	Birchiwald	Bern	High-speed railway line	A 1	50/30	no	2001
	Neueinschlag	Bern	4-lane motorway / High-speed railway line	A 1	60	no	2001
	Replanes	Neuchâtel	3-lane (?) fast road	J 10	30 m	Forest road	2001
	Chaumes	Neuchâtel	3-lane (?) fast road	J 10	30 m	No	2001
	Gde. Giswil	Obwalden	motorway?	A 8	80 m	No	in construction
	Gde. Kreuzlingen	Thurgau	4-lane	A 7	50 m	?	1999

Country	Name of overpass	Region	Type of road/railway line crossed	Code/no of road/railway line-	Width (at narrowest point)	Combined with road/agricultural track	Year of construction
			motorway				
United Kingdom	Epping Forest		motorway	M 25	?	?	?
	?	Oxfordshire	motorway	M 40	?	?	1991
	Temple Wood	Kent	railway	CTRL	?	?	2000
	Great Wood	Kent	railway	CTRL	?	?	2000

Annex VI. Species List

European Commission
EUR xxxxx – COST 341 – Habitat Fragmentation due to Transportation Infrastructure
Luxembourg: Office for Official Publications of the European Communities
2002 – xxx pp. – 17.6 x 25.0 cm
ISBN xx-xxx-xxxx-x
Price (excluding VAT) in Luxembourg : EURO xx.xx

COST 341 investigates the problem of 'Habitat Fragmentation due to Transportation Infrastructure', which has been recognised as one of the most significant factors which continues to contribute towards the decline of biodiversity in Europe.

Sixteen European countries and one international organisation have worked together under COST 341 with the following common objectives:

- To establish the current situation with regards to habitat fragmentation caused by transportation networks in Europe: and
- To identify best practice guidelines, methodologies, and measures for avoiding, mitigating against and compensating for the fragmentation effect.

This European Review is one of a package of COST 341 products. It represents a synthesis of information contained within individual National State of the Art Reports produced by the COST 341 member countries. The European Review explains the scope and extent of the habitat fragmentation problem across Europe and aims to identify the range of solutions currently implemented in order to address it.