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# Habitat fragmentation due to transportation infrastructure

## COST 341 national state-of-the-art report Sweden

Andreas Seiler and Lennart Folkeson (Editors)

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**Title:**
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**Abstract (background, aim, method, result) max 200 words:**
Fragmentation of landscapes and habitats is a major cause of the impoverishment of biodiversity in Europe. Transportation infrastructure, notably roads and railways, strongly contribute to the fragmentation. This is an important issue in infrastructure planning in the densely populated countries in Europe. Increasing attention is being paid to landscape fragmentation also in Sweden.

Landscape fragmentation comprises the splitting of habitats and ecosystems in smaller and more isolated units. Habitat loss and isolation are important features of the complicated fragmentation process. Land-take for transportation infrastructure destroys habitats of animals and plants. Infrastructure and traffic create barriers to animal movement and plant dispersal in the landscape. Other effects are disturbance caused by pollution and noise. Traffic also kills many animals.

This publication gives an overview of transportation and landscape fragmentation in Europe and Sweden. The report reviews on-going research as well as planning procedures and methods. Measures to strengthen the ecological functions in the landscape are described. The effectivity of ecoducts and other fauna passages are discussed, and follow-up methods and results are presented.

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.

**Keywords**:
Landscape, fragmentation, infrastructure, barrier, animal, fauna casualty, fauna passage, literature review

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Biotopfragmentering till följd av transportinfrastrukturen. COST 341 svensk nationell kunskapsöversikt.

**Referat (bakgrund, syfte, metod, resultat) max 200 ord:**
Fragmentering av landskap och biotoper är en viktig orsak till minskningen av den biologiska mångfalden i Europa. Transportinfrastruktur, främst vägar och järnvägar, bidrar starkt till fragmenteringen. Detta är en stor fråga för infrastrukturplaneringen i Europas tätbefolkade länder. Även i Sverige uppmärksammas landskapsfragmenteringen alltmer.

Landskapsfragmentering består i uppsplittring av biotoper och ekosystem i mindre och alltmer isolerade enheter. Fragmentering är en komplex process, där biotopförlust och isolering är de viktigaste delprocesserna. Mark tas i anspråk av vägar och järnvägar, och därmed förstörs livsrum för vilda djur och växter. Infrastruktur och trafik utgör barriär för djurs rörelser och växters spridning i landskapet. Andra effekter är störningar, t ex förorening och buller, och många djur dödas av trafiken.

Denna publikation ger en kunskapsöversikt över landskapsfragmentering och infrastruktur i Europa och Sverige. Rapporten behandlar pågående effektforskning samt planeringsmetoder och förhållningssätt. Åtgärder för att upprätthålla de ekologiska sambanden i landskapet beskrivs. Effektiviteten hos ekodukter och andra faunapassager diskuteras och uppföljningsmetoder och -resultat presenteras.

För att fragmenteringsproblematiken ska kunna hanteras på ett ändamålsenligt sätt och med effektiva verktyg, krävs ett fungerande samarbete mellan planerare, ekonomer, ingenjörer, ekologer, landskapsarkitekter och andra fackmän. Sådan samverkan krävs på alla planeringsstadier och i såväl små som stora infrastrukturprojekt.

**Nyckelord:**
Landskap, fragmentering, infrastruktur, barriär, djur, viltolyckor, faunapassage, kunskapsöversikt

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## Foreword

This publication gives an overview of the situation in Sweden concerning habitat fragmentation and transportation infrastructure. It gives a scientific description of the function of landscapes and the interaction of transportation infrastructure with landscapes, natural habitats and wildlife populations. It briefly describes the bio-geographical features of the country and the administrative and legislative framework pertaining to habitat fragmentation. The existing and planned transportation infrastructure is outlined, and approaches to minimise the effects of existing and future infrastructure are discussed. Fauna passages and other measures taken to mitigate the effects of transportation infrastructure are presented, as are investigations to document their effectiveness for animal movement in the landscape.

This report is one of the products of the COST 341 action on *Habitat Fragmentation due to Transportation Infrastructure*. The report is one of 13 national reports produced within action as a basis for the common European state-of-the-art review[1] published in 2003. The structure of the national reports was to follow that of the European review. Based on the European review and the national reports, the European handbook on Wildlife and Traffic[2] was published in 2003.

Information has been gathered from a wide range of sources, such as scientific reports, on-going projects, websites, and personal communication with scientists, infrastructure planners, authority and NGO representatives and other actors. A list of persons who contributed with either information or written text is given in Annex III. The information in the present report has been compiled by the two editors Andreas Seiler, Swedish University of Agricultural Sciences, and Lennart Folkeson, VTI. Chapter 1 has been written by Hans Bekker, DWW, the Netherlands. Andreas Seiler is the author of chapters 2 and 3. Chapters 1–3 and the Executive Summary have been copied without changes from the European review mentioned above. Most of the information in the report reflects the situation as of the year 2000. Some data have been updated in 2003. The manuscript has been scientifically examined by Anders Sjölund at the Swedish Road Administration, and discussed during a seminar held on the 19th of November 2003.

COST 341 is part of European Co-operation in the Field of Scientific and Technical Research (COST). The aims of COST 341 are i) to establish the current situation with regard to habitat fragmentation caused by transportation networks in Europe, and ii) to identify best practice guidelines, methodologies and measures for avoiding, mitigating against and compensating for the fragmentation effect. COST 341 originates in Infra Eco Network Europe (IENE)[3], a network for co-operation and exchange of information in the field of habitat fragmentation caused by infrastructure at a European level. COST 341, comprising sixteen European countries and the European Centre for Nature Conservation, started working in 1998 and formally finalised its activities with an

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[1] Trocmé, M., Cahill, S., de Vries, H.J.G., Farrall, H., Folkeson, L., Fry, G., Hicks, C. and Peymen, J. (Eds.) (2003) *COST 341. Habitat Fragmentation due to Transportation Infrastructure. The European Review*. – Office for Official Publications of the European Communities. Luxembourg. 253 pp.

[2] Iuell, B., Bekker, G.J., Cuperus, R., Dufek, J., Fry, G., Hicks, C., Hlavac, V., Keller, V., Rosell, C., Sangwine, T., Tørsløv, N. and Wandall, B. le Maire (Eds.) (2003) *Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions*. – KNNV Publishers.

[3] http://cordis.europa.eu/cost-transport/src/cost-341.htm

international conference held in Brussels in November 2003[4]. All COST 341 products are available on a CD-ROM and can also be downloaded from the COST 341 website, http://cost341.instnat.be. The Swedish national report found on the CD-ROM is a preliminary version of the current report.

The work of the editors and their participation in the COST 341 Management Committee has been financially supported by the Swedish Road Administration and Banverket, Swedish National Rail Administration, whose contact persons have been Inga-Maj Eriksson and Jan Skoog, respectively.

We hereby express our gratitude to the persons and organisations mentioned above for their contributions and support.

Grimsö and Linköping in May 2005

Andreas Seiler Lennart Folkeson

[4] European Conference on Habitat Fragmentation due to Transportation Infrastructure. Brussels, 13–15 November 2003.



Photo: L Folkeson, VTI

## Kvalitetsgranskning

Granskningsseminarium genomfört 2003-11-19 där Anders Sjölund, Vägverket, var lektör. Lennart Folkeson har genomfört justeringar av slutligt rapportmanus 2006-03-20. Projektledarens närmaste chef, avdelningschef Pontus Matstoms, har därefter granskat och godkänt publikationen för publicering.

## Quality review

Review seminar was held on November 19, 2003 with Anders Sjölund, Swedish Road Administration, as the presenter. Lennart Folkeson has made alterations to the final manuscript of the report. Research director Pontus Matstoms has examined and approved the report for publication on 2006-03-20.

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**Habit fragmentation due to transportation infrastructure – COST 341 national state-of-the-art report Sweden**

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## Executive Summary[5]

*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.

[5] Executive Summary copied from the European Review: De Vries, H.J.G. and Damarad, T. (2003). In: Trocmé, M., Cahill, S., de Vries, H.J.G., Farrall, H., Folkeson, L., Fry, G., Hicks, C. and Peymen, J. (Eds.) (2003) *COST 341. Habitat Fragmentation due to Transportation Infrastructure. The European Review*, pp. 11-14. – Office for Official Publications of the European Communities. Luxembourg. 253 pp.

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.

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 on-going 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.

**Biotopfragmentering till följd av transportinfrastruktur**
**– COST 341 svensk nationell kunskapsöversikt**

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## Sammanfattning

Fragmentering av landskap och biotoper är en av de viktigaste orsakerna till minskningen av den biologiska mångfalden i Europa. Många faktorer bidrar till fragmenteringen, men en av de viktigaste orsakerna är transportinfrastrukturen, främst vägar och järnvägar.

Landskapsfragmenteringens roll för den biologiska mångfalden är en fråga som kommit att få stort intresse i infrastrukturplaneringen ute i Europas tätbefolkade länder. På senare år har även i Sverige allt mer uppmärksamhet kommit att riktas mot detta problemområde.

Landskapsfragmentering består i uppsplittring av biotoper och ekosystem i mindre enheter som blir alltmer isolerade från varandra. Detta kan i många fall leda till en situation där bestånd (populationer) av växter och djur hotas, först lokalt men senare kanske även i större geografisk skala. Fragmentering är en komplex process, där biotopförlust och isolering är de viktigaste delprocesserna; mycket mark tas i anspråk av vägar och järnvägar, och därmed förstörs livsrum för vilda djur och växter. Infrastruktur och trafik utgör barriär för djurs rörelser och växters spridning i landskapet. Andra delprocesser utgörs av förändringar i lokalklimatförhållanden, näringstillgång och andra tillväxtbetingelser samt förorening från trafiken och infrastrukturen. Härtill kommer att många djur dödas av trafiken på vägar och järnvägar.

Det trans-europeiska transportnätverket (TEN-T) är under snabb och kraftig utbyggnad. Längden av denna infrastruktur fördubblades mellan 1970 och 1996 och upptar nu mer än 1,2 % av Europas landyta. En fortsatt kraftig utbyggnad av Europas väg- och järnvägsnät kommer att ske. Detta medför risk för en alltmer accelererad fragmentering av Europas naturområden, kanske inte minst i de nya EU-länderna. Att planera denna utbyggnad och förvalta den redan existerande infrastrukturen på ett sådant sätt att transportsystemet blir långsiktigt ekologiskt hållbart kan sägas vara en påtaglig utmaning för politiker och infrastrukturplanerare i Europas länder.

Vid nyinvestering i infrastruktur gäller det i första hand att lokalisera infrastrukturen så att de ekologiska sambanden i landskapet bibehålls. Kan man inte undvika känsliga områden, måste infrastrukturen utformas så att landskapekologiska samband i möjligaste mån bibehålls. Åtgärder för ekologisk anpassning av infrastrukturen kan minska skadorna. Sådana åtgärder kan inkludera en rad olika former av åtgärder. En av åtgärderna går under benämningen faunapassage. En faunapassage är en anläggning som byggs för att göra det möjligt för djur att passera över eller under en väg eller järnväg. En ekodukt är en specialform av faunapassage. En ekodukt byggs över en väg eller järnväg i syfte att förbinda ekosystemen på ömse sidor av infrastrukturen. Trummor och broar måste utformas så att djuren ges fri passage utefter hela vatten-

draget. Skötseln av anläggningarna är viktig för deras funktion för djur, växter och vattendrag. Även på befintlig infrastruktur kan effektiva åtgärder vidtas i efterhand för ekologisk anpassning. Effektiviteten hos vidtagna anpassningsåtgärder bör följas upp. Kompenserande åtgärder kan ses som en sista lösning i de fall där i första hand unvikande och i andra hand ekologisk anpassning inte utgör möjliga lösningar. Denna strategi stöds av EU-lagstiftningen, där viktiga instrument utgörs av miljöbedömnings-direktivet, habitat- och fågeldirektivet och landskapskonventionen. Tillsammans avser dessa främja utvecklingen av ett fungerande nätverk av sammanhängande ekosystem genom Europas länder. Visionen är ett fungerande ”ekologiskt nätverk” som existerar jämsides med det trans-europeiska transportnätverket.

Den europeiska kunskapsöversikten (Trocmé *et al.* 2003), som bygger på nationella underlagsrapporter, bl.a. föreliggande svenska rapport, anger följande viktiga ställningstaganden:

- Ett fungerande nätverk av biotoper är av fundamental betydelse för landskapets ekologiska funktion och för djurens behov att förflytta sig i landskapet. Att upprätthålla de ekologiska sambanden i landskapet bör vara ett strategiskt mål i transportsektorns miljöarbete. Skalmässigt bör arbetet med den ekologiska hänsynen i infrastrukturplaneringen fokusera på landskapsskalan.
- Naturvårdslagstiftningen bör integreras i infrastrukturplaneringen på så tidiga stadier som möjligt. För att fragmenteringsproblematiken ska kunna hanteras på ett ändamålsenligt sätt och med effektiva verktyg, krävs ett fungerande samarbete mellan planerare, ekonomer, ingenjörer, ekologer, landskapsarkitekter och andra experter och fackmän. Sådan samverkan krävs på alla planerings-stadier och i såväl små som stora infrastrukturprojekt.
- Problemområdets komplexitet och geografiska omfattning gör det nödvändigt att ett effektivt utbyte av kunskap och erfarenheter sker mellan Europas olika länder. Insamlingen av information om olika typer av ekologiska anpassnings-åtgärder bör systematiseras och samordnas mellan olika länder.
- Störningseffekter av infrastruktur och trafik behöver bli föremål för fler studier och effektivare åtgärder för att minimera skadorna på naturen längs anläggningarna.
- Faunapassager har visat sig vara ett framgångsrikt sätt att upprätta landskapsekologiska funktioner. Åtgärderna får dock inte koncentreras till spektakulära anläggningar för de stora djuren. Till relativt låg kostnad kan man även hos befintliga vägar och järnvägar förbättra permeabiliteten, alltså möjligheten för djur att passera den barriär infrastrukturen utgör. Exempelvis kan befintliga broar, viadukter och vägportar förses med tilläggsåtgärder som ger åtminstone viss passagemöjlighet för djur. Ekologer bör medverka vid bedömningen av dessa möjligheter och vid utformningen av åtgärderna.
- Effektiviteten hos ekologiska anpassningsåtgärder bör följas upp enligt standardiserad metodik. Kostnaden för sådan uppföljning bör från början inkluderas i budgeten för infrastrukturprojektet.

Problemet med infrastrukturens fragmenterande inverkan på biotoper och landskap kan endast lösas om det uppmärksammas politiskt och åtgärdas genom samverkan mellan olika fackområden på vetenskaplig och teknisk nivå. Aktiv medverkan av sakägare och allmänhet kan vara en nyckel till framgångsrika lösningar.

# Chapter 1. Introduction[6]

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

### *Habitat Fragmentation: The Problem*

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

### *Development of Transportation Infrastructure*

For more than 2000 years, roads, railways and waterways have been built in Europe to provide an efficient means of transportation for labour, goods and information. Many historic roads have developed from paths used for local communication, constructed where topography permitted. As a result of its long history, infrastructure was embedded and integrated in the landscape. During the last century, however, technical innovations have liberated planners and engineers from the natural constraints of the

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[6] Bekker, G.J. (2003) Introduction. In: Trocmé, M., Cahill, S., de Vries, H.J.G., Farrall, H., Folkeson, L., Fry, G., Hicks, C. and Peymen, J. (Eds.) (2003) *COST 341. Habitat Fragmentation due to Transportation Infrastructure. The European Review*, pp. 15-17. – Office for Official Publications of the European Communities. Luxembourg. 253 pp.

terrain. This has meant that modern transportation infrastructure can be superimposed on almost any prevailing landscape pattern, resulting in greater disruption of ecological linkages and processes. Across Europe, the length of roads and railways planned for construction in the future is significant: *i.e.* more than 12,000 km and 11,000 km respectively in western Europe by 2010 (EEA 1998; EEA 2000). 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 (Teodoraşcu 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 Conservation (ECNC) |
| France (F) | Romania (RO) | |

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

The goals of COST 341 were to:

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

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

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. The following chapters attempt to give an idea of the scope and extent of the habitat fragmentation problem in Sweden and identify the range of solutions which are currently used to address it. Chapter 4 identifies the main geographical regions and the main habitat types occurring in Sweden. This is followed by Chapter 5 giving an overview of the Swedish transportation infrastructure networks and the scale and significance of the habitat fragmentation problem caused by the existing infrastructure. A short 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 policies for the development of future transportation infrastructure. Economic aspects associated with fragmentation (fauna collisions in particular) are treated in Chapter 9. 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[7]

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 habitat

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

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[7] Seiler, A. (2003) Key Ecological Concepts. In: Trocmé, M., Cahill, S., de Vries, H.J.G., Farrall, H., Folkeson, L., Fry, G., Hicks, C. and Peymen, J. (Eds.) (2003) *COST 341. Habitat Fragmentation due to Transportation Infrastructure. The European Review*, pp. 19-29. – Office for Official Publications of the European Communities. Luxembourg. 253 pp.

biodiversity value of the landscape (Gaston 1998). *Biodiversity* denotes the total variation among living organisms in their habitats, including the processes that link species and habitats.

## 2.2 Landscape change and habitat fragmentation

Historically, human activities (driven by politics, economics, and cultural traditions) have altered landscape patterns, habitat quality and the 'natural' distribution of species (Stanners and Bourdeau 1995; Jongman *et al.* 1998). Across Europe, traditional small-scale landuse has been replaced by intensified methods that require large, homogeneous production units (Burel 1992; Jedicke 1994; Ihse 1995; Skånes and Bunce 1997). In modern rural landscapes, wildlife habitats have been reduced to small remnants scattered throughout the intensively used matrix. In addition, extensive natural areas, *e.g.* open marshland or contiguous forests, have been increasingly fragmented by infrastructure including roads, railways, waterways, drainage ditches, and power lines (*e.g.* National Atlas of Sweden. The infrastructure 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.

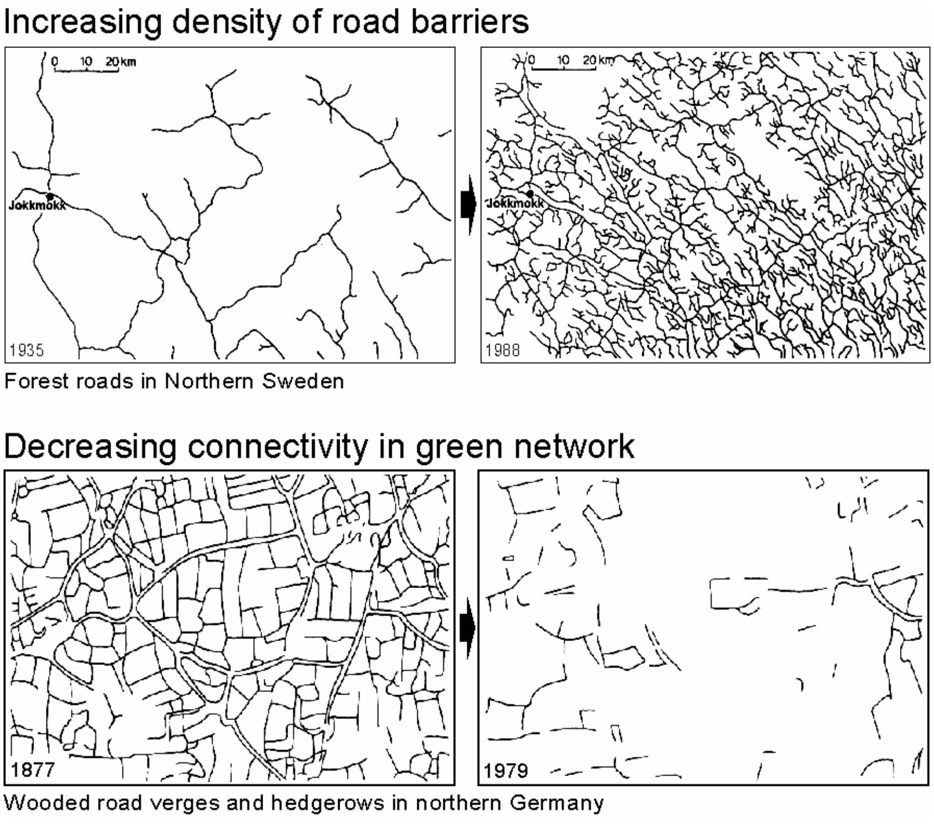


***Figure 2.1*** *Landscape change due to fragmentation and loss of connectivity. Top – Increase in forest road network in the Jokkmokk area in northern Sweden between 1935 and 1988 (After National Atlas of Sweden. The infrastructure 1992). Lower – Loss of vegetated corridors (tree rows, hedgerows, road 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 impose 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).

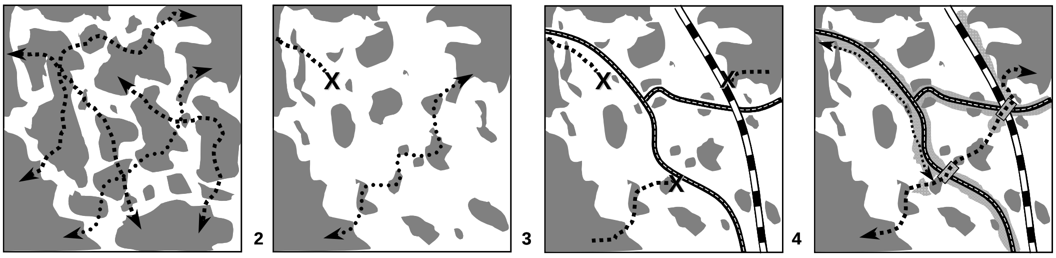


*Figure 2.3 (1) Fragmentation of an animals' habitat (shaded areas) reduces the ability of individuals to move across the landscape. (2) Some connectivity may be sustained through small habitat fragments or corridors. (3) Infrastructure imposes additional movement barriers and strengthens the isolation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

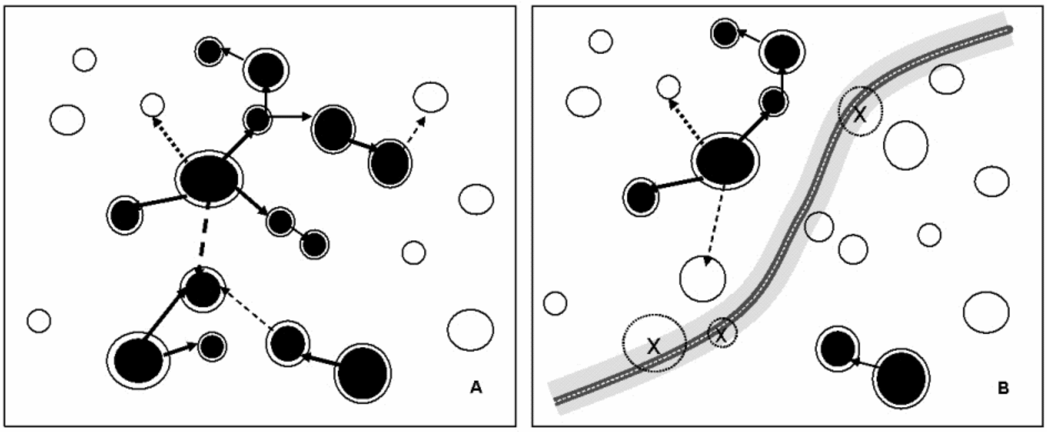


***Figure 2.4*** *Barrier effects on populations: (A) A metapopulation consists of a network of local populations that may vary in size and local dynamics, but are linked to each other through dispersal. Small local populations are more likely to go extinct than large populations, but the risks of this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

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).

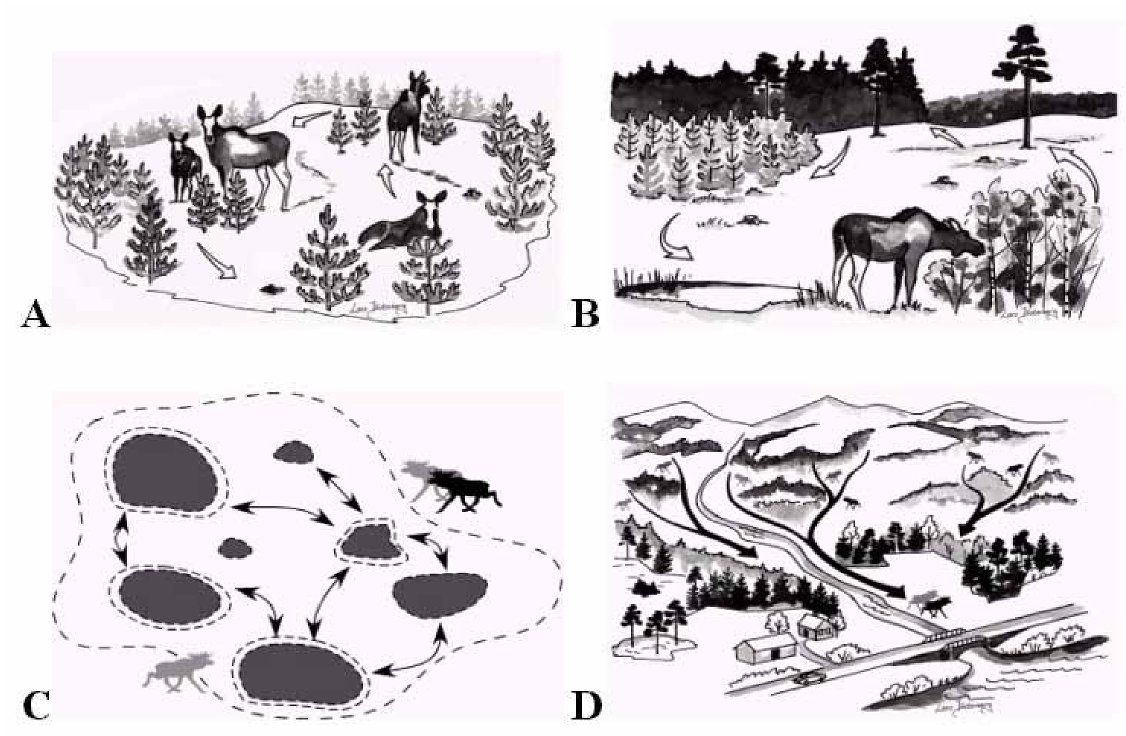


***Figure 2.5*** *Four basic types of animal movements: (A) Foraging movements of an individual within a forest stand; (B) diurnal or commuting movements between forest patches within the home range of an individual; (C) dispersal movements (emigration and immigration) between local populations; (D)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

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.

***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.)*

## 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.

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).

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.

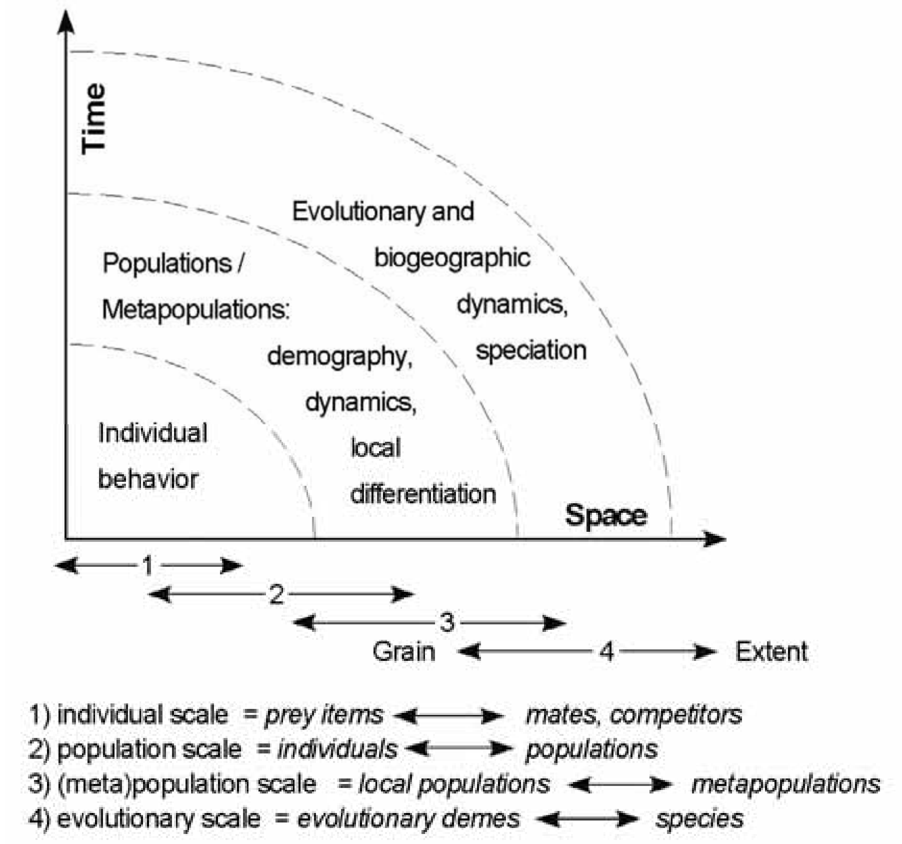


***Figure 2.7*** *Domains of scale in space and time. Enlarging the scale shifts the focus towards higher organisational levels that reveal new processes and dynamics. Nb. large spatial scales refer to small scales in map dimension. (Combined from Wiens 1989 and Haila 1990.)*

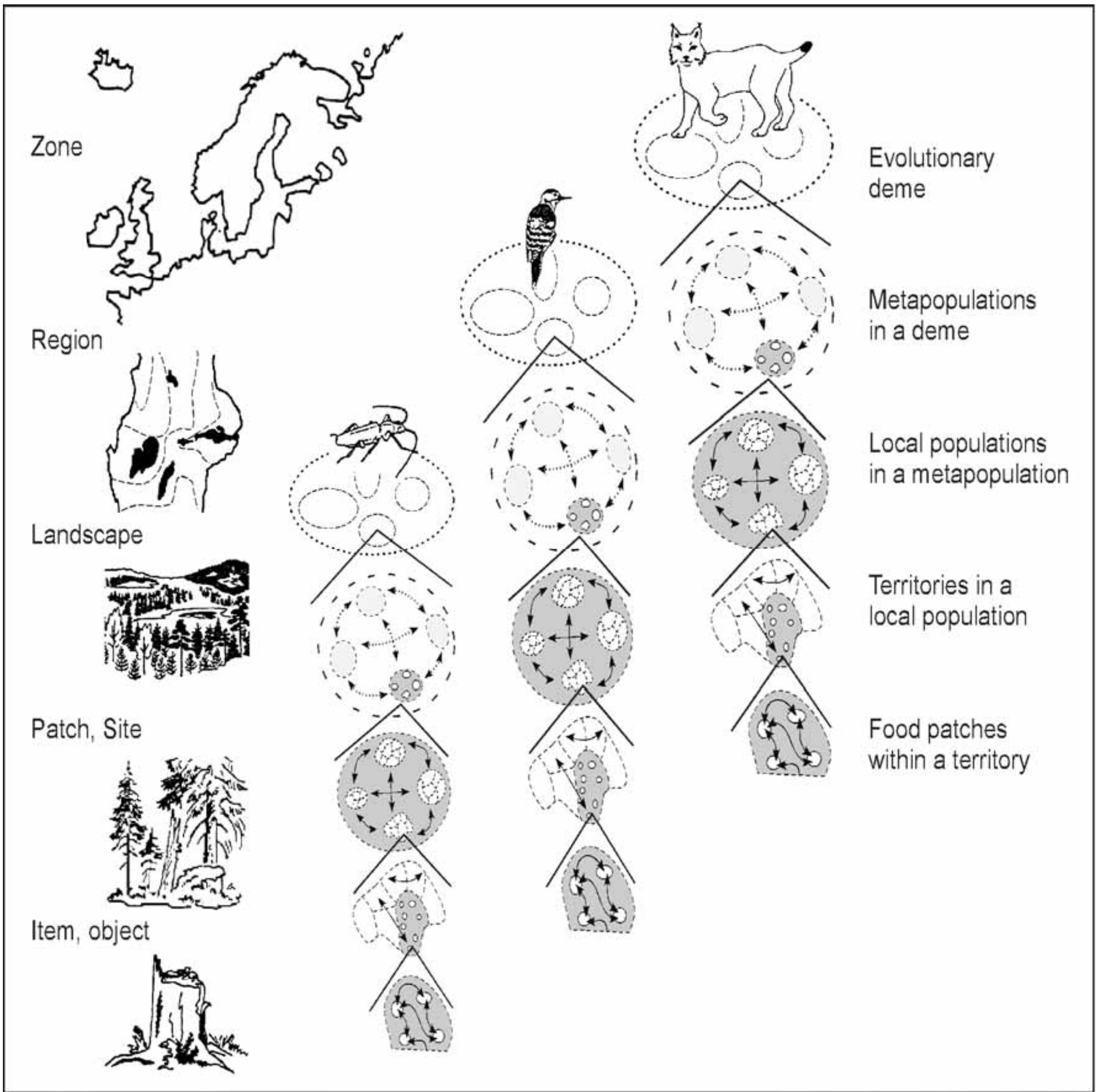


***Figure 2.8*** *Hierarchical layering in ecology. Food patches are nested in individuals' territories, which make up the habitat of a local population. In turn, these local populations make up metapopulations that together comprise the evolutionary deme of a species. At each hierarchical level (i.e.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

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 fragmentation effects is likely to be underestimated, because consequences to the populations will first become apparent at a larger spatial scale.

## 2.7 Summary

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

- *The effects of infrastructure on nature cannot be evaluated solely from a local perspective; infrastructure planning must focus on the landscape scale.*
- *Habitat connectivity across the landscape is essential for ensuring the survival of wildlife populations. Connectivity can be provided by ecological 'green' corridors, 'stepping stones', or technical mitigation measures e.g. constructing a bridge between severed habitats.*
- *The impact of habitat fragmentation on wildlife is dependent on individual species and landscape characteristics. Where the impact is below a critical threshold, populations can be sustained, but beyond this threshold, seemingly small changes in the environment may cause unexpected and irreversible effects (e.g. the extinction of local populations). The larger the spatial scale concerned, the longer the time-lag until effects may be detectable.*
- *Infrastructure planning needs to integrate both regional and local-scale issues. A hierarchical approach can help to identify the most important problems and their solutions at each planning level. People should 'think globally, plan regionally but act locally' (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[8]

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. For more discussion and data on secondary effects see Section 5.4.

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 Holzgang *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

[8] Seiler, A. (2003) Effects of Infrastructure on Nature. In: Trocmé, M., Cahill, S., de Vries, H.J.G., Farrall, H., Folkeson, L., Fry, G., Hicks, C. and Peymen, J. (Eds.) (2003) *COST 341. Habitat Fragmentation due to Transportation Infrastructure. The European Review*, pp. 31-50. – Office for Official Publications of the European Communities. Luxembourg. 253 pp.

environment further decrease the amount of habitat that is suitable or available for wildlife.

- *Disturbance/Edge effects* result from pollution of the physical, chemical and biological environment as a result of infrastructure construction and operation. Toxins and noise affect a much wider zone than that which is physically occupied.
- *Mortality* levels associated with traffic are steadily rising (millions of individuals are killed on infrastructure each year in Europe) but for most common species, traffic mortality 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).

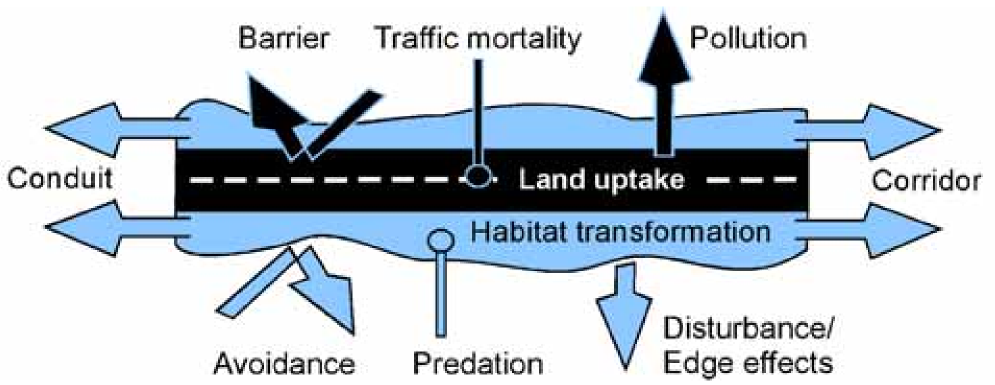


***Figure 3.1*** *Schematic representation of the five primary ecological effects of infrastructure which together lead to the fragmentation of habitat. (Modified from Van der Zande et al., 1980.)*

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 4.7).

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; Statistics Sweden 1999).

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

### 3.2.2 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, R *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.

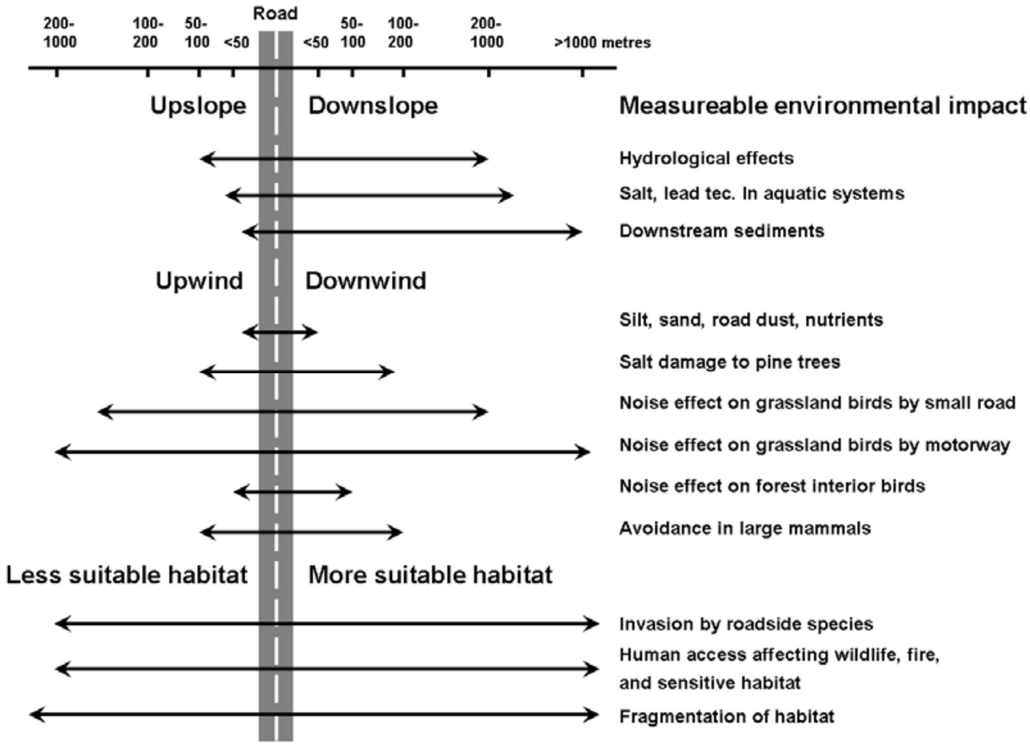


***Figure 3.3*** *Disturbance effects spreading from a road into the surrounding landscape. The distance over which disturbances affect nature depends on topography, wind direction, vegetation and the type of disturbance. The width of the affected zone is likely to be larger than some hundred metres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

### 3.2.3 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).

### 3.2.4 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).

### 3.2.5 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 (Van Gent 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)[9].

### 3.2.6 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

[9] The UK national state-of-the-art review; see further Trocmé et al. (2003)

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)[10].

[10] The UK national state-of-the-art review; see further Trocmé et al. (2003)

**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, R. *et al.* 1995) 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, M. et al. (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, M. *et al.* 1995).

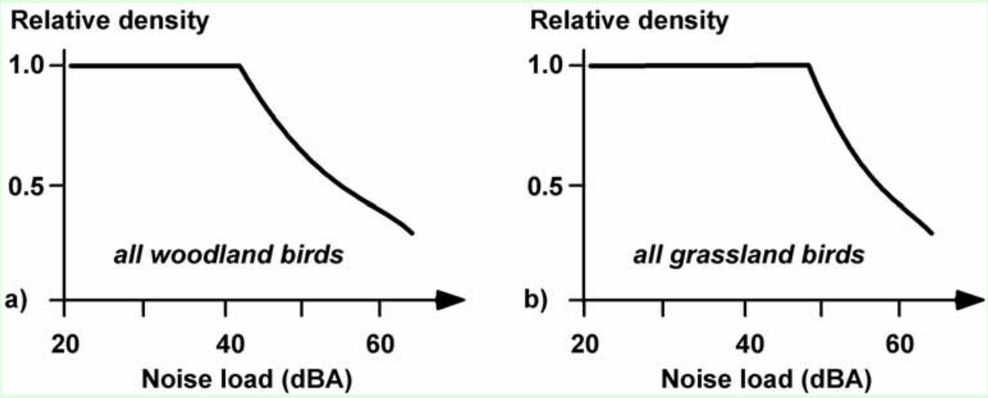


*Figure 0.1 – Schematic representation of the impact of traffic noise on breeding bird populations in The Netherlands. When the noise load exceeds a threshold of between 40 and 50 dBA, bird densities may drop significantly. The sensitivity to noise and thus the threshold is different between species and between forest and open habitats. (From Reijnen, M. et al. 1995.)*

Helldin and Seiler (2003) tested the predictions of Reijnen, R. *et al.* (1995) 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 (see Section 5.3.3).

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, R. *et al.* (1995) did not observe any effect of the visibility of moving cars on breeding birds, however, Kastdalen (personal communication) 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 discontinuous 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.

### 3.2.7 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.

## 3.3 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.)*

### 3.3.1 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; Hansen 1982; 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 (Sangwine, personal communication). 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 3.4). 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.

### 3.3.2 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 (*Clethrionomys 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, personal communication). 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.* 1998a; 1998b; 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.

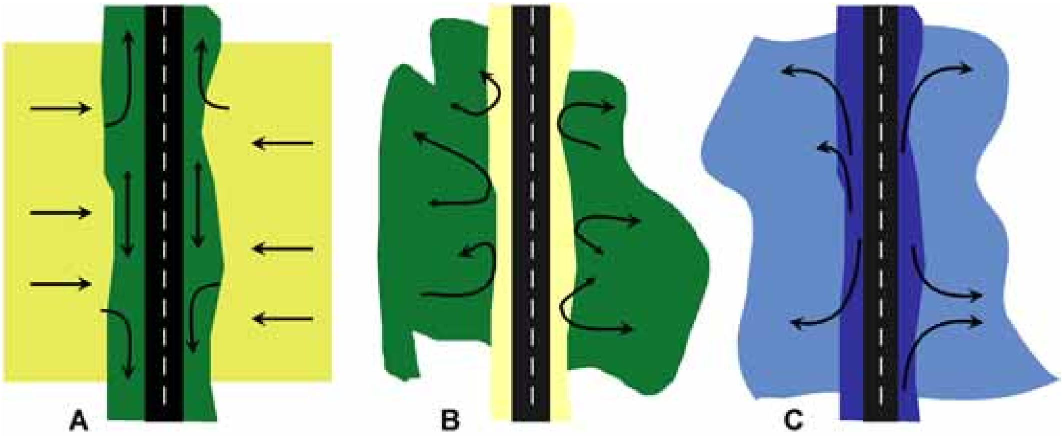


***Figure 3.6*** *The corridor function differs with respect to the surrounding landscape: A) Open, agricultural landscapes: richly vegetated verges can provide a valuable habitat for wildlife and facilitate movement. B) Forested landscapes: open and grassy verges introduce new edges and can increase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

## 3.4 Fauna casualties

### 3.4.1 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 5.3.4 and Table 5.8).

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 9) 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 € (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, personal communication) and train drivers in northern Sweden complain about the unpleasant experience of colliding with groups of reindeer and moose (Åhren and Larsson 1999).

***Figure 3.7*** *Wildlife casualties – a common view along roads and railways. (Photos by A. Seiler and J-O. Helldin.)*

### 3.4.2 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 5.8). 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).

### 3.4.3 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).

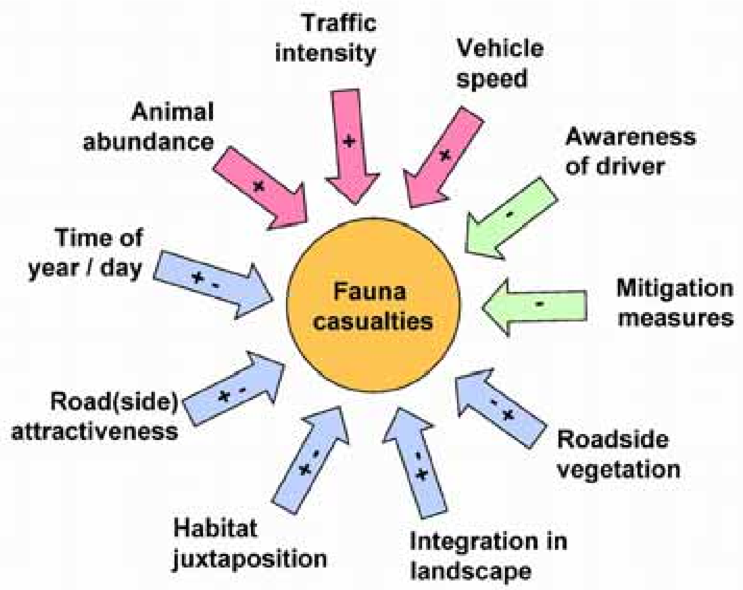


***Figure 3.8*** *Factors influencing the number of wildlife traffic accidents.*

Roadkills seem to increase with traffic intensity to a certain 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.* 1998b). 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 8.2).

## 3.5 Barrier effect

### 3.5.1 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 3.2.3). 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?

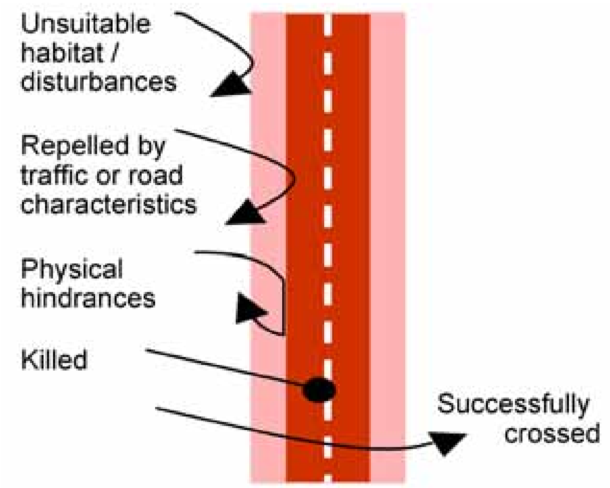


***Figure 3.9*** *The barrier effect of a road or railway results from a combination of disturbance/deterrent effects, mortality and physical hindrances. Depending on the species, the number of successful crossings is but a fraction of the number of attempted movements. Some species may not experience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

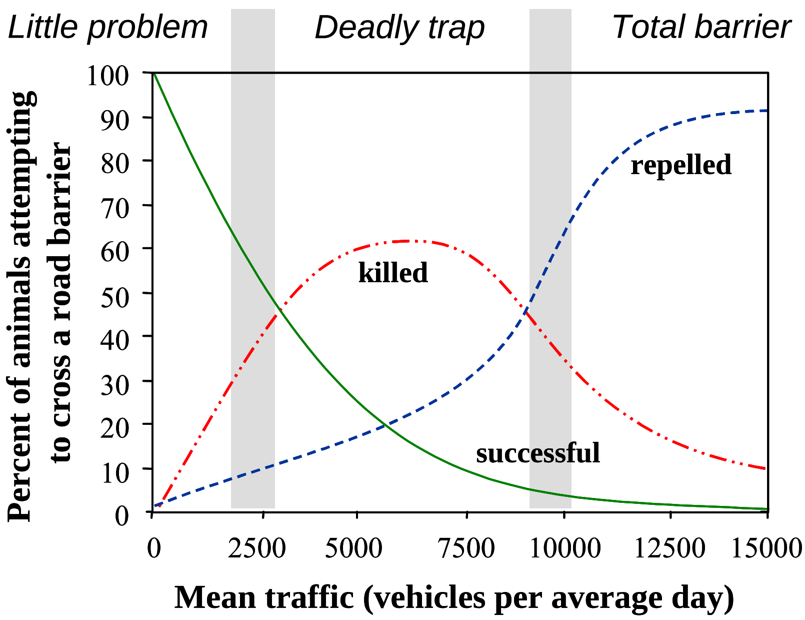


***Figure 3.10*** *Conceptual model of the effect of traffic volume on the proportion of mammals that successfully cross a road barrier. Small roads with little traffic are only a minor barrier to mammals. However, as traffic increases, the number of road kills quickly rises. Roads with very high traffic load, on the other hand, may repel animals and cause the number of kills to be reduced. The model is based on empirical data on police reported moose-vehicle accidents in Sweden. (Seiler, 2003.)*

### 3.5.2 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 inhibited by bridges or culverts that are too narrow (Warren and Pardew 1998).

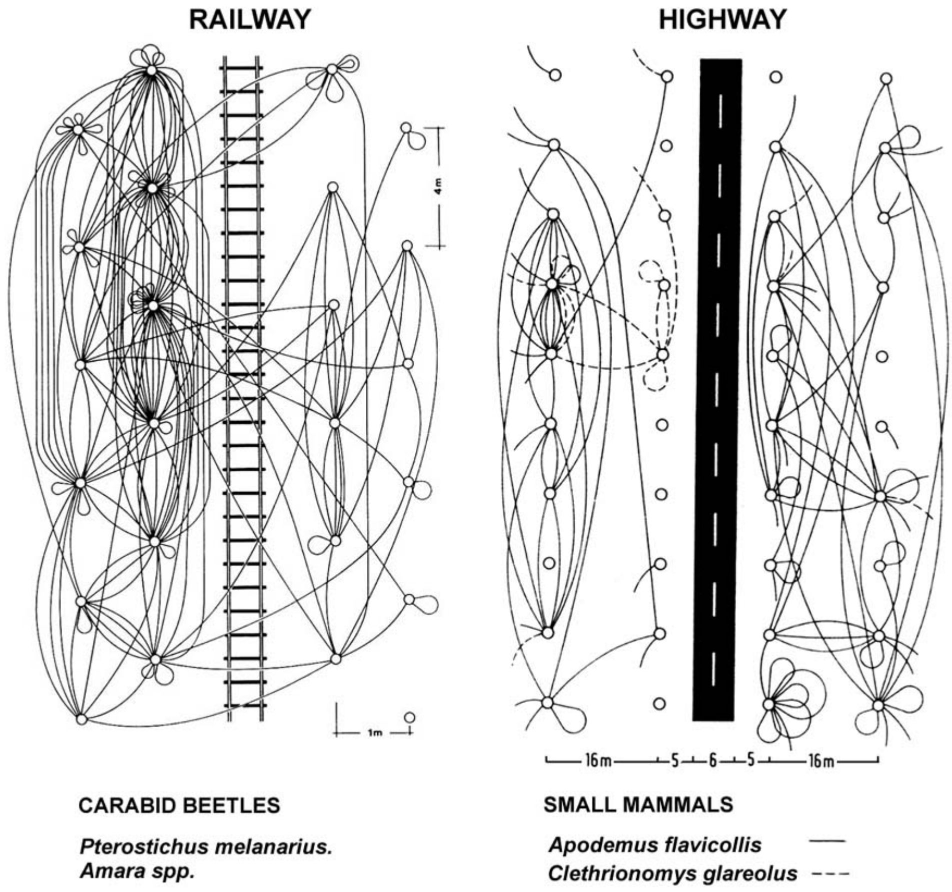


***Figure 3.11*** *Mobility diagram illustrating animal movements along and across a railway and road, based on capture-recapture data of: (left) Carabid beetles (redrawn from Mader et al. 1990); and (right) small mammals. (Redrawn from Mader, 1984.)*

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.

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.

### 3.5.3 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.

## 3.6 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.

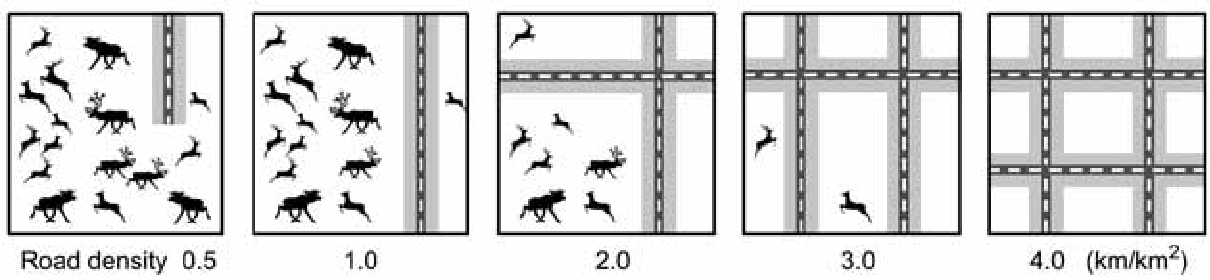


***Figure 3.12*** *Infrastructure causes a loss and degradation of habitat due to disturbance effects (grey corridors) and isolation. With increasing infrastructure density, areas of undisturbed habitat (white) are reduced in size and become inaccessible. Remnant fragments of suitable habitat may eventually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

## 3.7 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, etc. (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 8.2), 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’ (Forman 1995).

# Chapter 4. Swedish National Context from a European Perspective

## 4.1 Introduction

Some people may consider Sweden as the cold large country in the North, with long and dark snowy winters, wild reindeer and grizzly polar bears (although there aren't any). To many others, Sweden is a large holiday country with extensive wilderness areas, endless forests, large mires and rolling hills, cosy red timber houses next to a clear lake and a forest, that teem with fish, moose and mosquitoes (of which there is plenty). Indeed, most of Sweden is remote from busy cities, noisy roads, or industry. There is still plenty of space for recreation and nature experience, giving the impression of a vast resort of nature. In this respect, Sweden is the large country in the North, contrasting many other European landscapes on the continent (Figure 4.1).

However, Sweden is not simple wilderness: with a closer look, the thousands-year long human imprint on the landscape becomes evident: Marks of (pre-)historical landuse and industry are scattered throughout the country. Most forests have been clear-cut and replanted for more than one generation, and the forest road network has expanded into even the most remote areas. Virgin forests have become rare, even in Sweden. Many large rivers and lakes have been dammed for hydro-electrical power plants and pulp industries. Modern forestry, agriculture and urbanisation are reshaping the landscape and steadily increasing their demand on an effective and well-distributed infrastructure.

***Figure 4.****1 A typical landscape in central Sweden dominated by managed forests and lakes, with scattered small fields and pastures. The picture shows Grimsö Wildlife Research Station, S. central Sweden. (Photo: Andreas Seiler.)*

On the other hand, the Swedish population keeps its level and as more and more people leave the countryside to live in cities, the backcountry regains serenity. Not many new roads or railroads will be needed in the future; the existing network will rather be improved to maintain its modern standard. In most parts of Sweden, we are not facing a growing pressure on nature, but rather see opportunities to make up for earlier mistakes and improve the situation. Thus, it is not the prevention of new impacts that is our endeavour in the first place, but the better integration and maintenance of the existing infrastructure into the ecological context of the environment.


***Figure 4.2*** *Sweden from Space: As most of Sweden is covered by forest, Sweden is one of the few countries that comprise the green backbone of Europe.*

## 4.2 Biogeographical description

### 4.2.1 Basic facts

Sweden is the fifth largest country in Europe, after Russia, Ukraine, Spain and France (Figure 4.2). With 450,000 $km^2$, Sweden is roughly as large as Japan or California. The population is about 9 million and most of them live in the four major cities and in the southern part of the country (Table 4.1). Sweden's administration is divided into 21 counties and 288 municipalities. The country is rather long (1,557 km) and narrow, expanding from the nemoral, broad-leaved forest zone in the south to the boreal taiga in the north (Figures 4.3 and4.4). The country has a long shoreline and several large archipelago areas made up of tens of thousands of islands. The country's western border with Norway (1,619 km) runs mainly along a mountain range.

***Table 4.1*** *Facts about Sweden.*

| | | | |
|---|---|---|---|
| Total population | 9.0 million | **Islands (largest)** | |
| Work force | 4.3 million | Gotland | 3,001 km$^2$ |
| Land surface | 449,964 km$^2$ | Öland | 1,344 km$^2$ |
| Population density | 19 inhabitants/km$^2$ | Orust | 346 km$^2$ |
| GDP | US$ 211.5 | **Mountains (highest)** | |
| Currency: 100 SEK | = 9.4 € | Kebnekaise | 2,111 m |
| Inflation | 0.9 % | Sarektjåkkå | 2,089 m |
| Unemployment rate | 4.0-5.5 % | Kaskasatjåkkå | 2,076 m |
| Form of government | Constitutional monarchy | **Lakes (largest)** | |
| Legislature | Single-chamber parliament | Vänern | 5,585 km$^2$ |
| **Geographical data** | | Vättern | 1,192 km$^2$ |
| Most Northerly point – Treriksröset | 69° 4' Lat N | Mälaren | 1,149 km$^2$ |
| Most Southerly point – Smygehuk | 55° 20' Lat N | **Population of largest municipalities 1998** | |
| Most Westerly point – St. Drammen | 10° 58' Long E | | |
| Most Easterly point – Kataja | 24° 10' Long E | Stockholm | 736,000 |
| Land frontiers to Finland | 586 km | Göteborg | 459,600 |
| … and to Norway | 1,619 km | Malmö | 254,900 |
| Territorial waters frontier | 22,200 km | **Land cover** | |
| Connected | 2,181 km | Forest | 54 % |
| Length (from North to South) | 1,557 km | Mountains | 16 % |
| Land area | 410,934 km$^2$ | Wetlands | 11 % |
| Lakes | 39,030 km$^2$ | Lakes and rivers | 9 % |
| Total road network | 420,000 km | Arable land | 8 % |
| Total railroad network | 15,000 km | Built-up areas | 3 % |

A unique Swedish custom that greatly influences the people's attitude towards nature is the so-called "Allemansrätten", *i.e.* the right of public access to private land. Thanks to this right, which is enshrined in law, outdoor activities such as hiking, berry picking, hunting or fishing are rooted in the Swedish way of life. The right of public access gives you the right to enjoy the Swedish landscape. You may wander freely virtually anywhere, gather wild berries, pick mushrooms or flowers (if not protected) and even pitch a tent for one night, without any special permission. Naturally, you are expected to combine this freedom with good judgement and respect for nature and private property. The right of public access is only valid for individuals, and may not be utilized for commercial purposes or by organized tourist groups.

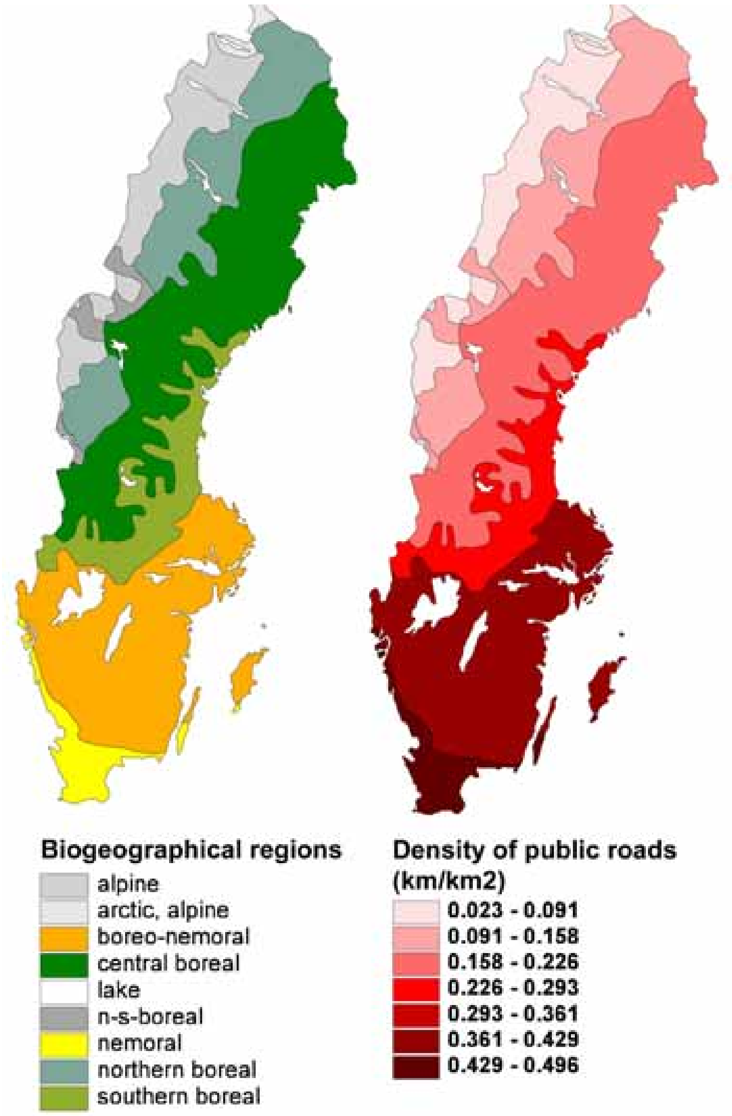


***Figure 4.3*** *Bio-geographical regions in Sweden (Source: National Atlas of Sweden. Geography of plants and animals 1996 (left) and National Atlas of Sweden. The infrastructure 1992 (right)).*

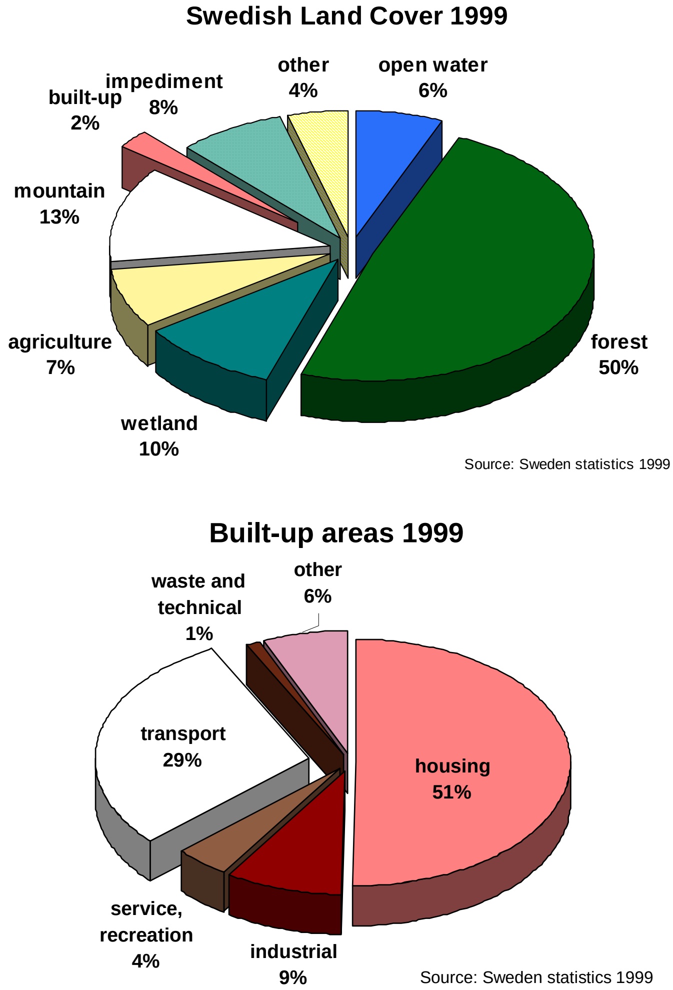


***Figure 4.4*** *Composition of land cover and built-up areas. (Source: Statistics Sweden 1999).*

### 4.2.2 Economy

Historically, timber, pulp and paper and iron and steel have formed the backbone of the Swedish economy. Over the last decades, however, industry has declined in importance just as in other European countries. Today, in addition to the traditional industries, industry based on high technologies such as telecommunications and pharmaceuticals is a large contributor to the economy. The per capita gross domestic product (GDP) in 2001 was SEK 254,000. The average annual GDP increase was 4.3 per cent during the five years 1997–2001. The annual inflation (consumer price index) was 2.1 per cent in 2002 and the unemployment rate 4 per cent (Statistics Sweden).

Sweden has 9.0 million inhabitants. Population numbers have been quite stable over the last decade. The increase for 2002 was 0.35 per cent. A total of some 85 per cent of the population lives in urban areas, mostly in three large conurbations Stockholm, Göteborg and Malmö (Figure4.5). Compared with most other EU countries, the population density in Sweden is low, averaging 19 inhabitants per $km^2$ (Figure 4.6).

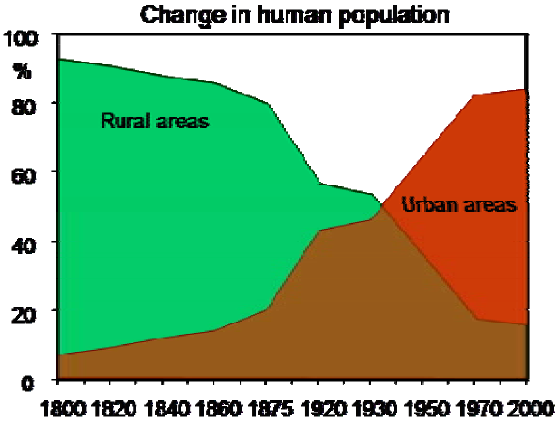


***Figure 4.5*** *Change in the urban and rural population in Sweden. (Source: Statistics Sweden 1999.)*

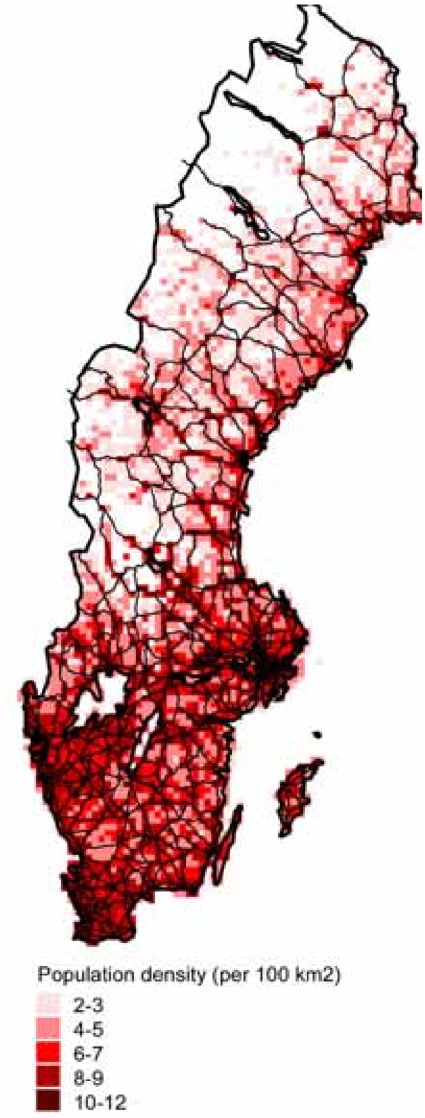


***Figure 4.6*** *Major road network and human population density. (Source: National Atlas of Sweden. The infrastructure 1992).*

### 4.2.3 Climate

Sweden and its neighbour countries around the Baltic Sea in the north of Europe, enjoy a relatively mild climate, although they are located at the same northerly latitude as Kamchatka and Alaska. Northernmost Sweden extends beyond the Arctic Circle. The seasonal variations in daylight are therefore considerable throughout the country.This means that the summer nights are short – in the far north of Sweden the sun is still above the horizon at midnight. The other side of the coin is that the days are short in the winter – the further north you get, the shorter they are and in the far north the sun doesn't rise at all during the winter.

The climate varies from warm temperate (nemoral) in the southern coastal areas to arctic-alpine in the Scandic mountain range where valley glaciers occur at the highest levels. The climate is influenced by the Atlantic Gulf Stream. The average temperature is only 1.8 degrees Celsius, ranging from +7 degrees Celsius in the south to -2 degrees Celsius in the north. The growing season spans 240 days in the south to only 120 in the north.

### 4.2.4 Forest

Swedish forests cover more than 22.6 million ha and make up about 54 % of the total land area (Figure4.7). Forests were and still are one of Sweden's key natural resources. Most of the forests, especially in southern Sweden, have been managed for centuries and more than 90 % of the total forest is privately owned. Only 5 % are common property. However, thanks to the right of public access to nature, everybody has the right to visit and enjoy the landscape.

***Figure 4.7*** *Old managed pine forest. (Photo: Andreas Seiler.)*

Due to changes in agriculture and the steadily growing urbanization, more and more of the Swedish land area has been transformed (back) into forest. Since 1920, the amount of timber (mainly Norway spruce and Scots pine) for instance, has increased by about 100 %, up to almost 3 billion $m^3$ (Source: Swedish National Forest Inventory, http://www-nfi.slu.se/). Intensive forestry has reshaped much of the Swedish landscape into a loose mosaic of forest stands of rather even aged monocultures that show very little structural diversity. Fragmentation of ecologically valuable (= old growth) forest stands is thus a significant problem in most of the managed forests in Sweden.

About 32 % of the managed forest area in Sweden has recently been clear-cut or replanted; 47 % must be considered as young or middle-aged forest. Most of these forests are to be thinned and managed. Only 20 % of the Swedish forest has grown old enough for the final harvest (Source: Riksskogstaxeringen). Many of the important structural and biological forest components such as old spruce and pine trees, trees with holes and cavities and dead wood material such as standing or lying dead trees have declined or are lacking in managed forests (Esseen *et al*. 1992). For example, the amount of deciduous trees in many forests has been reduced from about 30 % down to 24 % (8 % on average for entire Sweden) over the last four decades (Olsson 1992; Angelstam *et al.* 1997). The amounts of lying or standing dead wood in the managed forests are mostly below 5 $m^3$ wood per hectare. This should be compared to the natural forest with 20-100 $m^3$ of dead wood. The standing dead wood in Scots pine forests is less than 1 % of the trees in Sweden, and the lying is 4 %. These figures should be compared to 11 % and 27 %, respectively, in similar Russian forests (Angelstam *et al.* 1995). The amount of dead wood also decreases with the length of the time period the forests were managed, it is thus normally larger in the northern forests (Angelstam 1997). The large sized trees which are important to many species, *e.g.* woodpeckers, are following the same trend as the dead wood (Angelstam 1998; Östlund *et al.* 1997). As a result, species diversity is generally much lower compared to natural or unmanaged forests (*e.g.* Nilsson 1979; Gustafsson and Hallingbäck 1988; Pettersson *et al.* 1995; Uliczka and Angelstam 2000).

#### *4.2.4.1 The nemoral forest region*

Southernmost Sweden belongs to the nemoral forest region (broad-leaved forest region) which in its natural state contains oak (*Quercus robur, Q. petraea*), European beech (*Fagus sylvatica*), elm (*Ulmus glabra*), ash (*Fraxinus excelsior*), lime (or linden) (*Tilia cordata*), maple (*Acer platanoides)*, hornbeam (*Carpinus betulus*), hazel (*Corylus avellana*) and wild cherry (*Prunus avium*). Approximately 45 % of Swedish broad-leaved forest consists of beech woods, of which some 80 % comprise predominantly beech. An equally large proportion consists of pure oak woods and mixed stands in which oak is the predominant species. Broad-leaved forest in Sweden and the other Nordic countries represents the northerly outposts of a more uniform distribution range on the continent. Swedish broad-leaved forests cover some 150,000 hectares.

Most of the once forested area in the nemoral region of Sweden has been transferred into arable fields or used up by urbanisation. Despite the strong anthropogenic influence, broad-leaved forests still represent some of the most species-rich habitats in Sweden. About 33 % of the 348 vertebrates in Sweden depend on the nemoral broad-leaved forest in southern Sweden, despite its small contribution to the total forest cover (1 %). Only one-third of all birds and mammals have their main distribution in northern Sweden (Berg and Tjernberg 1996).

#### *4.2.4.2 The boreo-nemoral forest region*

North of the nemoral forest region is the boreo-nemoral forest region, which in Sweden is referred to as the "southern coniferous forest region". This is a zone lying between the broad-leaved forest in the south and the boreal coniferous forest in the north. A typical feature of this region is that it hosts species both from the north and from the south. This results in a rich variety of biotopes. Another reason for this is that the geology of the region makes for a patchwork landscape of moraines and post-glacial sediments of varying composition, due to the way in which the rise of the land following the last ice age has gradually widened the gap between land and water.

Spruce and pine forests dominate the southern coniferous forest region. Typical broad-leaved species such as ash (*Fraxinus excelsior*) and alder (*Alnus glutinosa, A. incana*) may be a common feature in places, whereas the harsher climate means that species such as beech and hornbeam only occur sporadically, mainly in the south of the region. Relict stands of other broad-leaved species also represent a characteristic feature of the landscape. These remnants from an ancient rural landscape are mainly found in conjunction with meadows and enclosed pastures in cultivated areas. Oak, ash, lime and maple are examples of tree species that are very important in terms of the biological diversity of the boreo-nemoral landscape.

#### *4.2.4.3 The boreal forest regions*

The boreal taiga forest starts north of 61° N and continues for a further thousand kilometres up to the northern mountains. The boreal forest region thus covers the major part of Sweden. Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) are the two dominant tree species. Pine prefers coarser, drier sedimentary soils, whereas spruce grows best on damper soils overlying fine-grained moraines or sediments. Pine is a pioneer tree that is able to gain a foothold quickly on recently cleared forestland or following fires, storms or clear-cutting. Spruce, like beech, is a typical secondary tree, preferring to regenerate from below in an existing stand. The natural taiga forest contains a limited proportion of deciduous trees such as birch and aspen (*Populus tremula*) (Figure4.8).

***Figure 4.8*** *The boreal forest landscape in central Sweden: Spruce and pine forsts intermixed with deciduous stands along streams or old farmland. (Photo: Andreas Seiler.)*

A sizeable proportion of older forest with numerous dead trees standing and lying where they have fallen is a natural feature of a healthy coniferous forest. However, modern forestry techniques have reduced the proportion of old and pristine forests. The northern coniferous forest displays a variety of characteristic features, depending on their geographical location, the local climate and soil conditions. A typical feature of the entire boreal forest landscape is a combination of several different biotopes such as forest, bogs and marshes, watercourses and lakes.

#### *4.2.4.4 The mountainous forest region*

The Scandinavian mountain range expands over more than 1000 km along the border between Norway and Sweden. The alpine or *fjäll* region includes both the zone above the tree line and the sub-alpine birch (*Betula verrucosa*) forest belt normally to be found between the tree line and the upper limit of the coniferous forest lower down. This belt is typical of the Scandinavian mountains and cannot be found elsewhere in Europe. Swedish mountain birch forests cover an area of 750,000 hectares and comprise the northern forest limit. The low alpine zone above the birch forest is treeless. In the southern parts of the mountainous region, it begins at about 900 m above sea-level and in the northern parts at about 600 m. The high alpine zone is found at still higher altitudes (1200—1600 m). Below the sub-alpine birch forest zone is the sub-montane coniferous forest zone which is a very important natural feature of the mountain region. This zone is home to Europe's greatest untouched coniferous forest, a forest that is essential for the biodiversity of the mountain region.

The prevailing westerly winds result in high precipitation in the mountain region. Some sites receive over 1,000 mm a year or even more. Thus, unlike some other mountainous areas of Europe, water is plentiful in the mountain region. A part of this resource has been exploited for the generation of hydroelectric power. Many rivers and lakes have also been regulated for this reason.

As early as 1909 some very extensive national parks were created in the mountain area, including Sarek and Stora Sjöfallet. Many large reserves have been created over the years since then. About 1 million hectares of coniferous forest are protected as nature reserves and national parks.

### 4.2.5 Wetlands

Wetlands, bogs and mires comprise a considerable part of Sweden. Depending on the classification, between 11 % and 20 % of the Swedish land cover is considered as wetlands. This equals about 93,000 $km^2$ and is about three times the total area of Belgium.

Wetlands play an important role for many plants and animals in Sweden. Many species depend entirely on them for their survival, and a number of other species use wetlands during part of their life cycle or as important supplementary environments. As a result, wetlands represent one of the most species-rich biotopes in Sweden. They contain unique ecological systems in their own right but also form an important part of larger-scale ecosystems such as the boreal forest.

However, in the course of the agrarian development wetlands have been extensively drained and some 10,000 $km^2$ have been transformed into agricultural land. This has been made possible by widespread drainage, lowering of groundwater levels, embankments and infilling. Such activities have almost completely ceased nowadays. Also forestry has led to a deprivation of wetlands: Over 15,000 $km^2$ have been drained due to forestry. Many of the Swedish wetlands have a natural forest productivity greater than 1 $m^3$ per hectare and year and can be used for timber production. However, in recent years the value of wetlands has been increasingly recognised by the forest industry, for example, and county administrative boards have been able to take a much stricter line over drainage proposals.

Since 1994, wetland drainage has been banned in areas of southern and central Sweden (Nature Conservation Act 1994). In other parts of the country, drainage can only be carried out with special permission. Recently, a Mire Protection Plan has been proposed for Sweden. The plan describes 491 of the most valuable mire sites in the country. Law already protects 146 of these sites and 345 wetlands are proposed as new nature reserves according to the Ramsar convention. At present 2,900 $km^2$ of mire are protected in total, although only 280 $km^2$ of this occurs outside the mountain region (Source: SWEIONET).

### 4.2.6 Agricultural land

Fourteen thousand years ago the whole of the present country of Sweden was covered by inland ice. As the ice slowly retreated, Man came to Sweden and the first known human dwelling place dates from around 10,000 BC. The fast retreat of the inland ice and the subsequent release of the land surface (causing a regression of the sea level) made significant imprint on the Swedish landscape, its topography, the direction of water courses, and the distribution of fertile soils that allowed for cultivation.

Today, only 8 % of the Swedish land is used for agricultural purposes. Historically, however, much more land was plowed or used for grazing livestock and hay making. The intensification of agriculture (and forestry) during the 1960’s created sharp contrast between wooded and arable land. Much agricultural land has been transformed into pine or spruce forest or, to a lesser extent, abandoned, especially in areas in the periphery of the large agricultural districts. This process had a particularly devastating effect on hay meadows and other land where fodder grew naturally. It also involves an increase in the size of managed fields and clearance of ”obstacles” to modern large-scale agricultural methods in the form of hedges, stone walls, stone heaps, small brooks and even historical roads. Most of the ecologically valuable edge habitats between forest and arable fields have now been lost and many areas have been deprived of their original (cultural) diversity (Ihse 1995).

Some details can illustrate the extent to which agricultural land was abandoned during the 20$^{th}$ century: The annual amount of tilled land being abandoned was c. 31,000 hectares during the period 1950–1970 and c. 8000 hectares during the period 1970–1990. Around the year 1920, natural forage (hay) meadows comprised c. 1.3 million hectares and tilled land comprised 3.8 million hectares. In 1988, ca. 568,000 hectares were grazed (meadows negligible in area) and ca. 2.9 million hectares were tilled land. Ten years later, 1998, the corresponding acreages were 450,000 and 2.7 million hectares, respectively.

Nowadays, great effort is made to preserve the remaining cultural and ecological values associated with traditional agricultural habitats. The national survey of meadows and pastures has identified some 200,000 hectares of land worthy of conservation.

### 4.2.7 Watercourses

In Sweden, there are some 60,000 kilometres of running water, *i.e.* brooks, streams and rivers, as well as some 90,000 lakes having an area of at least 1 hectare. Together

Sweden's lakes cover an area of almost 42,000 $km^2$ or 9 % of the country's total area. Lakes Vänern and Vättern are among the largest lakes in Europe and, together with the two next largest lakes (Mälaren and Hjälmaren), they account for no less than 24 % of the total lake area in Sweden.

Many Swedish rivers and lakes have been dammed since centuries for sawmills and iron industry. More recently, hydroelectric power plants have caused considerable damage. Today, 72 % of lakes and rivers capable of viable exploitation are now used in this way. The schemes invariably cause enormous and irreversible damage to the shores of these water bodies and their plant and animal life, as water levels are lowered and annual cycles reversed or disrupted.

### 4.2.8 Wildlife

#### *4.2.8.1 Biodiversity*

Following governmental and parliamentary decisions, the measures mentioned below are among those introduced in Sweden since the ratification of the Convention on Biodiversity in December 1993.

A strategy for biological diversity was enacted in 1994 (Government Bill 1993/94:30). Key elements include:

- Development of sector responsibility, *i.e.* that each sector of society should be responsible for ensuring that its own activities do not add to depletion of biodiversity but instead contribute to its conservation.
- Conservation efforts should focus on ecosystems and habitats.
- Efforts to formulate objectives whose achievement can be monitored must continue.
- Sweden has an unequivocal responsibility for its own biodiversity, including its native species.

In 1994 the Swedish Environmental Protection Agency presented a study entitled "Biodiversity in Sweden". The book describes in detail the status of biodiversity in Sweden. It also provides a picture of the most important factors causing adverse impact and the conservation measures taken to date. The study was produced in collaboration with four sectoral agencies (the National Board of Agriculture, the National Board of Fisheries, the National Board of Forestry and the National Board of Housing, Building and Planning) and the Swedish University of Agricultural Sciences, the Swedish Threatened Species Unit and the Nordic Gene Bank.

In 1995 the Swedish EPA and the four above-mentioned sectoral agencies each presented an action plan for biodiversity. They propose a series of specific objectives and measures designed to achieve conservation and sustainable use. The five action plans complement one another and should therefore be regarded as an entity.

The plans were confirmed by the Government and Parliament in 1997 and the agencies involved were directed to implement the proposed measures (see, *inter alia*, Government Bills 1996/97:75 and 1997/98:2).

The Government decided to submit Sweden's first national report to the convention (CBD) in January 1998. The report describes actions taken by Sweden over the first few years to meet its obligations. The emphasis is on Article 6 of the convention ("develop national strategies, plans or programmes") and on integrating conservation and sustainable use in relevant political guidelines and programmes for various sectors of society. A second national report was produced in 2001. These reports can be obtained at www.biodiv.org.

Other steps have also been taken as a direct result of Sweden's accession to the convention:

A Swedish Biodiversity Centre (CBM) has been established in Uppsala (www.cbm.slu.se). Its task is to co-ordinate and encourage research into biodiversity, run education and training courses and help to distribute research findings to their users. (Section cited from www.environ.se.)

*4.2.8.2 Threatened species*

At present, a total of 4120 species are considered on the Red list of Sweden (Table 4.2). Forestry, agriculture, and water power are the greatest threats to biodiversity, being responsible for 18 % and 15 %, respectively, of all threatened species (Figure 4.9). Infrastructure and urbanisation have a much lesser influence (4 %).

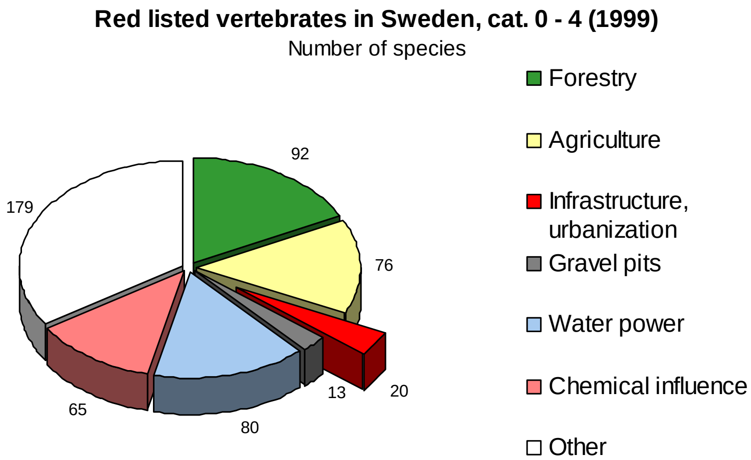


***Figure 4.9*** *Distribution of environmental threats to red listed species in Sweden. (Source: Swedish Environmental Protection Agency).*

***Table 4.2*** *The situation concerning red-listed taxa in Sweden (Data from Gärdenfors 2000).*

| Species group | Numer of red-listed species: data deficient | regionally extinct | critically endangered | endangered | vulnerable | near threatened | Total |
|---|---|---|---|---|---|---|---|
| Vascular plants | 13 | 30 | 58 | 111 | 157 | 136 | 505 |
| Stoneworts | 1 | 1 | 5 | 6 | 5 | 3 | 21 |
| Bryophytes | 38 | 21 | 15 | 20 | 69 | 75 | 238 |
| Macrofungi | 92 | 7 | 36 | 76 | 142 | 256 | 609 |
| Lichens | 38 | 17 | 30 | 56 | 61 | 52 | 254 |
| Mammals | 3 | 2 | 2 | 6 | 7 | 3 | 23 |
| Birds | 4 | 8 | 6 | 8 | 33 | 29 | 88 |
| Reptilia and Amphibia | 0 | 0 | 1 | 3 | 5 | 3 | 12 |
| Fish | 12 | 1 | 3 | 3 | 7 | 7 | 33 |
| Invertebrates | 351 | 171 | 123 | 281 | 618 | 793 | 2 337 |
| **Total** | **552** | **258** | **279** | **570** | **1 104** | **1 357** | **4 120** |

#### *4.2.8.3 Hunting*

Unlike some other European countries, hunting in Sweden is a socially deeply rooted and very popular sport, engaging over 300,000 registered hunters and many more helpers. Hunting, especially for moose, is very much a social event and its significance to the Swedish Public has often been stressed (Anonymous 1992). In addition, hunting and game management is regarded as an integrated part of Swedish wildlife conservation. It is intended to be a sustainable and wise use of the renewable natural resource ‘wildlife’, but also a means of control of species that may cause damage to private property, crops, domestic animals and forest regrowth. Hunting interests are also an important issue in EIA and it is often the local hunters who oppose to new road or railway plans and demand mitigation measures such as fences or fauna passages. In fact, without the wide-spread interest in hunting, many of the existing mitigation measures would probably not have been implemented at all.

Hunting rights in Sweden are linked to landownership, but they can also be leased out to individuals or associations. Leased hunting rights are especially common in northern Sweden where major parts of the country are owned by large (international) companies or the state. Much formerly state-owned forst has recently been privatised. In more southerly areas where available land is limited or where hunting concerns large game species such as the moose or large carnivores, co-operation is necessary to ensure sustainable hunting. Owners of hunting rights therefore often join into larger hunting management districts. Since 1985, hunters must pass a proficiency test on theoretical as well as practical aspects of hunting before their hunting permit is granted.

Hunting is mainly confined to autumn and winter (August-February). The start and duration of the hunting season for a particular species can vary considerably between regions. For example, moose hunting in southern and central Sweden starts in the beginning of October and continues for about two months. In northern Sweden the season for moose starts in the beginning of September and is divided into two parts with a break during the rutting season towards the end of September and beginning of October.

Among all game species in Sweden, the moose is certainly the most prominent one and the species with the largest economical and social interest. During recent years, bear and lynx hunting have become popular as well. Other common and highly valuable game species are other ungulates, beaver, grouse, especially capercallie and black grouse (see Figure 4.10). More information on hunting and game species can be obtained from the Swedish Association on Hunting and Wildlife Management (URL: www.jagareforbundet.se) and from Anonymous (1992).

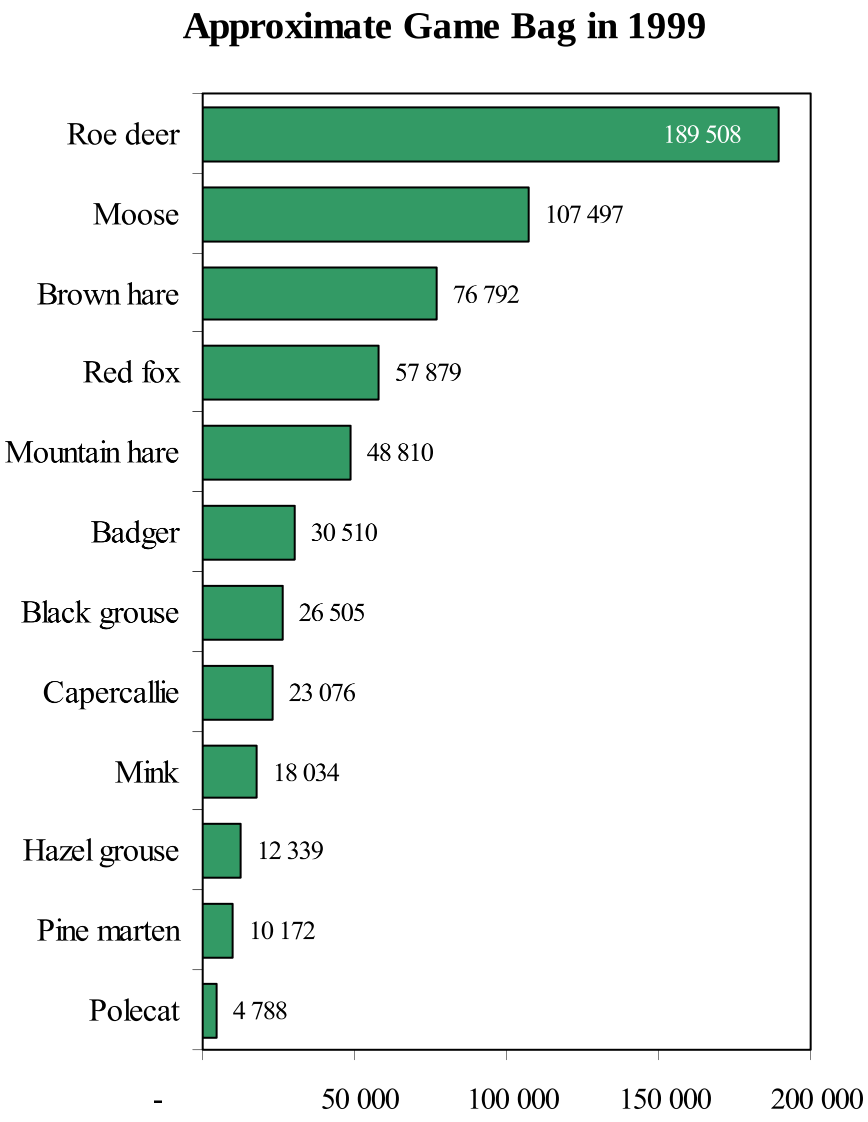


***Figure 4.10*** *Hunting statistics for some of the most common Swedish game species. (Source: Swedish Hunters Association, database 1999.)*

*4.2.8.4 Moose*

In Sweden, it is mainly the moose and the larger carnivores that catch special attention. The moose (*Alces alces*) is the largest and probably the most prominent wild animal in Sweden, and certainly the most important game species. About 100,000 animals are shot each year, which is less than 30 % of the living population. Meat produced in moose harvest exceeds 15,000 tonnes or more than 700 million SEK per year. Being a social event, moose hunting often includes not only the hunter but also the entire family.

Moose occur throughout Sweden except on the island of Gotland and the southernmost parts of the province of Skåne in the far south. Typical moose densities range between 10 and 15 animals per 1,000 ha. In northern Sweden, moose migrate several tens of kilometres between summer and winter foraging areas. Migratory behaviour is triggered by deep snow cover and is more pronounced in inland and highland areas. Recently, barrier effects on migratory moose of fenced roads and railways have been highlighted and evaluation studies are on-going (*e.g.*, Helldin and Seiler 2002; Seiler *et al.* 2003). Where migratory routes are interrupted by fenced roads for example, moose may accumulate and cause severe damage to young forests. Migratory moose, as well as stationary moose are also an important traffic safety issue (see Section 9.2).

#### *4.2.8.5 Large carnivores*

Sweden's four species of large carnivores - the brown bear, wolf, wolverine and lynx - have all been heavily depleted in numbers for a long time, but with the exception of the wolverine they have recovered in recent years. Possible explanations for this are protection by law, changes in attitudes and restrictions on hunting. For more details on the biology of these species see Box 4.2.8.

All four large carnivore species are today protected under Swedish hunting legislation. They are also included on the national red list of endangered mammals and birds. Following Sweden's entry into the European Union, they also come under the EU Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora, in which they are classified as strictly protected. Due to their enormous area requirements and their wide-ranging movements, all of the four carnivores are highly exposed to infrastructure (Figure 4.11). Until now, traffic does not appear to be an important threat. But as these species recover and expand their geographical distribution, infrastructure and traffic could become a limiting factor.

Today there is on-going research on effects of transportation and infrastructure on lynx and wolves in Sweden. The studies are made on three different scales 1. Landscape scale – where do lynx and wolves establish their home ranges in relation to roads. 2. Home range scale – how do lynx and wolves utilize their home range in relation to roads. 3. Individual scale – what factors predispose a certain road segment to be used as a crossing point for wolves and lynx.

Results from the wolf study (Karlsson *et al.* 2004) may serve as example:

- *Landscape scale.* Traffic related mortality was of little importance in the Scandinavian wolf population, being 8 % of the total mortality 1998–2003 (Skandulv 2001/2002). Nevertheless there was a clear pattern that wolf territories had lower densities of roads than neighbouring areas. Even stronger was the negative correlation between wolf presence and density of built-up areas. The density of built-up areas also seemed to decrease over time, suggesting that wolves shape their territories to contain as little built-up areas as possible. Road density was constant over time.

### Box 4.2.8. LARGE CARNIVORES

**Wolves**

The wolf and wolverine did not become protected until 1966 and 1969, respectively. National bounties continued to be paid for wolves and wolverines until statutory protection was introduced. Since then only a limited amount of culling – very limited indeed where the wolf is concerned – of these species has been permitted. Until the 1980s, the county administrative boards controlled hunting of large carnivores, but any culling and other measures applying to those species are nowadays decided on by the Environmental Protection Agency.

Since wolves move over large areas, the Swedish and the Norwegian wolves are considered as one population, the Scandinavian. Maybe the Finnish population should also be included, but we know very little about the degree of contact between the Scandinavian population and the Finnish. The majority of the Scandinavian wolves live in the counties of Värmland and Dalarna and neighbouring areas in Norway, which are Hedmark and Östfold. Dispersing individuals can be expected anywhere in Scandinavia. A winter census of 1998/99 showed that Scandinavia held about 62–75 wolves in 6 different packs and 7 scent marking pairs. The population has shown a positive trend, with an annual increase of 20–30 % during the last 5–6 years. Wolves are strictly territorial and the overlap between home ranges is very small if any. The mean home range size of radio-collared wolves in Scandinavia is about 1,000 $km^2$. On bare ground, the mean movement per day is 20–25 km. During a 10-day period the wolves often range their entire territory.

**Lynx**

The lynx was first declared a protected species in 1928, whereupon the population recovered to such an extent that open hunting was reintroduced in 1943. This lasted for over forty years, but in 1986 the species was again placed under protection outside reindeer-herding areas, and in 1991 this protection was made nation-wide. By that time, both inventories and shooting figures had indicated a serious decline in the lynx population. Hunting was obviously the main reason, but lynx also died because of sarcoptic mange. Under the new statutory protection the population again recovered, and a certain amount of culling has again been allowed since 1995.

Nowadays, lynx are rather common in the middle and northern parts of Sweden. In southern Sweden lynx reproduction is still very rare, however. In recent years the trend has been a decrease in the north and increase in number in the middle parts of Sweden, partially because of differences in hunting pressure. There is an agreement among most interest groups that the population should move further south. In 1997 there were about 1500 lynx in Sweden, since then there may have been a slight increase in numbers.

On-going radio-tracking studies reveal some important basic facts: The mean home range size for males is about 500 $km^2$, and for females somewhat smaller, about 300 $km^2$. The overlap between home ranges of for example related individuals can be large. Per day, radio tracked females moved on average 10-15 km. Due to this high mobility, lynx are exposed to relatively high traffic mortality. For instance, among the 375 known cases of mortality (except licensed hunting) between 1995 and 1998, 59 lynx were killed in traffic, 50 by cars and 9 by trains (Source: Skandulv 1999). More than 150 lynx are legally harvested each year, poaching is also known to be quite extensive. Mortality related to traffic could become more important in the future when lynx start to colonize southern Sweden with its higher densities of roads and humans.

**Brown bear**

The brown bear was the first predator species to be protected in Sweden. It was made subject to far-sighted protection measures already between 1910 and 1942. Subsequent estimates suggest that by about 1930 the Swedish brown bear population may have been reduced to no more than about 130. A recovery then set in, however, and in 1943 an open season for brown bear was re-introduced. This lasted until 1981, when licensed hunting was introduced, with the Environmental Protection Agency deciding, year by year, the number of bears allowed to be shot during a certain period in a number of defined areas. After Sweden became a member of the EU, bear hunting was changed again. It is now only permissible by authority of culling provisions. In recent years, however, culling has been permitted everywhere in northern Sweden and in parts of north-central Sweden. At present, there are approximately 1000 brown bears in Sweden. The bear's presence in our forests is nowadays seen in a more positive light than in earlier times. In 1997, a total of 48 bears were shot legally.

- *Home range scale.* Within territories wolves were found to move independently of roads of all sizes but avoided built-up areas.
- *Individual scale.* The most important variable determining the likelihood of wolves crossing a specific road segment was the presence of a connected road. This variable was significant only in road category 1 (*i.e.* national roads and highways). In the other categories of roads (smaller public roads) no significant variables were found. This is most certainly due to the fact that roadside fences are used only on roads in category 1. Where there is a road connecting to the large fenced road there is an opening in the fence. Resident wolves undoubtedly know where these openings are located and use them for crossings. It seems therefore that fences could be used to direct movements of resident wolves to or from certain road segments.

The distribution of wolves in Scandinavia results from a combination of habitat preference and habitat suitability. Wolves do prefer areas with low densities of human settlements. Road density does not seem to be an important factor. However, it affects the suitability of the habitat through legal and illegal human related mortality. Habitat fragmentation by roads *per se* is not of any importance. But the indirect effect as a vector for mainly illegal killing is probably regulating both the distribution and the size of the Scandinavian wolf population.

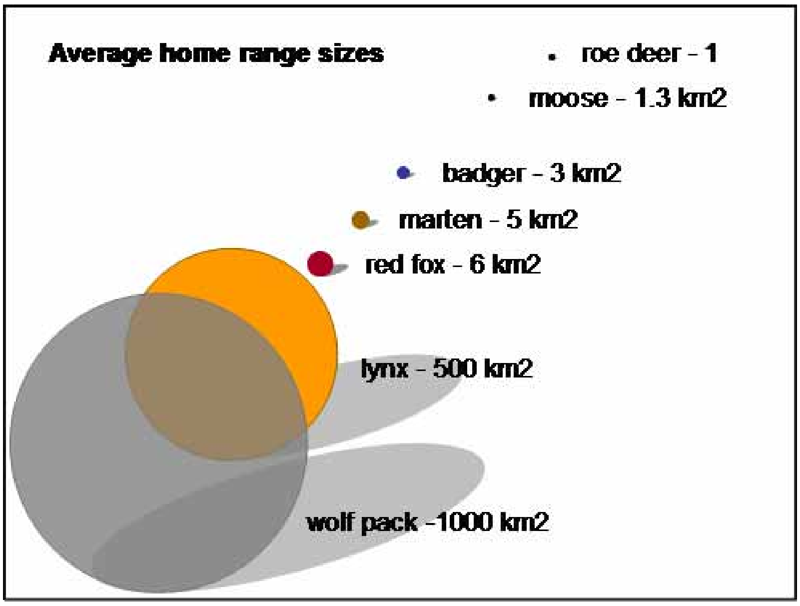


***Figure 4.11*** *Average home range size of large mammals in Sweden. (Sources: Wolf and lynx: Grimsö Wildlife Research Station, Annual report of Large carnivore Group, 1999; red fox: Lindström 1989; marten: Brainerd et al. 1995; badger: Seiler 1992; moose: Cederlund and Okarma 1988; roe deer: Cederlund and Liberg 1995.)*

## 4.3 Overview of fragmentation

Fragmentation of natural land – or wildlife habitats – has been considered in many ways in Sweden. Changes in landscape pattern due to forestry, agriculture and urbanisation are documented and studied rather extensively during the last 15 years. Much effort has been put into studies of single species depending on rare and fragmented habitats. For more information on specific habitat types and species, see Sections 4.2.4 to 4.2.8.

Scientific research on the process and consequences of habitat fragmentation is however international, since the problem is recognized worldwide (*e.g.* Andrén 1994). Recent work has been done on modelling, with the purpose of discerning possible thresholds for when the landscape becomes unsuitable as a habitat for the species. Not much research has been made so far on providing empirical evidence of the effects of habitat fragmentation in Sweden. Studies are currently being made on the subject in some of the departments of the Swedish University of Agricultural Sciences. For example, studies in Umeå are being made on how to connect important areas of old-growth forest into so-called core areas. However, a few studies are published as yet. Jennersten (1988), for example, showed that the plant Maiden Pink (*Dianthus deltoides)* had lower densities and fewer seeds, due to low pollination rates, in fragmented areas. Furthermore, a population decline of many farmland birds over the last decade has been reported. Berg (1992) suggested that the results of his study indicated that the decline of the Swedish Curlew (*Numenius arquata*) population was caused by changes in landuse, resulting in decreased grassland area and increased habitat fragmentation. The forest bird Hazel grouse (*Bonasia bonasia*) was also affected by the size of the forest fragmentation in the sense that it only occurred in large-sized fragments (Åberg *et al.* 1995). Birds depending on deciduous trees in the boreal forest have also been studied with respect to the fragmentation of deciduous forest stands (*e.g.* Enoksson *et al.* 1995; Jansson and Angelstam 1999). An inventory of breeding bird species in the Stockholm city area indicated that small forest fragments in the urban environment could be used as part of a territory provided they are not too isolated from natural or semi-natural vegetation. The study also pointed to the importance of dead and decaying wood to the presence of breeding birds. This type of features was associated with the shoreline habitats inaccessible to human visitors (Mörtberg and Wallentinus 2000).

## 4.4 Administrative and legislative framework

### 4.4.1 The Environmental Code

Swedish environmental legislation has recently been reformed. The central environmental acts have been amalgamated into the Environmental Code which came into force on 1 January 1999. The Code constitutes modernised, broadened and tightened environmental legislation aimed at promoting sustainable development (cited from SWEIONET).

The Government's overall environmental policy objective is to solve Sweden's major environmental problems within a generation, *i.e.* 25 years.

### 4.4.2 Purpose and scope of the Environmental Code

The aim of the Environmental Code is to promote sustainable development that ensures a healthy environment to both the current and future generations. To achieve this aim, the Code is to be applied so that:

- human health and the environment will be protected against damage and nuisance, regardless of whether this is caused by pollution or other influences
- valuable natural and cultural environments will be protected and conserved
- biological diversity will be preserved
- land, water and the physical environment will generally be used so as to safeguard long-term good management of resources from an ecological, social, cultural and socio-economic viewpoint
- re-use and recycling as well as other management of material, raw materials and energy are promoted so that an ecocycle is created.

The areas of application of the Environmental Code are directly linked to the aim of sustainable development. The Code is applicable to all activities or measures that are of significance if this aim is to be achieved. It concerns all types of measures and operations that can be of importance to those interests which the Code is intended to protect, regardless of whether they are part of a private individual's daily life or are some form of business activity.

The areas of application of the Code are not just important for the situations in which the Code can be used. Above all, the Code decides what type of environmental issues can be examined in a court of law. For example, a pre-condition that may be set using the Environmental Code for the start of an environmentally hazardous activity might be anything that benefits ecologically sustainable development.

All in all, this means in many cases that the regulations that were part of previous environmental legislation now have a new and broader application.

### 4.4.3 General rules of consideration

The second chapter of the Environmental Code contains a number of general rules of consideration, for example the precautionary principle, the polluter pays principle, the product choice principle and the principles regarding resource management, the ecocycle and suitable localisation of activities and measures. Legislation acts as a preventive tool because it requires everybody who runs a business or operation or plans to take an action, to gain knowledge on the environmental effects. The general rules of consideration also make it clear that the risks of environmental impact are to be borne by the polluter and not by the environment.

Supervisory and licensing authorities have the power to base their decisions on these general rules of consideration concerning injunctions, bans, permit conditions etc. As a result, the content of these rules becomes much more concrete through regulations or decisions in each individual case.

### 4.4.4 Objectives and goals for environmental quality

The Environmental Code puts more emphasis on goal and result management than did the previous environmental legislation. This means that the licensing and supervision of activities and measures must in the future take the goals of environmental policy into consideration. Licensing and supervision work is to be steered by the national objectives, specified in the form of regional and sector goals.

Government ordinances and the regulations laid down by authorities in the environmental field will be governed not just by the overall aims of the Code and its general rules of consideration, but also by other environmental goals that have not been included in the wording of the Code (cited from SWEIONET).

Environmental quality standards are a new feature of the Environmental Code. These are regulations relating to the lowest acceptable quality of the soil, water, air and the environment in general. Whilst previous environmental legislation was only aimed at minimising and alleviating environmental disturbances, as far as was reasonable, the Environmental Code on the other hand also places direct demands on the final result, *i.e.* on what properties the environment must have for it to be acceptable.

Regulations governing several different types of area protection have been brought together in the Environmental Code. Examples are biotope protection, shoreline protection and the possibilities of setting aside national parks or nature reserves or declaring areas of national interest for nature conservation or recreation. Together with the regulations regarding species protection, the aim is to preserve biological diversity.

One reason why compliance with the previous environmental legislation has been found lacking is that the risk of being punished for an environmental crime has been seen as rather small. There has therefore been a need for a rapid and effective way of reacting to infringements of the environmental rules. With the Environmental Code, environmental sanction charges were introduced. The sanction charges are levied directly by the supervisory authorities when an infringement has been established. Penalties can be imposed for certain infringements in the form of charges the extent of which have been previously stipulated by the Government (cited from SWEIONET).

### 4.4.5 Environmental Quality Objectives

The main goals of Parliament's environmental policy have been developed over the last years. In April 1999, the following Environmental Quality Objectives were adopted by Parliament:

- Clean air
- High-quality groundwater
- Sustainable lakes and watercourses
- Flourishing wetlands
- A balanced marine environment, sustainable coastal areas and archipelagos
- No eutrophication
- Natural acidification only
- Sustainable forests
- A varied agricultural landscape
- A magnificent mountain landscape
- A good urban environment
- A non-toxic environment
- A safe radiation environment
- A protective ozone layer
- Limited influence on climate change

Further development of these 15 objectives is underway and detailed proposal for sub-goals have recently been presented to the government by the Swedish Environmental Protection Agency (cited from SWEIONET).

### 4.4.6 Laws replaced by the Environmental Code

The Code incorporates the provisions of fifteen earlier environmental laws. These are:

- The Nature Conservation Act
- The Environment Protection Act
- The Dumping of Waste in Water (Prohibition) Act
- The Fuels (Sulphur Content) Act
- The Agricultural Land Management Act
- The Public Cleansing Act
- The Health Protection Act
- The Water Act
- The Pesticides (Spreading over Forest Land) Act

- The Chemical Products Act
- The Environmental Damage Act
- The Natural Resources Act
- The Biological Pesticides (Advance Testing) Act
- The Genetically Modified Organisms Act
- The Flora and Fauna (Measures Relating to Protected Species) Act

*(cited from SWEIONET).*

## 4.5 Landuse planning in relation to nature conservation and infrastructure

Nature conservation in Sweden focuses on the protection of selected objects such as species or biotopes, but pays rather little attention to the sustainable management of landscapes (Seiler and Eriksson 1997). This object-orientated approach may be adequate in site related conservation works, but for use in infrastructure planning, it has proven to be insufficient (Anonymous 1996). A more holistic and process-oriented approach is needed to integrate infrastructure with the landscape context.

The problem is twofold: On the one hand, we need empirical background data on the effects of infrastructure on wildlife that helps to identify impact thresholds. These field data must be put into a large-scale spatial context. On the other hand, empirical data must be generalized and translated into practicable rules for evaluation, mitigation and management. To achieve these goals, biological expertise must be combined with civil engineering.

## 4.6 Transport planning

National landuse interests, including protection/conservation, are geographically defined by Swedish legislation (the Environmental Code). Multimodal transport planning is dealt with in the context of strategic analyses which study alternative directions of actions, their costs and the achievement of policy goals (incl. environmental goals). The alternative directions are usually based on assumptions on projects and their impact assessment and cost benefit analyses. However projects are not defined or decided on at this strategic level of planning.

Strategic environmental assessments are presented for policies, directive plans and ten-year programmes, but not always based on an integrated working process. Environmental assessment for networks and for transport corridors are not officially a part of this but rather applied on an *ad hoc* basis in some cases. When major road infrastructure projects are analysed in feasibility studies, future expected or planned changes of the rail system are sometimes taken into account or even included in the study. Joint road/rail location has been considered in a few cases but there is no policy to promote it. The prerequisites for the location of a road or railway in the landscape are so different that a case-by-case approach is needed.

## 4.7 Nature conservation and EIA

Nature conservation has a long tradition in Sweden, starting with the foundation of national parks and natural monuments in 1909. A nature conservation act appeared in 1952.

Prior to 1999, there were several forms of protected areas, *e.g.* national parks, nature reserves, conservation areas, natural monuments and biotope conservation areas. In the Environment Code, coming into force in 1999, nature reserves and conservation areas have been merged together under the name of nature reserve. New protection forms are national urban parks and culture reserves. Also the Natura 2000 areas have been integrated into the Environmental Code among special protection areas.

The Government decides on the establishment of national parks and national urban parks. These parks are managed either by the Environmental Protection Agency, county administrative boards or special foundations. County administrative boards or municipalities can take decisions on nature reserves and culture reserves. Large costs are associated with the establishment, administration and management of nature reserves and culture reserves. These reserves are managed by county administrative boards, municipalities, foundations, regional forestry boards or local associations or farmers.

Certain types of areas (varying in size) such as avenues, old stone walls and stone heaps, have been devoted a general protection in the form of habitat protection areas.

Wildlife and plant sanctuaries give protection to especially valuable habitats such as ravine woods and certain types of broad-leaf forest wetlands. The management of habitat protection areas as well as wildlife and plant sanctuaries is administered by the county administrative boards or the regional forestry boards.

The establishment of natural monuments, comprising *e.g.* large solitary trees and conspicuous nature forms, rests with the county administrative boards.

Shoreline buffer zones, usually 100 m in width (casually extended to 300 m upon decision by the Government), give a general protection to all seashores and shores of lakes and watercourses. This is a means of safeguarding public access to shores for recreation activities. This section of the Environmental Code formalises part of the very ancient Swedish right of public access to nature. Environmental Impact Assessment has a short history in Sweden. A demand to include descriptions of environmental impacts was introduced into the Environment Protection Act in 1983 and the demand for environmental impact assessments was introduced into the Roads Act in 1987. From 1992–93, environmental assessment was also applied to the strategic planning of roads.

According to the EIA guidelines of the Swedish Road Administration (Pettersson and Eriksson 1995), evaluation of ecological effects on wildlife populations and landscape ecosystems should be included in the EIA document. In many cases, however, ecological evaluations have to be based upon expert judgements, because no relevant experience exists and the empirical data cannot be gathered within the given time limits of the EIA. Due to the lack of methods for ecological effect evaluation, it is common practise to focus at the descriptive level, *i.e.* to present lists of the occurring species, habitats or specific landscape features. EIA documents only rarely contain predictions of possible consequences of road construction for the future development of the landscape (including changes in human settlement, traffic flow or landuse) and the effects on biodiversity, ecological qualities and processes (DeJong *et al.* 2004). Where predictions are made, assessments of uncertainties are generally missing. Overall, ecological effect evaluations within the EIA document still provide only little advice to road planners in Sweden (Anonymous 1996; Seiler and Eriksson 1997).

The problem is rooted in the general attitude towards nature conservation in Sweden that focuses on the protection of selected objects such as species or biotopes. but pays rather little attention to the sustainable management of landscapes. This object-orientated approach may be adequate for site related conservation work, such as deloped for forestry or agriculture, but it has proven to be insufficient for use in infrastructure planning (Eriksson & Skoog, 1996). Four reasons for this failure have been identified:

1. The general conservation approach focuses on spatially explicit patterns, but it pays no attention to the ecological processes that link these patterns throughout the landscape. The natural environment is usually described in terms of geological and vegetational characteristics and thus appears rather stable from a human point of view. Ecological processes are more dynamic and complex.
2. Because not all nature is considered as valuable in the common approach, measures to mitigate adverse effects are only required for high ranking, protected areas. No mitigation concepts are developed for the landscape itself.
3. Categorisation of nature is dependent upon the investigator's perspective and may therefore fail to identify important patterns that are dominant on another scale. This problem is especially apparent in GIS-based analyses of remotely sensed landscapes, since the grid size of the image may not necessarily be identical with the ecological grain of the landscape.
4. The common approach is static with only little consideration of the temporal and spatial dynamics in the landscape ecosystem. Descriptions of a status quo in the landscape offer no tool for prediction and evaluation of composite effects of landscape changes.

Thus, a more holistic and process-oriented approach is needed to achieve a sustainable utilisation of landscape resources (Seiler and Eriksson 1997; Seiler and Sjölund 2005; Swedish Road Administration 2005).

## 4.8 Administration

Sweden's 21 county administrative boards, which are regional branches of the national government, are responsible for environmental protection in their respective regions. They decide upon issues related to hazardous activities in cases where the Environmental Court does not have jurisdiction. The municipal authorities regulate small-scale hazardous activities, however. The county administrative boards are responsible for continuously monitoring the environmental quality in their respective counties. They are also responsible for enforcing other parts of the Environmental Code, for example matters regarding chemical products, natural resources, water and public installations concerning water supply and sewage etc. They also make decisions regarding nature reserves, nature conservation areas, and bird and seal sanctuaries.

Sweden's 289 municipalities play a very important role in environmental protection and urban and rural planning. The municipalities are empowered to limit emissions and other environmental hazards from many activities, which together add up to tens of thousands of pollution sources. Each municipal council must ensure that industry, traffic, waste management and energy use take health and environmental considerations into account (cited from SWEIONET).

# Chapter 5. Habitat Fragmentation due to Existing Transportation Infrastructure

## 5.1 Introduction

The impact of transportation infrastructure on nature has been increasingly acknowledged during the recent years in Sweden. Although the overall density of transport infrastructure is rather low, especially when compared to other European countries, fragmentation caused by roads and railroads is recognized as a potential regional and local problem. Barrier effects on large wildlife species (*e.g.* moose, bear, and wolf) and on aquatic species, disturbance effects on birds and sensitive wildlife habitats (*e.g.* wetlands), and the loss of designated and valuable habitats are important issues dealt with in an increasing number of Environmental Impact Assessment studies. Vehicle-animal collisions have since long attracted attention, especially as accidents with moose and reindeer are important traffic safety and economical issues. Over the past years, several research projects have been started to quantify the fragmentation impact of roads and railroads on wildlife and to develop evaluation methods that can be used in planning and maintenance of infrastructure.

With the increasing spatial demands of the road network and its physical encroachment on the land, conflicts between transport infrastructure and the natural, and cultural, heritage of the landscape have become inevitable (*e.g.* Nihlén 1966). Already with the construction of the first motorways, public concern about the aesthetic values of the landscape was stirred: the new bold roads would not fit into the traditional small-scaled landscapes. By 1930, a special landscape consultancy bureau was established to guide road planners in building aesthetically and culturally adapted motorways (Nihlén 1966). However, it was not before 1987 that road construction actually required approved EIA studies in Sweden (Pettersson and Eriksson 1995). Due to insufficient empirical data and the lack of adequate evaluation tools, the quality of the EIA work could not always fulfil the required standards or consider impacts on ecological properties in the landscape (*e.g.* Anonymous 1996, Seiler and Eriksson 1997). More recently, increased environmental responsibility of the transport authorities, together with the implementation of Agenda 21 into national policies and plans, has stimulated a greater engagement of road planners also in ecological-environmental concern. Authorities now ask for improved methods to evaluate the problem and to meet national and sector-level policies on conservation of biodiversity and sustainable development (Eriksson and Skoog 1996). The concepts of mitigation and compensatory measures are to be developed that can operate across scales and be applied to strategic planning of new infrastructure, as well as to maintenance of existing links.

To understand the complex environmental impact of modern infrastructure and amend it in an ecologically sound and sustainable manner, we need a holistic landscape approach considering both cultural (historic) and natural (ecological) aspects in the landscape. We need improved empirical data that helps drawing general conclusions and build predictive models that can be used for strategic impact assessments. The following chapters shall provide a brief overview of the state of the art in our knowledge.

## 5.2 Transportation networks

Most of the personal and goods transport in Sweden is today bound to roads (Table 5.1). Eighty-eight per cent of the personal transport occurs on roads, and the trend is increasing. Railroads still play an important role in freight transport. Inland waterways are of minor significance to transportation within Sweden (Table 5.2).

***Table 5.1*** *Distribution of personal transport in Sweden. (Source: Swedish Road Administration 2000a.)*

| ***Total person-kilometres travelled*** | ***ca. 120 billion. km*** |
|---|---|
| Passenger cars | 77 % |
| Train | 8 % |
| Coach, bus | 7 % |
| Air, bicycle, subway, tram, sea, pedestrian | 8 % |

***Table 5.2*** *Surface-freight traffic in Sweden. (Source: Swedish Road Administration 2000a.)*

| | | |
|---|---|---|
| Lorries * | 32,600 million tonne-km | 55 % |
| Railway | 18,700 million tonne-km | 31 % |
| Shipping | 8,400 million tonne-km | 14 % |

* estimated annual increase about 5 %

Despite the relative small population, the Swedish road network is extensive (Figure 5.1). On average, there are about 1.03 km road per km$^2$ of land, although there is a strong regional variation (Table 5.3). Typical of rural areas in central and southern Sweden are road densities of around 2 km per km$^2$. In total, there are more than 421,000 kilometres of roads of different standards and purposes. Private roads make up the major part of the road network (68 %, 284,000 km). State subsidies are given to 74,000 km of these private roads, whereas the remainder is privately financed and sometimes closed for public use. Some 200,000 km of private roads are built solely to access and extract timber resources (National Board of Forestry 2000). Official statistics suggest that more than 70 % of the managed forest in Sweden already lies within 500 m of the nearest access road (Source: National Board of Forestry 2000).

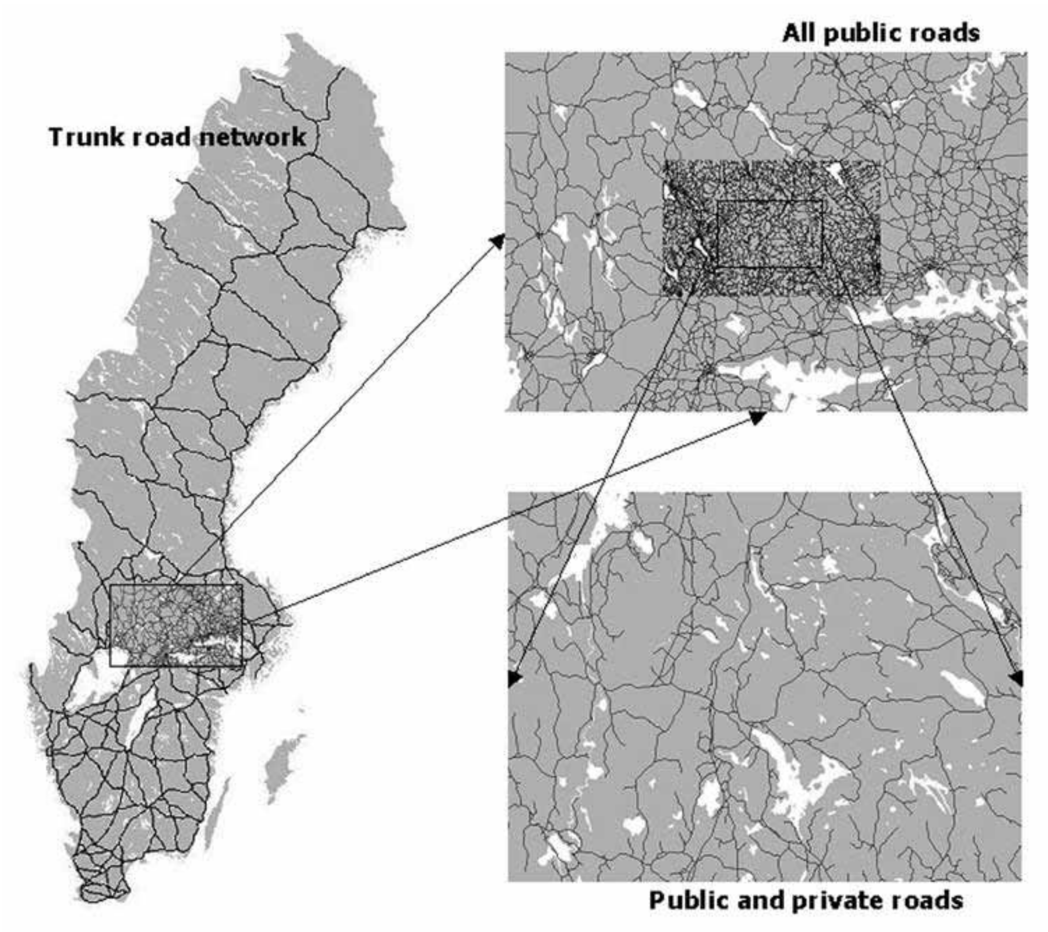


***Figure 5.1*** *The Swedish network of public and private roads in 1990 (from Seiler 2001).*

***Table 5.3*** *Swedish road network in 1998. (Source: Swedish Road Administration 2000a).*

| ***Swedish roads and transport*** | ***km*** | ***km road / km² land*** | ***% length*** | ***Traffic (billion km)*** | ***% traffic*** |
|---|---|---|---|---|---|
| Roads trafficable in 1998 | 420,681 | 1.03 | 1.00 | 50.5 | 1.00 |
| *of which open to public* | *210,681* | *0.52* | 0.50 | | |
| **State-administered roads *** | **97,983** | **0.24** | **0.23** | | |
| *national main roads* | *14,615* | *0.04* | 0.03 | *22.2* | *0.44* |
| *… of which motorway* | *1,428* | *0.001* | 0.003 | | |
| *county roads* | *83,368* | *0.20* | *0.20* | *13.1* | *0.26* |
| Municipal roads | 38,500 | 0.09 | 0.09 | 13.1 | 0.26 |
| Private roads with state subsidies | 74,198 | 0.18 | 0.18 | 1.5 | 0.03 |
| Private roads without subsidies | 210,000 | 0.51 | 0.50 | 0.5 | 0.01 |

* 77 % of which is paved.

The responsibility for the public road network outside urban areas and for major through roads in towns and cities rests with the Swedish state. Urban road networks are managed by the municipalities. Private roads are – as the name tells – due to private responsibilities, and can thus vary greatly in standard. However, the Swedish Road Administration plays a central role in advising and defining general road standards, and these apply to private and forestry roads as well.

The state road network can be distinguished into three main categories of roads with different strategic importance: main national trunk roads and highways are of vital importance to the continued welfare development of the country; the network of county roads is of strategic importance to the regional development; and local public roads are mainly connective roads between or within villages.

Most of the state-administered road network is concentrated around the major cities Stockholm, Göteborg and Malmö, whereas the network is sparse in large areas in the northwest where the population density is very low (Figure 5.2). It is in these north-western alpine and arctic regions where one may still find extensive wildlife habitats without any permanent infrastructure (except from tourist trails and scooter traffic).

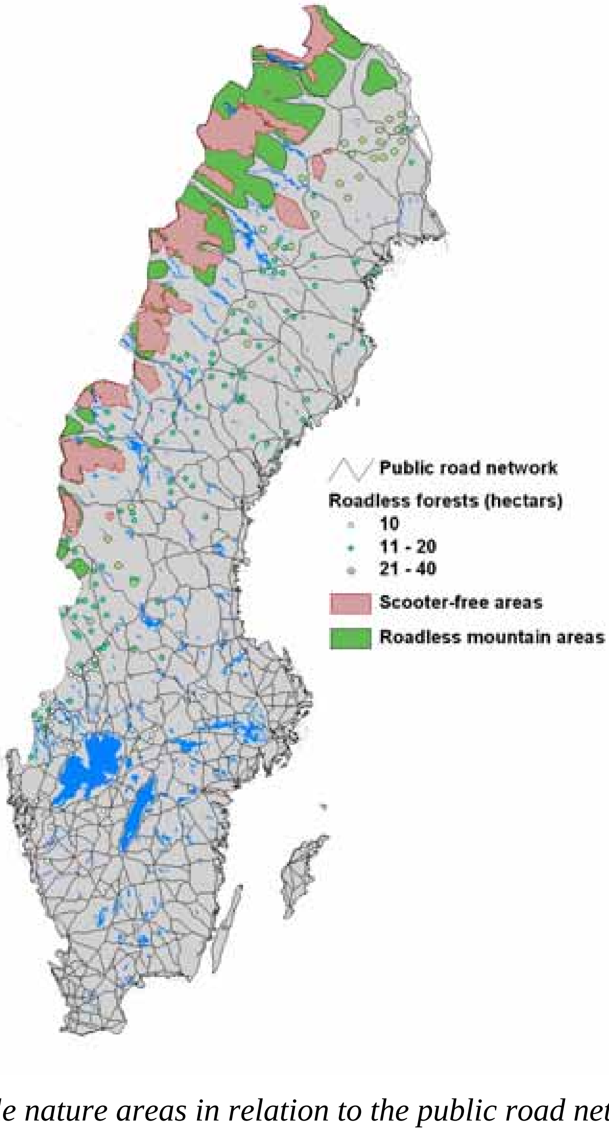


***Figure 5.2*** *Valuable nature areas in relation to the public road network. (Source: National Atlas of Sweden. The infrastructure 1992).*

The density of the state-owned road network reaches about 0.24 km/km$^2$. For municipal roads, the figure is 0.09 km/km$^2$. Due to the large amount of private roads, the density of trafficable roads amounts to 1.03 km/km$^2$, however (Table 5.3). Railways contribute little, and the combined road and railway network in Sweden reaches a density of 1.07 km/km$^2$.

However, in the southern and more populated regions of Sweden, the total infrastructure density is typically higher, around 2 km per km$^2$ land, including private as well as public infrastructure. For instance, in the former county of Malmöhus in the south-western corner of Sweden, the density of state roads alone has been calculated at 0.9 km/km$^2$ (contrasting 0.24 in the country as a whole). In this area, land polygons delineated by public roads range between 0.6 and 5200 ha with a mean size of 481 ha. Half the total area of Malmöhus is occupied by open agricultural land and built-up areas (85 % and 11 %, respectively), with a mean road density of 1.1 km/km$^2$ and a mean polygon area of 350 ha (Skage, personal communication). For the rest of Sweden (except the alpine and artic region), the average mesh size of the public road network is considerably larger (44 km$^2$; Table 5–4).

***Table 5.4*** *Landscape fragmentation due to infrastructure: Size and variation of the mesh size in the network of public roads in Sweden.*

| ***Nemoral and boreal region*** | | | | | | ***Arctic reg.*** |
|---|---|---|---|---|---|---|
| ***Mesh size (km$^2$)*** | ***<100*** | ***100–500*** | ***500–1000*** | ***1000–2500*** | ***sum*** | ***>4500*** |
| Count | 6904 | 757 | 39 | 16 | 7716 | 7 |
| Mean (km$^2$) | 20 | 196 | 674 | 1505 | 44 | 11356 |
| *Std. Dev.* | *21* | *91* | *142* | *419* | *104* | *14177* |

Another example of the variation in infrastructure density between various parts of the country can be given: When dividing the Swedish land surface into a grid with 100 km$^2$ cells, road density per cell varies considerably (Figure 5.3). Most cells have a road length of between 20 and 40 km, yet there are also many with up to 80 km. There are fewer cells with road lengths below 10 km and not a single one without any public road. This implies that most unfragmented land polygons in-between the public road network are smaller than 20 km$^2$ (Table 5.4). Typical of more populated areas, however, is a density above 2 km of roads per square kilometre of land (*e.g.* Seiler 1999a). In these areas, the mean patch size of completely unroaded habitat, *i.e.* the mesh size of the road network, is generally less than a few hectares. Considering only public roads, the average mesh size is below 14 km$^2$. For comparison, this is more than ten times the home range size of a moose (ca. 1.2 km$^2$), but only a fraction of the average home range of a lynx or wolf (50–60 km$^2$; Figure 4.11, A. Seiler, unpublished).

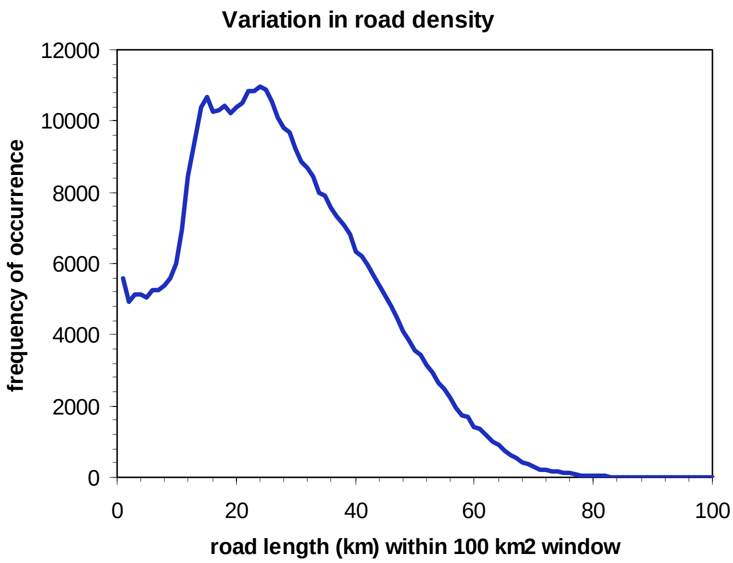


***Figure 5.3*** *Length of public roads in Sweden per 100 km² window.*

As in most countries, road traffic increases steadily with 1–2 per cent each year and is expected to do so for the next 15 years (Figure 5.4). The largest increase is expected to occur in the traffic work (driven mileage) of trucks and lorries (2.5 %, SIKA 2002). This increase is only partly due to the increase in the number of vehicles: Over the past 25 years, the number of trucks has risen with about 30 % while passenger cars have become more than twice as frequent as in 1975 (Figure 5.5). The number of passenger cars in the county is almost 4 million (Table 5.5).

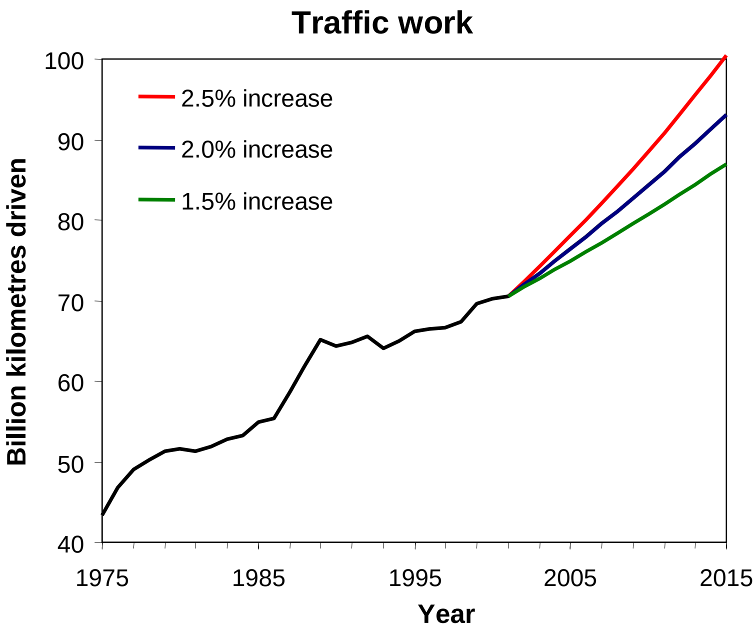


***Figure 5.4*** *Development of road traffic intensity from 1975 to 2000 and the expected increase until 2015 (driven kilometres by all vehicles combined). (Source: Edwards et al. 1999; SIKA 2002.)*

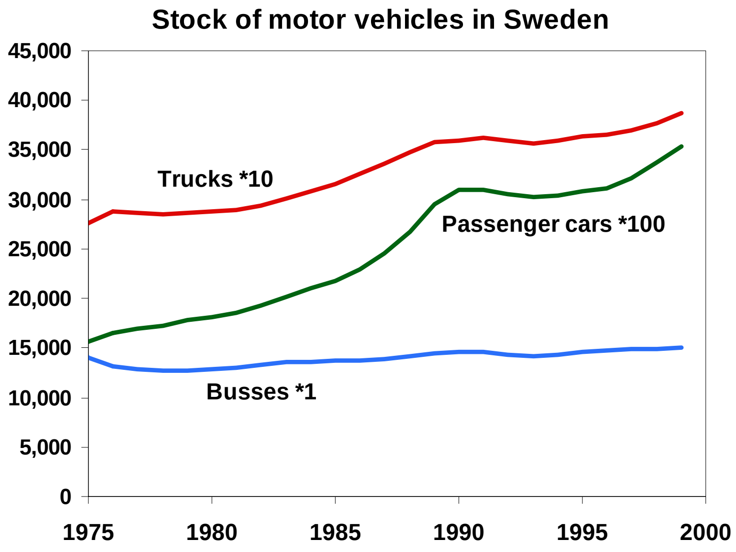


***Figure 5.5*** *Stock of motor vehicles in Sweden between 1975 and 1999. (Source: SIKA 2000).*

***Table 5.5*** *Number of motor vehicles in use (31 December 1998). (Source: Swedish Road Administration 2000a.)*

| ***All vehicles*** | ***4,576,711*** |
|---|---:|
| Passenger cars * | 3,770,212 |
| Motorcycles | 130,000 |
| Lorries | 336,803 |
| Busses | 14,902 |
| Tractors | 324,794 |
| Cross country scooters | 149,000 |

- car density: 428 passenger cars per thousand inhabitants

### 5.2.1 Highways/motorways

Motorways in Sweden sum up to a length of 1,428 km (Figure 5.6). Most of the major road network is of lower standard. Highways and motorways carry about 44 % of the traffic load. With speed limits of 110 or 90 km/h and road widths of more than 13 m, these roads provide efficient linkages between metropolitan areas throughout the country. However, highways in less-populated inland areas, such as the traditional inland tourist road "Inlandsvägen" can partially be of lower standard. Many of the major highways are fenced against moose and reindeer to reduce the risk for human injuries and death in animal-vehicle collisions.

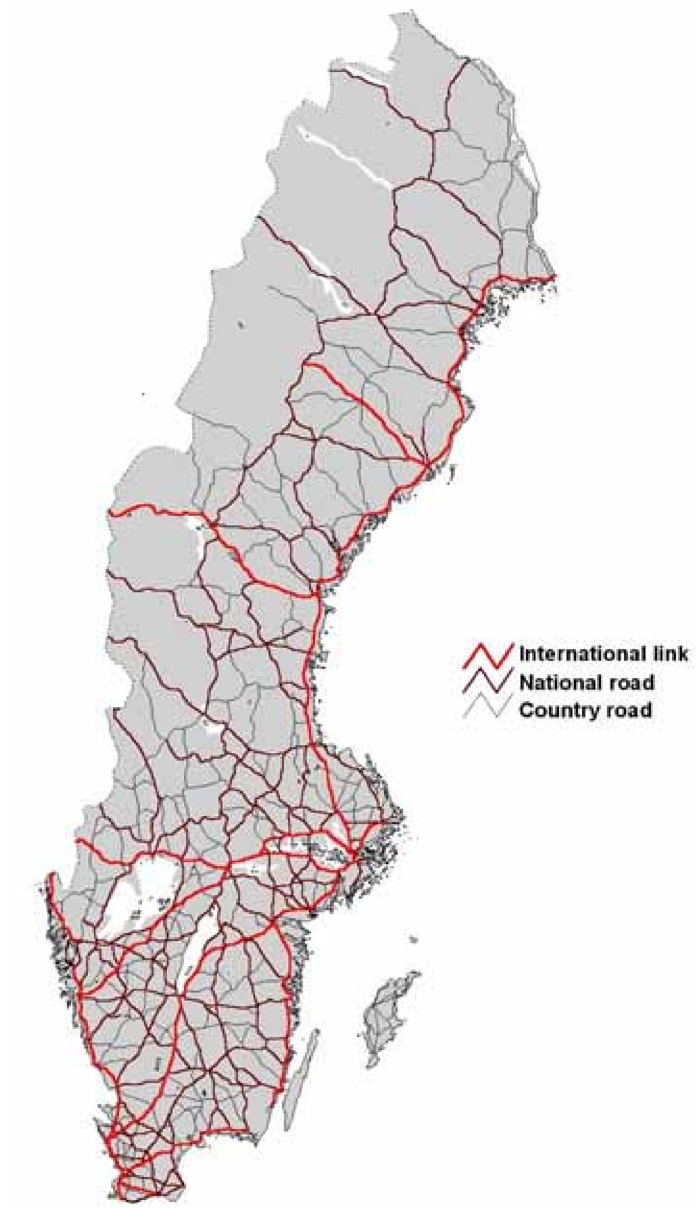


*Figure 5.6 Major roads and county roads in Sweden in 1990. (Source: National Atlas of Sweden. The infrastructure 1992).*

### 5.2.2 Secondary road infrastructure

Private roads without state subsidies are estimated to sum up to about 210,000 km of length. The majority of these roads (about 200,000 km) are forest roads, built to access forest properties and extract timber (Source: National Board of Forestry). Some private roads, especially in agricultural areas, may date back to medieval times; still the majority has been built during the past 50 years. Overall, more than 70 % of the managed forest in Sweden lies within 500 m of the next access road. The annual increase in forest-road length is estimated at about 1,500 km on average over the last 45 years (Figure 5.7). However, exact statistics do not exist, as many of these roads are not always open to the public. Most of the forest roads are being built in northern and mountainous areas.

The density of public roads increases with the proportion of agricultural and urban areas in the landscape. Yet, in forested regions, the network of private roads is typically denser. On average, thus, total road density does not differ much between agricultural and forested landscapes.

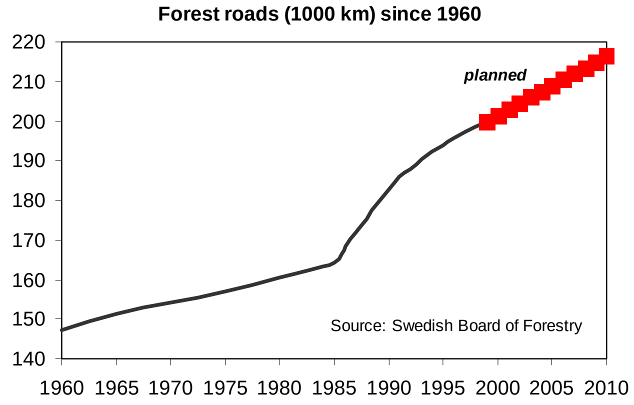


***Figure 5.7*** *Increase in forest roads since 1960. (Source: National Board of Forestry 1999.)*

### 5.2.3 Railways

The Swedish rail network (Figure 5.8) sums up to 15,000 km of track (Table 5.6). The state-owned operational rail network comprises about 11,000 track km, 15 % of which has dual tracks. The Trunk network comprises 76 % of the state-owned rail network. The County lines are important to the regional and local passenger traffic. Some rail linkages between cities and their suburbs are privately owned. Major trunk railroads are estimated to cover about 75 $km^2$ of land and county railroads about 34 $km^2$ (Source: Swedish National Rail Administration 1999).

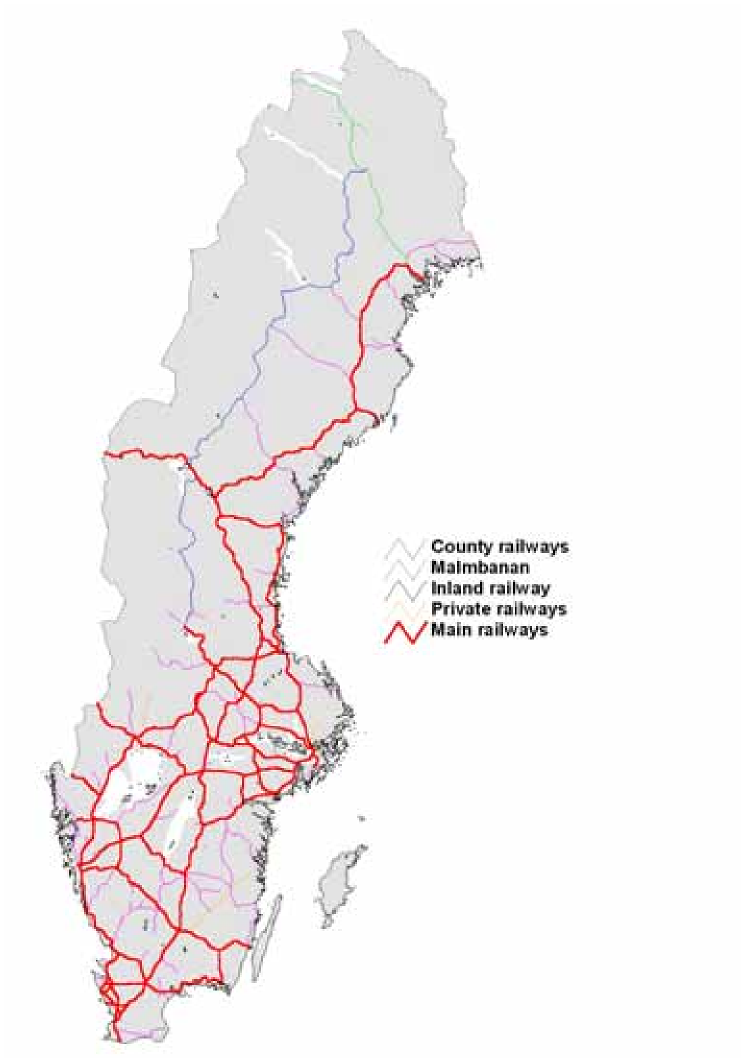


***Figure 5.8*** *The Swedish rail network in 1990 (Source: National Atlas of Sweden. The infrastructure 1992.)*

***Table 5.6*** *Railroads and rail transport in Sweden. (Source: Swedish National Rail Administration and Statistics Sweden 1999.)*

| ***Swedish railroads 1998*** | ***kilometres*** |
|---|---|
| **National railroads** | **12,339** |
| *Trunk railroads* | *8,417* |
| *County railroads* | *3,089* |
| *Other railroads* | *720* |
| *of these are double track* | *1,510* |
| *or electrified* | *7,614* |
| non-operational tracks | 113 |
| **Private railroads** | **3,010** |
| | |
| ***Traffic on national railroads*** | |
| number of passenger vans | 1,943 |
| number of waggons | 19,232 |
| passenger kilometres (million) | 7,144 |
| tonne-kilometres (million) | 19,086 |

### 5.2.4 Waterways

The Swedish waterway network is very limited in extent (Table 5.7, Figure 5.9). Nowadays, only the 97 km of canals allowing vessel traffic to the large lakes Vänern and Mälaren are of any commercial importance. The rest of the canals mainly serve leisure traffic. The construction of the canals in the end of the 18th and in the 19th century largely enhanced the industrial development of the country, however (National Atlas of Sweden. The infrastructure 1992). It should be added that the Swedish canals are much less artificial in appearance than those in, *e.g.*, the Netherlands. Many canal stretches are technically improved natural watercourses, winding through the landscape, retaining much of their natural features and having less steep and high shore walls than in many Central European countries.

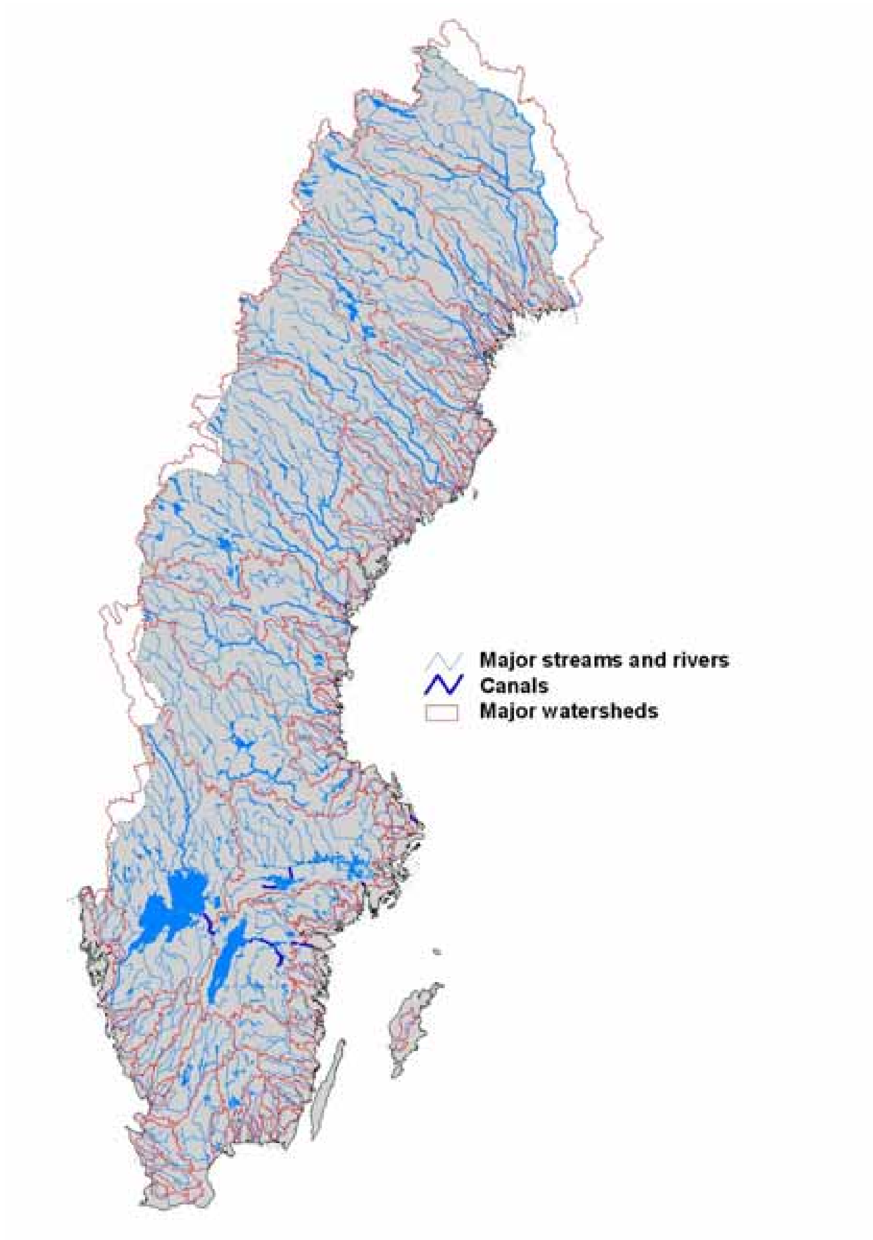


***Figure 5.9*** *The network of streams and canals in Sweden. (Source: National Atlas of Sweden. The infrastructure 1992.)*

***Table 5.7*** *Swedish canals (Source: National Atlas of Sweden. The infrastructure 1992.)*

| ***Length of canals in 1992 (km)*** | ***1,052*** |
|---|---|
| **Canals of industrial importance** | |
| Göta älv/Trollhätte kanal (Göteborg-Lake Vänern) | 82 |
| Södertälje kanal (Baltic sea-Lake Mälaren) | 15 |
| **Canals mainly serving leisure traffic** | |
| Dalslands kanal | 254 |
| Strömsholms kanal | 227 |
| Göta kanal (Baltic sea-Lake Vänern) | 190 |
| Hjälmare kanal | 90 |
| Säffle kanal | 80 |
| Kinda kanal | 80 |
| Others | 34 |

## 5.3 Effects of the existing transportation network on nature

Only recently, habitat fragmentation due to infrastructure has been recognized as a potential problem in Sweden. Barrier effects on large wildlife species (*e.g.* moose, bear, wolf), noise disturbance effects on birds, and indirect loss of critical wildlife habitats (*e.g.* wetlands) are considered as critical factors of the fragmentation impact (Seiler 1996a). However, there is still very little knowledge on how to measure and evaluate this kind of fragmentation and integrate the issue into planning practises. The impact of infrastructure on the landscape has been listed in policy papers of the sector (Westermark 1996), but so far no operative goals have yet been defined that consider fragmentation aspects.

Nature conservation in Sweden focuses on the protection of selected objects such as species or habitats, but pays rather little attention to the sustainable management of landscapes. Encroachment on single habitats designated for nature conservation are legally regulated and require mitigation, but ecological properties that relate to the landscape system, such as habitat connectivity, are hardly thought about. The common object-orientated approach may be adequate for site related conservation work, but for use in infrastructure planning, it has proven to be insufficient (Anonymous 1996). Still, fragmentation due to infrastructure does not appear as an urgent environmental problem in Sweden – at least not at a national scale. This is partly because the road network is so much less dense and less used than in other European countries, but also because knowledge of the long-term and large-scale effects of infrastructure is scarce. In addition, most of the valuable habitats that receive some kind of legal protection (such as national parks, nature reserves, Natura 2000 areas) are located in areas with very little infrastructure anyway. Thus, the question still remains, as to where and when infrastructure in Sweden actually is a threat to wildlife.

At local scales, however, the situation is rather different: In areas where infrastructure dissects important migration routes for wildlife or isolates local populations of already endangered species, fragmentation problems have been highlighted. At several places mitigation measures, such as fauna passages or fences, have already been implemented, and more are being planned. In reality, however, not all planned measures are implemented. In addition, new research has been initiated to fill gaps in knowledge, evaluate existing fragmentation pattern, and develop tools for the planning, design and maintenance of mitigation measures (see below).

### 5.3.1 Habitat loss

Inevitably, infrastructure causes a direct and indirect loss of nature because land is physically occupied or becomes inaccessible to wildlife. Public infrastructure facilities (road surfaces, railway surfaces) occupy about 0.7 % of the Swedish land cover (Statistics Sweden 1999). Seiler and Eriksson (1997) estimated that roads and road verges outside urban areas cover about 5000 $km^2$ of land. Railroads add approximately 150–200 $km^2$. Altogether, infrastructure in Sweden occupies an area of the size of all national parks combined (up to 1.5 % of the Swedish land surface). Disturbance and pollution effects that spread from roads and railroads cause considerably greater loss and degradation of habitat, which however has not yet been estimated (compare Section 5.3.3).

Additional loss of habitat can arise when road barriers are combined with natural dispersal barriers for wildlife (such as large lakes, rivers, large continuous agricultural areas, or built-up areas). The combined effect can lead to isolation of local populations, as has been discussed with respect to moose populations along the Baltic coast line that are partly separated from inland populations due to the highway E4 and the major railway (Helldin and Seiler 2002).

One rather simple way to illustrate the extent of habitat lost or affected by infrastructure is to quantify the land within a specified corridor along roads and railroads. For example, land cover composition in a 200 m wide corridor along public roads is dominated by coniferous forest. This is not surprising, as more than 50 % of the Swedish land cover is forest (Figure 4.4). However, agricultural or open land occurs more often in the corridor than expected from the overall contribution to Swedish land cover (Figure 5.10). This indicates that public roads are more often constructed in agricultural landscapes where human population density is higher than in forested landscape.

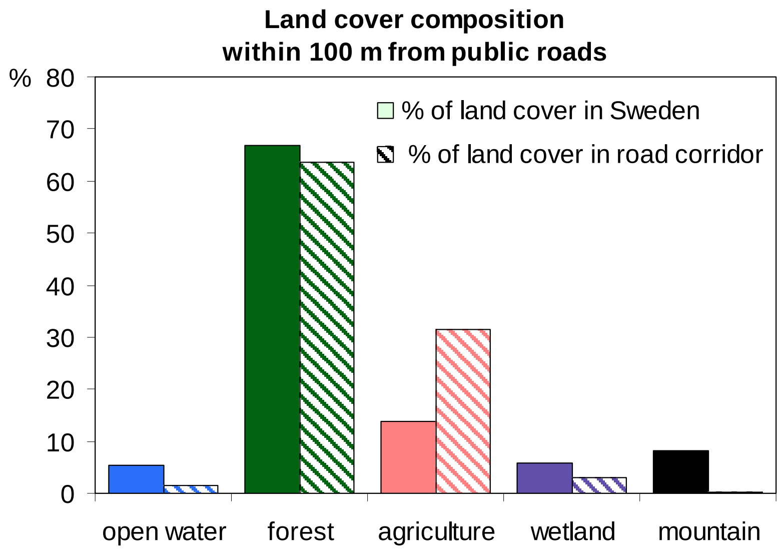


***Figure 5.10*** *Land cover composition in Sweden compared to land cover composition in a 100 m wide buffer zone at each side of public roads. (Source: A. Seiler, unpublished.)*

However, it must not be overseen that road verges and roadsides can introduce new habitats and thus even enrich landscape diversity. Roadside habitats can provide valuable resources to some wildlife species. For instance, if managed adequately, roadsides can comprise a refuge for rare grassland species (see the following section), or provide nesting and foraging sites to birds and by that compensate for the loss and disturbance of the original habitat. The effect of the road clearance on forest edges can also be favourable to some bird species and counteract the adverse effects of the road traffic or road maintenance (Helldin and Seiler 2003).

### 5.3.2 Corridor function

Road verges and roadsides are highly disturbed environments that suffer from pollution and the vicinity to traffic, but simultaneously they also have the potential to provide valuable resources. Over the centuries, road verges have thus been looked upon in very different ways. The peasant of ancient times saw a forage resource for his cattle in road verges and roadsides, and thus managed the vegetation so as to optimise forage production. With increasing motorized road traffic and decreasing interest in the verge as a hay producer during the last half of last century, verge management was reduced to removing biomass threatening traffic safety and the technical functioning of the road. The lack of mowing and grazing resulted in a gradual disappearance of low-growing plants and more favourable conditions for tall-growing species. For some time herbicides were applied to reduce biomass production but herbicide usage is forbidden in Swedish road keeping since many years.

Along with the rapid decrease in the managing of grasslands, the area of managed meadows has been reduced from over 2 million ha to 300,000 ha during the last 50 years (Figure 5.11). Roadsides as remnants of the disappearing meadow landscape have therefore attracted increased interest among naturalists. Roadsides along Swedish roads have been estimated to cover more than 200,000 ha, an area comparable to that of the island of Öland in the Baltic. During recent years, also the Swedish Road Administration has become increasingly aware of the biological value of roadsides, and a roadside flora has recently been published (Sjölund *et al.* 1999).

***Figure 5.11*** *Typical grassy roadside vegetation along a highway in Sweden. (Photo: Mats Lindquist.)*

During 1995 and 1996, the Swedish Road Administration conducted inventories to identify botanically valuable roadsides along the state-owned road network. This was done in accordance with a programme for biologically sound management of roadsides. Road stretches were classified in three categories: i) roadsides with very high botanical values (species-rich habitats and/or red-listed species); ii) roadsides with high botanical values (high species richness but not by its own determining the level of management); iii) existing and planned roads where the aim is to enhance the botanical values. Roadsides along some 6,000 km of roads were classified into these categories. Roadsides inhabited by up to 80–115 plant species were identified, making these roadsides comparable to the most species-rich "natural" meadows in Sweden. It has been estimated that one-third of the Swedish flora can be found in roadsides. The inventories have been published in a set of publications (Sjölund *et al.* 1999). Even if roadsides accommodate many species typical of meadows, it should be pointed out that roadsides *are* no meadows.

So far, the habitat and corridor function of roadsides has been addressed mainly from a plant-ecological point of view. Little is known about how animals move or live along roadsides, or how roadsides could be managed to provide habitat and corridors also for larger species. Traffic safety issues and management practices have yet required road verges and roadsides (within the fenced road corridor) to be open, not attractive to larger mammals or people and safe for vehicles to drive upon (in case of unintended deviation from the lane). The idea that road verges could contribute to the re-connection of wildlife habitats across otherwise open agricultural or urban landscapes is new but has been considered for instance for the metropolitan area around Stockholm.

### 5.3.3 Disturbance

Road traffic gives rise to pollution of air, watercourses, groundwater, soil and vegetation. Although most of the pollution effects are confined to the vicinity of roads, they have received much attention. Already during the early 1970's comprehensive research was conducted (*e.g.* Göransson *et al.* 1978; Bäckman *et al.* 1979). For instance, several studies addressed environmental effects of road de-icing salt on adjacent vegetation and groundwater. Discolouring and dieback of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) along winter-salted roads, for instance, is a common phenomenon in Sweden (Bäckman and Folkeson 1995). The effect of air-borne salt on exposed coniferous seedlings has recently been investigated in a doctoral work (Blomqvist 2001). Pollution due to deicing salt, heavy metals and other chemical toxins is mostly restricted to the vicinity of roads. Only a tiny share of these agents may spread over more than 100 m (Blomqvist 1998).

Disturbance effects on wildlife caused by other factors than pollution have so far received only little attention in Sweden. Recent studies may shed new light on this topic: For instance, on-going radio telemetry studies on wolf and lynx suggest that these species prefer to establish territories in areas of relatively lower road density (Jens Karlsson, Grimsö Wildlife Research Station). An on-going snow-tracking study on moose and roe deer indicate avoidance of trafficked roads (Seiler, A., unpublished).

Wallentinus (2000) compared the occurrence of birds and ungulates before and after a new stretch of highway E3 (north of Stockholm) was taken into use (15 years between the studies). The results were not consistent among species: for birds, some species (mainly opportunistic species such as wagtail, chaffinch, great tit and yellowhammer) had increased in abundance. Others (mainly thrushes, black grouse and to some extent owls) had decreased – noise was suggested to be the triggering disturbance factor. Some species did not seem to be affected at all by the presence of the road, *e.g.* willow-warbler, tree pipit and robin (Wallentinus 2000).

According to a Dutch study (Reijnen, R. *et al.* 1995), traffic noise is suggested as one of the main factors responsible for reduced densities of breeding birds near roads. Helldin and Seiler (unpublished) tested predictions made in the Dutch model under Swedish conditions. However, as in Wallentinus' study, the results differed largely between species but also between landscapes. In agricultural landscapes, reduced abundances of birds within the predicted disturbance zone were observed. In forested landscape, however, no general difference in bird abundance with distance from roads could be established. There was though a tendency for lower abundance close to roads in six species, but the opposite tendency was found in four other species. Accordingly, the predictions derived from the Dutch model were only partly correct, and it was concluded that the model might not be directly applicable in Sweden. It was suggested that habitat changes as a consequence of road construction under some circumstances could override the negative effects of traffic noise on the surroundings. Ecologically sound planning of infrastructure could thus not only reduce the adverse effects on nature but also enrich landscapes with new semi-natural elements (Helldin and Seiler, 2003).

Another aspect of disturbance from roads is due to the ecological contrast between road corridor and the adjacent habitats. Species that are adapted to the disturbed environment of the road corridor or introduced through roadside planting or traffic-mediated seed transportation may easily spread into the surrounding and compete with or prey on native species. As a consequence, species diversity near roads is often skewed towards a higher proportion of generalist and exotic species. Also, opportunistic species and predators are more likely to benefit from the disturbance effects (and the food provided by road casualties). As a consequence, one might expect increased abundance of generalist predators such as crows, badgers and foxes along road-forest edges and thus elevated predation rates on the fauna living alongside roads. Elevated predation rates along edges between forests and open fields have been documented in several other studies (*e.g.* Andrén and Angelstam 1988). To test this hypothesis, Forsberg and Helldin

(2000) studied predation rates on artificial ground nests placed in mature forest at different distances from major public roads. However, no difference in predation rate was observed in relation to the distance from roads.

Obviously, more empirical data is needed to predict the amplitude, the spread, and the consequence of disturbance effects from roads on wildlife. More studies must be carried out on different roads and species and in different landscapes, in order to define the width of the "road-effect zone" and develop a general tool for impact assessment.

### 5.3.4 Fauna casualties

Only little is known about vehicle collisions with other species than ungulates in Sweden. Field studies on wildlife road casualties date back to the 1960's (Bengtsson, 1962), providing first rough national road kill estimates  of between 550,000 and 20 million wild animals per year (Bolund 1974). Improved estimates were obtained through systematic road inventories during the mid 1970's in south-central Sweden (Göransson *et al.* 1978). This study suggested a minimum of 1.0 million casualties in birds and 0.5 million casualties in medium sized mammals (excluding small mammals and ungulates) at a national level each year. For most species, road mortality was considered being within tolerable limits, accounting for less than 5 % of the assumed population size. Since this study, however, traffic intensity has increased with about 50 %, the length of motorways has doubled, and the number of ungulate-vehicle collisions has multiplied (Seiler *et al.* 2004). It is reasonable to believe that road mortality has increased also in other species. Svensson (1998) estimated from his personal experiences of collisions with birds that road traffic in Sweden may kill 8 times more birds than previously suggested by Göransson *et al.* (1978).

Recently, a questionnaire with Swedish car drivers provided updated estimates of mammalian road kills (Seiler *et al.* 2004). The sudy suggested a nationwide loss of 7,000–13,500 moose (*Alces alces*), 43,500–59,000 roe deer (*Capreolus capreolus*), 63,500–81,500 hares (*Lepus* spp.), 22,000–33,000 badgers (*Meles meles*), and 6,500–12,500 foxes (*Vulpes vulpes*) for the mean reference year 1992 (Table 5.8). Among game species, the nationwide road-kill estimates represented between 7 % and 97 % of the average annual harvest, and between 1 % and 33 % of the assessed total population in 1992. The frequency of road-kills appeared to have increased over the past 40 years, probably because of changes in traffic volume and population sizes (game bags) (Seiler 2004). However, in badgers and hares, the ratio of the estimated road-kill to the annual harvest increased two fold, which suggests an increase in the relative importance of road mortality. Of course, the uncertainty in these estimates is large, but they are supported by other, independent estimates on animal-vehicle collisions and well in line with the official statistics on ungulate-vehicle collisions.

A prominent example of road-kills is the badger. Badger carcasses are a common sight along trafficked roads during spring and early summer. Between 25 % and 50 % of the badgers trapped and marked at the Tovetorp field station (Ahnlund and Lindahl 1980) and the Grimsö Wildlife Research Station (Seiler *et al.* 2003b) were killed by road traffic. Overall, road traffic is likely to be the largest single cause of death in this species, amounting to over 11 % of the living population annually (Seiler *et al.* 2004). This level of road mortality has been evaluated as being close to the critical threshold that the Swedish badger population can sustain without declining (Seiler *et al.* 2003b). Thus, although the Swedish badger population is considered as one of the largest in Europe (Griffiths and Thomas 1993) and although road traffic is relatively limited compared to other European countries (Trocmé *et al.* 2003), traffic already has a significant impact on Swedish badgers.

Road traffic is presumed to be an important cause of death in otter (*Lutrea lutrea*) and other carnivores. For example, 64 % of the 158 otter carcasses collected by the Swedish Museum of Natural History during 1975 to 1998 were killed in traffic, whereas 20 % starved (Swedish Road Administration 2000c). Twenty seven per cent of the 37 wolves (*Canis lupus*) collected by the Swedish Veterinary Institute between 1977 and 2000 died on roads and 16 % on railways. Twelve wolves had been shot illegally. In lynx (*Lynx lynx*), 16 % of the 375 known carcasses were due to traffic – 50 killed by cars and 9 by trains (Anonymous 2000). Of course, these numbers are skewed towards a higher proportion of traffic mortality, as animals killed on roads or railroads are more likely to be found and reported than animals that die elsewhere.

A more realistic picture on mortality factors can be obtained from marked animals. Radio telemetry studies in south-central Sweden indicate a somewhat lower contribution of traffic mortality. During the recent 4 years, 3 (11 %) out of 27 marked lynx were killed on roads, 4 were illegally shot, 5 were hunted and 4 died due to Sarcoptic Mange. Telemetry studies on moose indicate that traffic contributes between 6 and 12 % to the total moose mortality in Sweden; hunting responds for about 60–80 % (Cederlund and Wallin, personal communication).

Road accidents involving large ungulates are especially well documented in Sweden (Figure 5.12). Official police statistics on ungulate-vehicle collisions derive from a road accident database that was held by the Swedish Road Administration during 1970 to 1999. The problem with increasing ungulate-vehicle collisions was highlighted already during the late 1960's (Anonymous 1971) when they accounted for 19 % of all police reported road accidents. In recent years, this percentage has climbed to over 60 % and police reported ungulate-vehicle collisions amounted to over 5,000 moose, 25,000 roe deer, 2,000 reindeer (*Rangifer tarandus*), and approximately 1,000 other ungulates each year (Lavsund and Sandegren 1991, Seiler 2004). This increase coincided with a doubling in traffic volume since 1970, but more important for the trend and the large-scale spatial pattern in collisions was the increased abundance of moose and roe deer.

***Figure 5.12*** *Vehicle collisions with roe deer are frequent in Sweden. Road railings and exclusion fences can slow down animals that try to leave the road surface, which will increase the risk of accidents. (Photo: Andreas Seiler.)*

However, official road accident statistics systematically underestimate the true number of ungulate-vehicle collisions, because not all collisions are detected by the driver, reported to the police, or registered by the Swedish Road Administration (Almkvist *et al.* 1980). Studies during the 1970's suggested that about 25 % of all ungulate – vehicle collisions involving human injury, and approximately 60 % of all ungulate – vehicle collisions with material damage only, are not filed by the Swedish Road Administration. Collisions with moose on highways are more likely to be registered than collisions with roe deer on county roads. However the pattern was not conclusive and the authors recommended to assume a standard proportion of 60 % unregistered collisions (Almkvist *et al.* 1980).

***Table 5.8*** *Estimates of the total number of animal-vehicle collisions in Sweden during 1992 based on a questionnaire with Swedish car drivers (Seiler et al. 2004). Game bag statistics and population estimates obtained from Anonymous (1992). MCF = Mean collision frequency per 100 km road.*

| Species | N | MCF | road kill in 1992 with 95% C.I. | game bag 1992 | road kill % game bag | population size 1992 | road kill % population |
|---|---|---|---|---|---|---|---|
| **Moose** | 37 | 0,15 | 10 000 | 99 372 | 10,1 | 250 000 | 4.0 |
| *Alces alces* | | | *7000-13500* | | *7.1-13.6* | | *2.8-4.5* |
| **Roe deer** | 188 | 0,77 | 51 000 | 372 050 | 13,7 | 1 000 000 | 5.1 |
| *Capreolus capreolus* | | | *43500-59000* | | *11.7-15.9* | | *4.4-5.9* |
| **Hares** | 270 | 1,11 | 72 500 | 207 200 | 35,0 | 800 000 | 9.1 |
| *Lepus spp.* | | | *63500-81500* | | *30.6-39.3* | | *7.9-10.2* |
| **Badger** | 102 | 0,42 | 27 500 | 28 100 | 97,9 | 250 000 | 11.0 |
| *Meles meles* | | | *22000-33000* | | *77.5-118.1* | | *8.7-13.3* |
| **Red fox** | 34 | 0,14 | 9 000 | 31 300 | 28,8 | 100 000 | 9.0 |
| *Vulpes vulpes* | | | *6500-12500* | | *20.3-40.3* | | *6.4-12.6* |
| **med. sized mustelids** | 17 | 0,07 | 4 500 | 62 052 | 7.3 | 365 000 | 1.2 |
| *Martes martes, Mustela spp.* | | | *2500-7000* | | *4.1-11.4* | | *0.8-2.2* |
| **Rabbit** | 32 | 0,13 | 8 500 | 71 500 | 11.9 | 150 000 | 5.7 |
| *Oryctolagus caniculus* | | | *5500-12000* | | *8.0-16.6* | | *3.8-7.9* |
| **Squirrel** | 93 | 0,38 | 25 000 | - | - | 200 000 | 12.5 |
| *Sciurus vulgaris* | | | *20000-30000* | | | | *10.1-15.1* |
| **Hedgehog** | 38 | 0,16 | 10 000 | - | - | - | - |
| *Erinaceus europaeus* | | | *7000-14000* | | | | |
| **Domestic dog** | 10 | 0,04 | 2 500 | - | - | - | - |
| *Canis familiaris* | | | *4500-14000* | | | | |
| **Domestic cat** | 60 | 0,25 | 16 000 | - | - | - | - |
| *Felis catus* | | | *12000-20500* | | | | |

Although most data on traffic related mortality in animals concerns roads, it should not be forgotten that many animals are killed through collisions with trains. Radio-telemetry studies on over 400 moose from four regions in Sweden suggest that trains may account for up to half of all traffic related mortality in moose (Wallin, K. and Cederlund, G., unpublished data).

The Swedish National Rail Administration has not yet granted permission to make inventories of train-animal collisions along railway lines. Since 2000, however, train-driver reports on animal-related issues are compiled and filed by the Swedish National Rail Administration. Preliminary analyses of these first statistics suggest that trains may kill at least 1,000 roe deer and 900 moose each year. Moose accidents on railways may thus be 4 to 5 times as frequent as on public roads (Seiler, C., unpublished). However, it is unknown to what degree these official reports represent the true number of animal kills and whether this relation also applies to other species than moose and roe deer.

A recent study from the Northern railway region provides more detailed information: Between January and June 1999, trains in this region hit 117 moose and 643 reindeer. During this period, collisions with larger wildlife produced a loss of more than 2.2 million SEK (262,000 €) due to train delays, repairs of trains, and costs for the loss of animals and the personnel removing the carcasses (Johansson and Larsson 1999). In the Northern railway region, approximately 5 moose get killed per 100 km railway and year, with peak rates during winter (Figure 5.13). For comparison, car traffic on public roads in northern Sweden causes less than 3 moose casualties per 100 km and year.

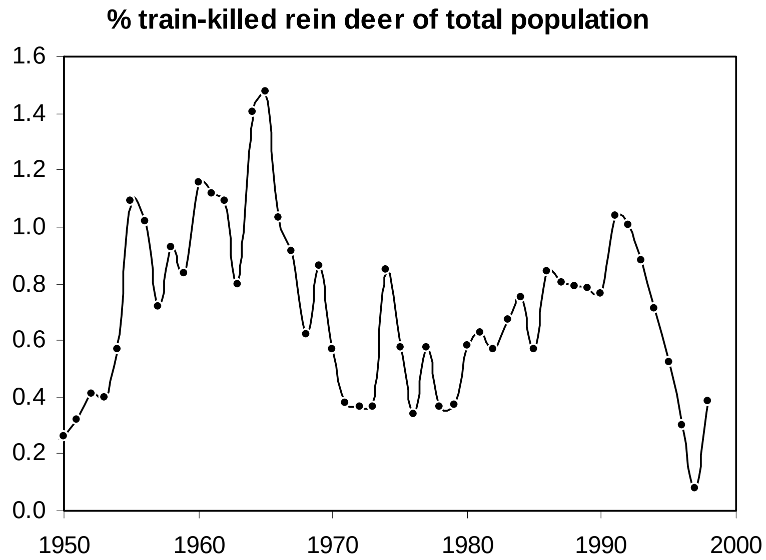


***Figure 5.13*** *Official records on train – reindeer collisions in the Northern Railway Region in Sweden. (Source: Åhrén and Larsson 1999.)*

### 5.3.5 Barrier effect

Relatively little is known about the barrier effect of roads and railroads on terrestrial fauna in Sweden. Although some studies give evidence of some barrier effect on wildlife, there are no studies that have actually quantified the amplitude of the effect in relation to species, road width, traffic intensity or other parameters. However, during recent years, a number of field studies and inventories have been started to measure mortality as well as barrier and disturbance effect of trafficked roads on larger mammals. Much focus has been on the moose, because of the increasing amount of road fencing and because it requires probably the widest passages of all mammals. Besides for moose, some effort has been put into reducing barrier problems for otters, amphibians and fish (see below).

At Grimsö Wildlife Research Station, for example, radio-tracking studies on wolves and lynx revealed that these large carnivores did easily cross highways and motorways but preferred to establish territories in areas where the density of roads was lower than expected by random (contact: Jens Karlsson). On-going snow-tracking studies at Grimsö Wildlife Research Station shall quantify the effect of traffic on movements of large and medium sized mammals across roads (contact: Andreas Seiler). At the

University of Karlstad, a radio-telemetry study on moose movements in relation to highway E6 and a recently built overpass shall reveal the efficiency of the overpass and the effect of fencing and traffic volume (Figure 5.14, contacts: Mattias Olsson, Per Widén).

Evidence of barrier impact on moose and its consequences to forestry have been documented in the High Coast Project (see Section 5.5.3; Seiler 1999c; Seiler *et al.* 2003a). Similarly, Ball and Dahlgren (2002) studied whether roads, fences and forest composition influence the use of young pine stands by moose. Moose browsing increased with pine-tree density, site productivity and proximity to a highway. This suggests that browsing damages on pine trees may increase as moose accumulate in the vicinity of road barriers.

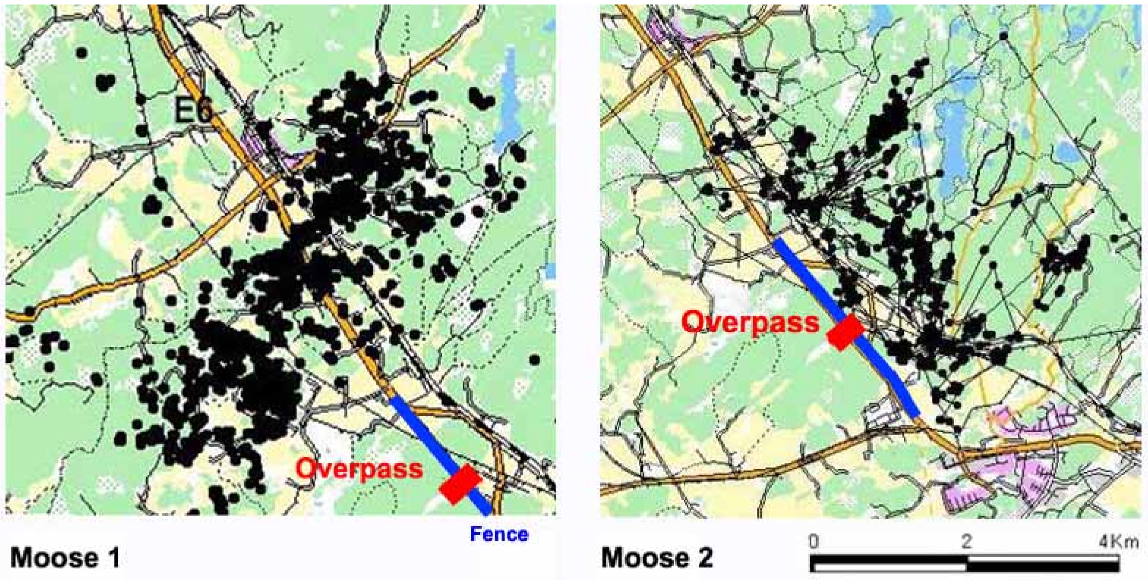


***Figure 5.14*** *Movements of two radio tracked moose in relation to the overpass over highway E6 north of the city of Uddevalla on the west coast. Where the highway is unfenced, moose 1 frequently uses habitats on either side of the road. Near the overpass, exclusion fences (indicated by blue colour) prevent moose 2 from crossing the highway (provided by Mattias Olsson, University of Karlstad).*

Much consideration has be given to the barrier effect of culverts and bridges on aquatic and semi-aquatic animals in Sweden (Sandell *et al.* 1994; Hammar 1996). Numerous inventories suggested that more than half of the existing culverts under private forest roads and public roads may be misplaced and can impose movement barriers to fish (Grahn and Öberg 1996; Abrahamsson and Pettersson 1997; Spansk 1997; Bergengren 1999). Inventories in the county of Västernorrland showed that 88 % of all culverts constituted some kind of barrier to aquatic fauna and 30 % of all bridges over rivers were not adapted to otters. Altogether, creeks and rivers in this county appeared to be highly fragmented due to crossing roads, railroads and other physical barriers. On average two fish barriers and three barriers for other aquatic fauna exist per 10 km of river (Bergengren 1999).

Recent inventories in the Uppland region revealed that about 66 % of all road and railway bridges were badly adapted to the needs of otters. One-third of the roads carried heavy traffic and thus comprised potential high-risk elements in the otters' home range (Hammar 1996). Otters are often reluctant to cross under narrow bridges or culverts where they cannot place markings, and prefer to climb up across the road or railroad. Due to this behaviour, otters are exposed a high mortality risk (compare Section 5.3.4).

### 5.3.6 Fragmentation

Infrastructure in Sweden is generally not considered as a severe threat to wildlife – at national level. Road casualties in moose and roe deer, for instance, make up some 10 % of the annual game bag (Table 5.8). In most mammals, road traffic probably kills less than 10 % of the overall population, although there are exceptions such as the badger or the hedgehog. Species with large individual home ranges and small population sizes (such as wolf and lynx), and species with pronounced migratory behaviour (such as many amphibians, and moose in northern Sweden), are however especially exposed to infrastructure and more sensitive to losses and isolation than are smaller and abundant species (compare Section 5.3.6).

Fragmentation effects at landscape (population) level have been addressed in large carnivores (Karlsson, J., Grimsö Wildlife Research Station), moose (Helldin and Seiler 2002) and amphibians (see below). Fragmentation effects relate to the network of roads and railroads rather than to single infrastructure links. Thus, it is the joint effect of many roads, their density and distribution in the landscape – and in combination with other factors such as built-up areas or topographic features – that has to be measured and evaluated (compare Section 5.3.6).

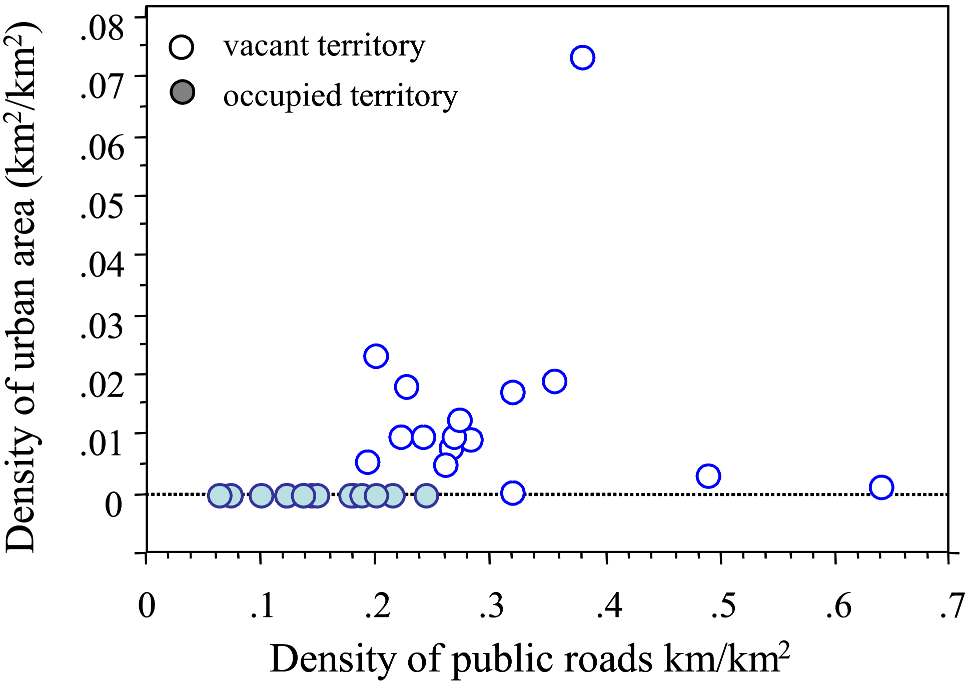


***Figure 5.15*** *Density of urban areas and roads within territories occupied by wolves and randomly distributed "vacant" territories. A Minimum Convex Polygon (MCP) around all wolf territories in Scandinavia was used to define the study area. Polygons with the same size and shape as the wolf territories were randomly distributed over the MCP but not allowed to overlap real wolf territories. The density of roads and built-up areas was then measured inside the polygons. Logistic regression was used to analyze the data. (Source: Karlsson, J. et al., unpublished data.)*

For example, on-going radio-telemetry studies on wolves (contact: Jens Karlsson) suggest that areas with road densities above 0.25 km/km$^2$ are unfeasible for the establishment of wolf territories (Figure 5.15). However, more important than road density is the density of urban areas for the establishment of wolf territories (Figure

5.16). It is thus not the roads *per se* that compose a problem to wolves, but the presence of humans (Karlsson *et al.* 2004).

Fragmentation effects of infrastructure have also been studied on amphibian populations. For example, a study on the common frog (*Rana temporaria*) in the urban area around Stockholm showed that the presence of trafficked roads near breeding ponds has strong influence on the extinction probability of local frog populations in the metapopulation (Sjögren-Gulve 1995; Figure 5.17). It appears likely that also in other areas, such as southern Sweden, infrastructure contributes to the overall decrease in amphibian numbers.

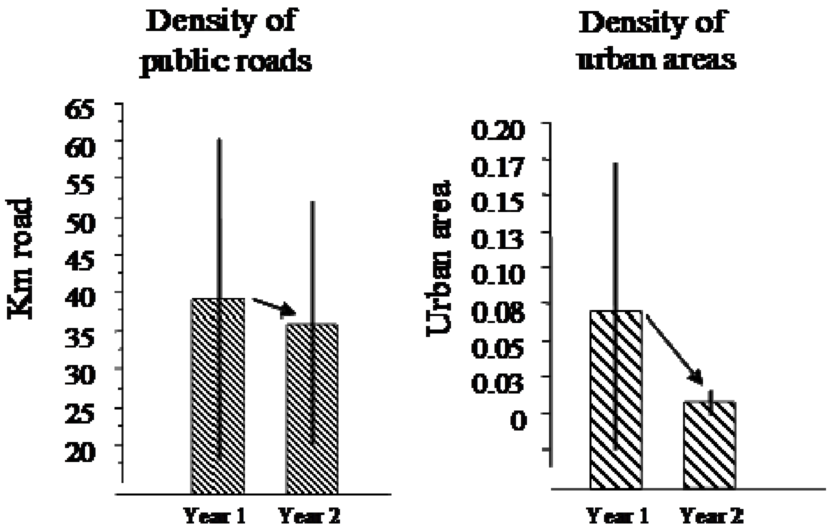


***Figure 5.16*** *Wolf territories change in size and composition over time, which illustrates habitat preferences. Three years after the establishment of new wolf territories in Sweden, these territories contained signicantly less urban areas than during the first year of their establishment but were indifferent with respect to road density. (Source: Karlsson, J. et al., unpublished data.)*

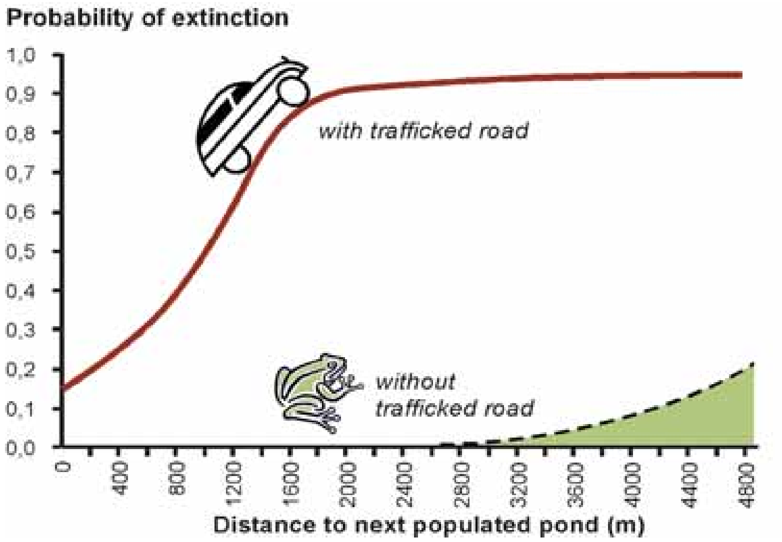


***Figure 5.17*** *Likelihood of local extinction of common frog populations in the Stockholm area in relation to the distance from the closest populated breeding pond and the presence of trafficked roads within 200 m of the focal pond. Redrawn after Sjögren-Gulve (1995).*

### 5.3.7 Environmental bottlenecks

Environmental bottlenecks with respect to infrastructure barriers have not yet been officially identified in Sweden, neither at national nor at regional scale. Suggestions have been made, though, mostly related to large-scale natural barriers such as lakes or coastlines and the artificial barriers imposed by the major motorways and trunk railroads. For instance, the region between the large lakes Vänern, Vättern and Hjälmaren in south-central Sweden is considered as an important dispersal corridor for large carnivores progressing from northern to southern parts of the country. This large-scale dispersal corridor is crossed by the major infrastructure links between the metropolitan areas of Stockholm, Örebro and Karlstad/Göteborg. So far, however, there is no evidence that the motorway and the railroad actually impede carnivore dispersal southwards.

River valleys in northern Sweden can be considered as another type of natural bottlenecks. Undoubtedly, a great ecological role can be ascribed to the long valleys of the numerous rivers falling into the Baltic Sea. These valleys, often used for agriculture in much of their length, have always facilitated inland colonisation and migration movements of plants and animals as well as people through the surrounding forest. Likewise, relatively good movement facilities have been offered by the low continuous coastal areas, usually limited in breadth. This pattern is intersected by modern infrastructure running mainly from south to north, causing a repeated accumulation of environmental conflicts from valley to valley. Otters dispersing along the river system, as well as moose migration routes, follow the landscape pattern, which causes increased risk for collisions between vehicles and wildlife at the crossing points. Recent highway and railroad projects in this region have therefore paid special attention to wildlife movements (*e.g.* Schibbye *et al.* 1995; Borgenstierna 1999).

At a more 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, wildlife casualties on near-by roads, as well as the experiences of the local hunters. So far, predictions from these studies could not yet been tested.

## 5.4 Secondary effects of transport infrastructure

Typical secondary effects of road constructions are the development of out-of-town establishments, the opening up of formerly undisturbed areas to leisure activities and the deforestation of remote forests. These secondary effects express themselves in a range of ways: Out-of-town establishments, for instance, cause landscape severance, habitat loss, disturbance from traffic and other human activities and deteriorate the quality of adjacent wildlife habitats. As opposed to the societal and economical consequences of these establishments, their ecological consequences are widely neglected in the planning of infrastructure. No tools for prediction or evaluation of secondary effects in the course of strategic environmental assessments have yet been deployed in Sweden.

A typical secondary effect that follows the construction of new highways or trunk roads is the expansion or alteration of forest-road networks. The result is often the deforestation of extensive areas formerly little influenced by man, also in very remote areas. Loss and radical change of habitats is an obvious effect, but disturbance, albeit transient, from machinery used in deforestation is an additional effect that receives very little attention. Improved access to remote area by new forest roads also increases illegal hunting and persecution of large carnivores. The problem is most recognised in the northern parts of Sweden where terrain scooters are frequently used for out-door leisure activities. The snow-scooter accessibility to formerly undisturbed wilderness areas has increased greatly in recent years. However, the nuisance from leisure scooter traffic has now initiated public debate. Interestingly, snow-scooter traffic for leisure purposes is prohibited in the neighbouring countries Norway and Finland (see Figure 5.2).

The establishment of road and rail infrastructure is also thought to give rise to extensive changes in the use of agricultural land. Suggested effects include agricultural land being abandoned either due to the dissection of fields by the new infrastructure, or due to the obstruction (or limitation) of the access to agricultural land beyond the road or railway. Few hard data are available to support or reject this theory, however. No data thus exist on the possible abandonment of agricultural land due to road and rail construction. It can be argued that this area is negligible in relation to the enormous area of tilled, meadow and grazed land having been abandoned due to $20^{th}$-century changes in the agricultural policy largely resulting from changing economical conditions world-wide (see Section 4.3). Also, where possible, roads and railways have largely been located to forested areas or to the border zone between forested and open areas. These facts seem to indicate that only a limited area of agricultural land has been abandoned solely because of infrastructure development. The situation might, of course, be different in areas where agriculture is the sole landuse, *e.g.* in parts of Skåne, Sweden's southernmost province.

## 5.5 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 (Göransson *et al.* 1978; Bäckman *et al.* 1979). Major gaps in (ecological) knowledge have been identified concerning, *e.g.*, 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 railroad, and methods to predict potential hotspots of ecological conflicts during the planning phase. Also, further improvement is needed to the design and implementation of mitigation measures, as well as the quality control of existing measures through follow-up studies.

Concepts for ecological impact evaluation have been presented (*e.g.* Eriksson and Skoog 1996; Seiler and Eriksson 1997), and a great variety of new studies have been initiated to produce quantifiable data for the development of indicators and evaluation tools. These studies can roughly be distinguished into the following categories:

1. Project-related follow-up or monitoring studies of impacts and/or mitigation measures (case studies)

   Follow-up studies are linked to project specific problems and mainly financed within the road or railroad project. They may be part of the EIA work of the infrastructure project. These studies are not designed to answer to general questions about impacts and effects but may add to the collection of empirical background data. So far, no scientific quality control has been required for these studies.

2. Problem-oriented field studies or simulation models

   These studies are generally designed to answer a specific question and develop new empirical knowledge on effect thresholds and relationships. They are thus not (necessarily) related to a particular road project or location. Some of these studies are combined with other scientific research projects, however.

3. GIS studies with remotely sensed landscape data

   Spatial analysis of existing empirical data combined with remote sensing provides a new approach to ecological impact evaluation at landscape scale. So far, only few studies have involved GIS and more basic research is needed to validate potential indicators and evaluation criteria.

4. Implementation / test in actual infrastructure projects (planning and/or construction)

   Several attempts have been made to apply the existing knowledge from research and EIA projects on planning procedures and the identification of the need for more detailed research.

5. Development of indicator systems and evaluation methodology

   Critical to the development of techniques and methodology for an ecological impact assessment is the translation of empirical data, models and field experiences into measurable criteria. Such criteria are to be derived from environmental policies and mitigation plans and quantified in GIS studies or field inventories.

The rest of this chapter gives some examples of important studies concerning wildlife in Sweden.

### 5.5.1 Case study: Highway 31

Follow-up studies have so far been fairly rare in Sweden. One of the few properly planned baseline studies has been performed to collect biological data prior to the construction of national highway 31 in a hilly coniferous forest area rich in wildlife near Jönköping, southern Sweden (Folkeson and Seiler 1996; Seiler and Folkeson 1996; Helldin and Seiler 2003). Data on the occurrence of wildlife, birds and vegetation before the construction of the road have been collected for 3 years. To collect baseline data to which the foreseen barrier and disturbance effects of the planned road on mammals could be compared, snow tracking has been performed in two lines at 50 and 250 m on each side of a 4-km stretch of the planned road. To estimate any future change in habitat use of mammals in a 3x4 km area, droppings have been registered in hundreds of circles sized 100 $m^2$ for moose and 10 $m^2$ for roe deer and hare. Breeding birds have been registered by identifying the singing of birds from observation points located at lines 100 and 300 m on each side of the future road.

Few years after the completion of the road, which was planned for 2001 or 2002, the study will continue. In addition to the inventories that have been conducted during the baseline study (1997–2000), inventories on traffic casualties will be performed. The use of the planned fauna passages will be studied by video and track counts. Finally, a complete evaluation of the observed changes in wildlife movement and density will be made. The final report is estimated to occur in about 2005 or 2006.

### 5.5.2 Case study: The Ring road around Malmö

In order to follow up the influence of the establishment of the Ring road around Malmö, southernmost Sweden, on local animal populations, a baseline study was started in 1997. The Ring road connects motorways with the Öresund Bridge which was opened in July 2000. This very flat and open area is characterised by intense agriculture in the close vicinity of the urban area of Malmö and suburbs. Two bird breeding areas rich in species have been dissected by the Ring road (dual-carriage motorway). To mitigate the effects of this barrier, man-made habitats extending beneath the motorway have been constructed to re-connect the dissected habitats. In this way, novel habitats were created but, on the other hand, birds could fall victim to car collisions. The chosen mitigation measure might thus impose positive as well as negative effects on the bird populations.

The study commenced in 1997 by the establishment of five investigation areas where inventories of small birds, pheasants and field hares were performed and parts of the hedgehog population were tracked during the breeding season. Radio-tracked hedgehogs were shown to move over areas of varying size. Some of the hedgehogs utilised habitats on land that was to be taken for the construction of the Ring road. The hedgehogs inhabiting these areas were supposed to be killed by cars within one year of the opening of the motorway. Apart from this, minor effects on animal populations were expected. The long-term value of the two planned wildlife underpasses will depend on the frequency with which they will be used by ground-inhabiting animals (contributed by Görgen Göransson, University of Kalmar).

### 5.5.3 Case study: Highway E4 in the High Coast area

The new highway E4 along the Baltic coast of northern Sweden cuts through seasonal migration routes of moose (*Alces alces*) that move several kilometres between summer habitats in the inland and coastal winter habitats. Large seasonal differences in moose densities together with high numbers of moose-vehicle collisions suggested a strong migratory behaviour. To counteract barrier effects of the fenced road and increase traffic safety, two moose underpasses and several broadened road underpasses have been constructed. As the road was opened for traffic in 1997, a monitoring study was initiated to evaluate the effect on moose and the efficacy of fences and underpasses. The study contained mark and recapture of moose, estimation of moose density by faecal counts, inventories of browsing damages and available forage, snow tracking along the road, and track counts in underpasses. During winter, migrating moose accumulated west of the highway barrier, reaching densities of more than twice that of the eastern, coastal habitats. Browsing damages on young forest stands west of the road consequently increased from 5 % to over 40 % during the three-year study period. Underpasses were used only occasionally by moose (about 1.5 tracks per month) and there was no seasonal or directional difference in the frequency of tracks. This suggests that only stationary but not migratory moose were utilizing underpasses. In addition, snow tracking revealed that many moose were reluctant to enter the underpasses and instead preferred to cross the fenced road. The conclusion was drawn that the mitigation measures have not been effective in counteracting the barrier effects of the new highway. The project was commissioned by the Swedish Road Administration and was conducted between 1998 and 2000. It was planned and organised by Grimsö Wildlife Research Station, SLU (Seiler 1999b; Seiler *et al.* 2003a).

### 5.5.4 Case study: Moose overpass over highway E6 near Uddevalla

In 2002, the University of Karlstad started to study effects of fauna passages. The main aim of the project is to study the relationships between wildlife, motorways and fauna passages. To what extent are fauna passages used by different species, and can the fauna passages reduce barrier effects in a landscape split by fenced motorways? Different constructions and their efficiency as wildlife crossings will be evaluated. This is being done by GPS monitoring of moose, camera monitoring of fauna passages and track counts to examine passage intensity of moose, roe deer and other wildlife through different types of passages along the highway (E6 in the province of Bohuslän). Data from GPS radio collared moose (a total of 20 moose) will be used to study movement in relation to the highway and the wildlife crossings. Location of moose is recorded every two hours for up to 21 months for each moose. A camera documents moose activity on the overpass so that the behaviour, gender and age classes of moose using the overpasses can be documented. The results will be used to support the development of the design, size and placement of future wildlife crossings. The project will run for five years until the end of 2006.

### 5.5.5 GIS study: Ecoways

The project Ecoways contains several sub-studies that contribute to a PhD study on fauna casualties (A. Seiler, unpublished). 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. This is done by i) identifying and mapping of conflict points between roads and the ecological infrastructure in the landscape, ii) mapping and GIS analysis of hotspots of fauna casualties, especially moose—vehicle collisions, iii) field inventories of wildlife barriers and passages such as culverts, tunnels, bridges and overpasses, and iv) evaluation of the need for improvement and mitigation measures using data on fauna casualties as indicators of the quality of the barrier effect. Spatial reference data are provided by statistical databases of the Swedish Road Administration and thematic satellite images (Landsat TM).

The project has been planned in co-operation between Andreas Seiler (Grimsö Wildlife Research Station, SLU), Lennart Folkeson (VTI) and Anna Ward (Swedish Road Administration).

### 5.5.6 GIS study: ECLIPS – Ecologcial planning of infrastructure with remote sensing

This project comprises a framework for a series of different on-going studies and shall help improve the development of spatial evaluation criteria for ecological and cultural values in the landscape. Through the combination of ecological (mostly fauna-related) and cultural (historical) values, the project uses a holistic approach towards landscape analysis.

Most of the background data derives from satellite imagery in combination with field inventories and existing landscape data. Results from empirical studies shall be combined with the spatial landscape data to a GIS-based planning tool. The project involves researchers from different universities in Sweden. A final report is in progress (Nordström *et al.* 2003) (Contacts: Anders Sjölund, Swedish Road Administration, and Jan Skoog, Swedish National Rail Administration).

### 5.5.7 Research project: Fauna casualties

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 identify and evaluate the risk for fauna casualties and find adequate mitigation measures. Data on casualties is collected through field inventories along public roads in south-central Sweden. Other ways of data collection are under discussion. Landscape data is combined from Landsat TM satellite images, thematic satellite maps and topographic maps. Road and traffic data is provided by the Swedish Road Administration.

Fieldwork started in September 2000; a pilot study had already been conducted during summer 1999. The project is financed by the Swedish Road Administration and intended to run for at least two years. Project leaders: A. Seiler and J-O Helldin, Grimsö Wildlife Research Station.

The Swedish Road Administration intends to provide a web-based database on concluded and on-going research projects in the near future. More information is or will be available at:

URL: http://www.vv.se and URL: http://www-grimso.slu.se/research/roadsandwildlife.

### 5.5.8 Conference: The 2nd Nordic Conference on Wildlife and Infrastructure

In May 2003, the 2nd Nordic Conference on Wildlife and Infrastructure was held during the in Malmö, Sweden. The conference was organised by the Swedish Road Administration and the Swedish National Rail Administration, in co-operation with The Swedish University of Agricultural Sciences, Grimsö Wildlife Research Station. The goal was to update knowledge about the topic of wildlife and transport among Nordic countries and improve implementation of wildlife concern in the planning, construction and maintenance of infrastructure.

The conference was initiated by an internet-based discussion introducing the topic and helping to focus on the most relevant questions. During a two-day conference, 65 researchers, engineers, planners and decision makers from the four Nordic countries Denmark, Finland, Norway and Sweden met in Malmö to exchange experiences, discuss new approaches and improve Nordic co-operation. The conference was concluded with excursions to the new Ringroad around the city of Malmö and a motorway construction site near the town of Örkelljunga.

The conference expressed the need for improved communication within and among authorities and countries. It was recommended to establish a Nordic Group of Experts that could organize annual workshops, regular conferences and maintain a common Internet site in order to promote Nordic and international cooperation. These activities were seen complementary to the European cooperation of the Infra Eco Network Europe (IENE).

More information (in Swedish) about the conference and its resumé can be obtained from http://www.vv.se/templates/page3_459.aspx.

## Chapter 6. Minimising Fragmentation through Appropriate Planning

In 1999, the Swedish government adopted a radical goal for the road safety work: ”*The long-term goal for the road safety shall be that no person shall be killed or severely injured due to traffic accidents. The design and function of the transport system shall be adapted to the demands that follow from this*.” (Swedish Road Administration, 2000a).

This implies, with the protection of human life and well-being as the basis, for the Swedish Road Administration to create a road environment that minimises the risk of road users making mistakes and prevents serious human injury when designing, operating and maintaining the state road network. It also implies the need of thorough analysis of accidents that have resulted in death or serious injury in traffic and, where feasible, the initiation of suitable measures so as to avoid the repetition of such accidents. Due to this focus on human life, however, animal related accidents have lost much of their significance to road planners. Statistics on ungulate – vehicle collisions have been collected and stored by the Swedish Road Administration between 1970 and 1999. Since 1999, only accidents that involve human injury or death are registered, which is less than 5 % of all police reported ungulate – vehicle collisions. Before that change, the Swedish database on road accidents was dominated (>60 %) by animal related accidents (Seiler 2004). In the northernmost county, ungulate – vehicle collisions made up more than 70 % of all road accidents. In contrast to non-wildlife related accidents, collisions with ungulates have become extremely frequent in Sweden. On an average day, approximately 12 passenger cars collide with a moose in Sweden, and 0.2 % of these collisions lead to injuries for the driver or the passengers. About 70 collisions with roe deer are recorded on an average day, yet less than 1 % leads to personal injuries (compare Section 5.3.4; Figure 6.1, Figure 6.2). Each year, about 12 people are killed and more than 600 are injured in animal related road accidents in Sweden. However, this is less than 10 % of all road accidents involving human injury or death (Table 6.1). The true percentage, however, is likely to be smaller, as most accidents without severe damage to vehicle or human life are not reported. Also, the proportion of ungulate – vehicle collisions involving human injury or death in Sweden decreased from 5 % in 1983 to 2.2 % in 1999 (Swedish Road Administration database). This decrease contrasts the growing rate of human injuries in other, non-wildlife related road accidents (+20 %) and may approve for some beneficial effect of the mitigation efforts taken so far (compare Section 7.3.2).

Most of the animal-vehicle collisions that lead to human injury (78 %) involved moose. The large shoulder height of moose (up to 2 m) and the heavy body weight (ca. 500 kg) can result in collisions where the whole body mass of the animal strikes directly against the windshield pillars and the front roof of the vehicle. Such accidents can cause severe head and neck injuries to front seat passengers (Björnstig *et al.* 1986).

Besides the body size of the moose, factors responsible for human injury in collisions are also to be found in driver behaviour, vehicle speed, vehicle design and visibility along with the road (Almkvist *et al.* 1980). Lavsund and Sandegren (1991) reported that an increase in vehicle speed from 70 km/h to 90 km/h can cause a threefold increase in the risk for human injury in ungulate – vehicle collisions. Many drivers do not pay much attention to roadsides or may not detect approaching animals in time. Tests with warning signs, flashing lights and moose dummies, placed alongside roads to alert drivers, revealed that a majority of signs were not even registered by the drivers (Åberg 1980).

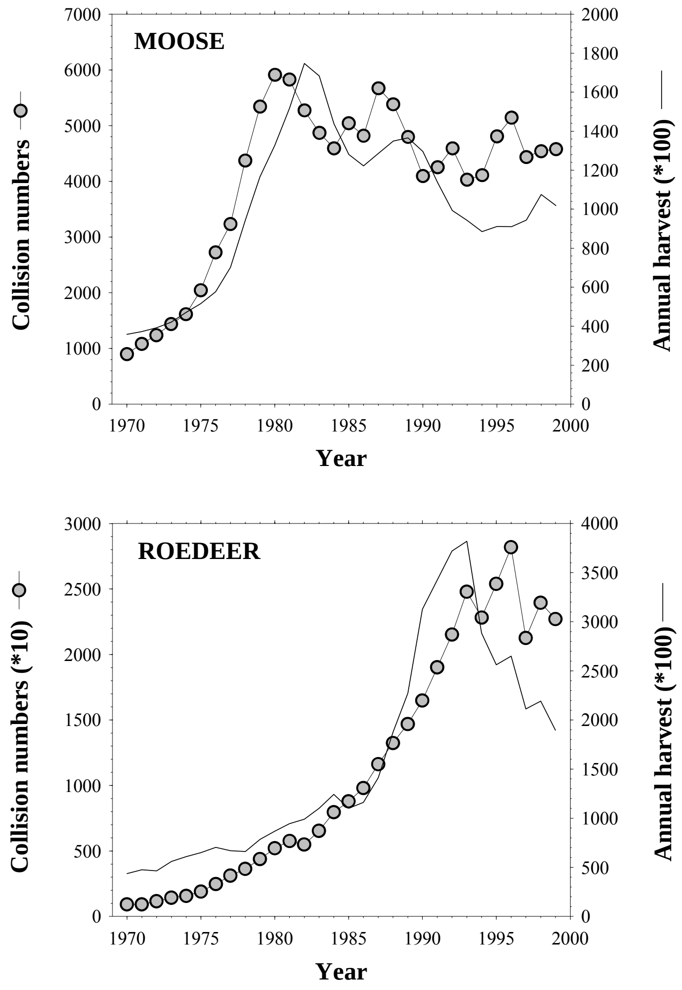


***Figure 6.1*** *Police reported road casualties in moose and roe deer in Sweden in relation to hunting statistics (from Seiler, 2004).*

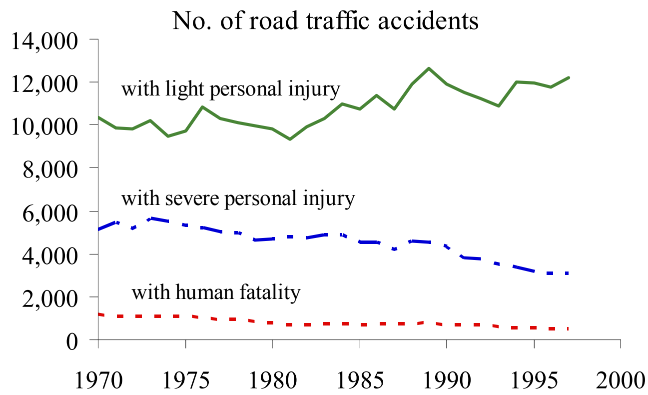


***Figure 6.2*** *Development of road accidents since 1970. (Source: Statistics Sweden 1999.)*

***Table 6.1*** *Police reported road accidents in 1997. (Source: Swedish Road Administration database.)*

| ***Cause*** | ***With human injury*** | | | | ***Without injury*** | ***Total*** |
|---|---|---|---|---|---|---|
| | **light** | **severe** | **lethal** | **sum** | | |
| Moose | *402* | *46* | *9* | 457 | 3,981 | 4,438 |
| Roe deer | *129* | *19* | *4* | 152 | 21,108 | 21,260 |
| Reindeer | – | *1* | – | 7 | 2,260 | 2,267 |
| Red deer | *6* | – | – | 6 | 265 | 271 |
| Wild boar | *1* | – | – | 1 | 89 | 90 |
| Other wildlife | *27* | *3* | – | 30 | 354 | 384 |
| Domestic animals | *12* | *3* | – | 15 | 628 | 643 |
| Unknown animal | *51* | *5* | *1* | 57 | 7 | 64 |
| **Sum animals** | ***634*** | ***77*** | ***14*** | **725** | **25,089** | **25,814** |
| Non-animal related accidents | *4,940* | *1,560* | *346* | 6,846 | 9,770 | 16,616 |
| *% Wildlife* | *11 %* | *5 %* | *4 %* | *10 %* | *72 %* | *61 %* |

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

## 7.1 Introduction

Avoidance, mitigation and compensatory measures can be viewed as three main categories of measures to counteract the problems of habitat fragmentation due to transportation infrastructure. Avoidance is the primary strategy to be chosen. If for instance valuable landscapes or habitats cannot be avoided in the planning of infrastructure, mitigation measures are to be taken. If mitigation measures such as fauna passages are not sufficient, compensatory measures can be taken so as to create, *e.g.*, a new wetland as a compensation for a destroyed meadow. There is no strict distinction between avoidance, mitigation and compensatory measures – rather there is overlap between the categories, and different measures are often used in combination.

## 7.2 Avoidance of habitat fragmentation

Avoidance can be said to have a long tradition in Swedish road planning. In many cases valuable habitats have been avoided thanks to a striving among at least some road planners to protect especially valuable natural areas or areas of particular beauty. Routing and design of the infrastructure to harmonise with the landscape is an old principle, even if there are numerous examples of insensitive localisation of roads in vulnerable landscapes (Nihlén 1966).

During the last decades, avoidance of the most valuable landscapes has become an increasingly adopted principle, even if there is an example of fairly recent road building in a national park (Abisko) in the far north. In road and railway planning on the strategic level, consideration is taken to especially valuable areas of national interest for, *e.g.*, recreation. The Environmental Code states that special consideration shall be given to the interests of tourism and outdoor recreation, in connection with assessments of the permissibility of development projects in a large number of small and large areas listed in this law.

## 7.3 Overview of mitigation measures

### 7.3.1 Fauna passages

Neither the Swedish Road Administration nor the Swedish National Rail Administration possesses a complete national overview of measures for fauna – either taken or planned. The existing record of built fauna passages and ecologically adapted culverts is certainly incomplete and still lacks a consistent quality control, but it is intended to be improved and competed in the near future. The register stretches back to 1997 and will be updated on a yearly basis (Table 7.1). During these years, 32 different types of measures have been taken to provide animals with possibilities to cross roads. Most of the measures are designed for smaller mammals such as otter, badger and red fox. Not included in this list are 49 culverts for creeks and small rivers that imposed movement barriers to fish but that have been replaced during 1997–2002. The Swedish Road Administration now makes recommendations on how to consider fish migration and otter movements when constructing roads – either private or public (Swedish Road Administration 2000 b, 2000c). Table 7.1 presents the number of fauna passages that have been registered by the Swedish Road Administration between 1997 and 2002.

Moose and deer passages include: 2 underpasses for moose under E4 in the High Coast area in 1997 (Figure 7.1, see also Section 5.5.3); one combined road-wildlife bridge over highway E6 near Uddevalla in 2000 (see Section 5.5.4), one viaduct for highway 35 (in 2002), and one underpass near Valdemarsvik (in 2002) built for a forest road but widened to support the use by wildlife. At Burlöv, southernmost Sweden, an overpass has been built for pedestrian and cycle traffic over the busy highway E6. The overpass has been planted with trees and bushes and enables animal passage between the urban/agricultural areas adjoining the overpass. Even if the passage has features in common with an ecoduct, it could rather be called a "socioduct" – in any case, it allows both pedestrians, cyclists and animals a passage over the motorway.

In the same area (Malmö), the motorway to the Copenhagen bridge has been equipped with a wide underpass where the natural vegetation and structure have been retained. The underpass connects recreational areas at both sides of the passage and serves both animals and pedestrians.

Registered amphibian passages include two fenced culverts built in 1998, one at Fjugesta and one at Nääs (contacts: Claes Andrén and Jens Malmgren), as well as one site in the province of Bohuslän and one on the island of Öland (contact: Anders Sjölund) where amphibians were captured and manually moved across the road.

These examples may illustrate the need for defining criteria that must be fulfilled in order to typify a construction as fauna passage. A preliminary list of such minimum criteria for fauna passages has already been been proposed (Sjölund, personal communication).

***Table 7.1*** *Numbers of fauna passages for terrestrial wildlife built in Sweden during 1997–2002. (Source: Swedish Road Administration annual reports.)*

| Number of passages for … | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | Total |
|---|---|---|---|---|---|---|---|
| moose and deer | 2 | 0 | 1 | 1 | 0 | 2 | 4 |
| otters and small mammals | 0 | 0 | 5 | 5 | 8 | 6 | 24 |
| amphibians | 0 | 2 | 0 | 0 | 0 | 2 | 4 |
| Total | 0 | 2 | 6 | 6 | 8 | 10 | 32 |


***Figure 7.1*** *Moose snow tracks at the entrance of one of the moose underpasses constructed under highway E4 in the High Coast area in northern Sweden (A). Moose often avoided entering the underpass (B). Some individuals turned around exactly at the entrance (C). Snowtracks suggest that moose may have been scared away from the underpass, maybe by passing vehicles. (Photo: Erik Ringaby.)*

In the spring of 2000, the first overpass especially adapted to ungulates was taken into use in Sweden (Figure 7.2; see also Section 5.3.5). It consists of an overpass over highway E6, a dual-carriage motorway on the west coast. The overpass was originally planned merely for a local access road to a single farm situated close to the motorway. To facilitate passage for moose and roe deer, the bridge was broadened to 16 m at the waist and 21 m at the openings (the original bridge was planned to be 5 m wide). The bridge spans over 60 m. The sides are covered with a 2 m high gray opaque glass screen that reduces the noise from vehicles and prevents the animals from viewing the motorway. Glass screens were chosen for aesthetic reasons. The overpass is provided with sand surfacing on both sides of the gravel road. The moose fence and planted vegetation at the entrances are supposed to lead the animals towards the bridge. The use of the bridge is being studied by means of radio-telemetry and tracking. The first results show a frequent usage by both moose and roe deer (Figure 7.3) (Olsson and Widén, unpublished).

***Figure 7.2*** *The first road overpass in Sweden adjusted for moose located at highway E6 near Uddevalla on the west coast. (Photo: Mattias Olsson.)*

***Figure 7.3*** *Snapshot of a moose slowly walking across the overpass at highway E6 near Uddevalla in May 2003. (Photo: Mattias Olsson.)*

### 7.3.2 Fences

Various mitigation measures against ungulate – vehicle collisions have been tested on Swedish roads since the 1970's (*e.g.* Anonymous 1980, Björnstig *et al.* 1986, Skölving 1987, Lavsund and Sandegren 1991), but only exclusion fencing and roadside clearing have proven to work cost-efficiently (Niklasson and Johansson 1987, Lavsund and Sandegren 1991; see also Feldhamer *et al.* 1986, Clevenger *et al.* 2001). Small-scale experiments suggested that fencing can reduce the rate of accidents with moose by more than 75 %, and with roe deer by up to 55 %, while the clearance of forested roadsides from palatable or attractive forage for ungulates may result in a 20 % reduction of ungulate-vehicle collisions (Almkvist *et al.* 1980, Skölving 1985, Nilsson 1987). Roadside clearance has become a standard in Swedish road and rail management, whereas fencing has been focused on heavily trafficked roads where the risk for human injury is high. In many cases, the selection of road stretches to be fenced is still based on a limited basis of knowledge on, *e.g.*, local ungulate populations and their movement patterns. Also, the cost efficiency of fencing certain stretches is often not known. Until 2001, more than 5000 km of public roads have been fenced against moose, and the recent traffic safety policy aims at a significant extension of mitigation fencing (Sjölund, personal communication). Extended fencing, however, increases the risk of isolation effects on wildlife. To counteract isolation and increase traffic safety, the Swedish Road Administration now advises to combine fences with especially designated wildlife passages at locations where collisions are most frequent or the need for continued wildlife movement is high.

Where fenced roads cut important moose migration routes, or where fences dissect landscapes over long distances, damages to the fences occur frequently as the animals try to jump over or break through the fence in order to reach the other side of the road. When animals enter the fenced road corridor, the risk of collisions with vehicles increases significantly. Thus, the actual barrier effect of moose fences – and the accident-reducing effect – must be considered as below 80 %. For instance, Wallentinus (2000) reported from a 15-year monitoring study along a partly fenced road segment that moose accidents were more common on the fenced road stretch than on the unfenced part.

To evaluate the efficacy of fences in reducing accidents with moose, it is necessary to know where and when fences were built. Between 1980 and 1999, approximately 34 % of national roads and motorways have been fenced against moose and other large wildlife. About half of all moose collisions recorded during this period occurred on main national roads. If one assumes all fences to be equally efficient (75 % reducing collision risks), one may thus expect a 12.75 % (= 0.34*0.5*0.75) reduction in the ratio between moose collisions, annual moose harvest and the total traffic work (kilometres driven by vehicles) in Sweden from 1980 to 1999. If fences were effective at a national scale, the ratio should at least be smaller than compared to the ratio during the years before 1980.

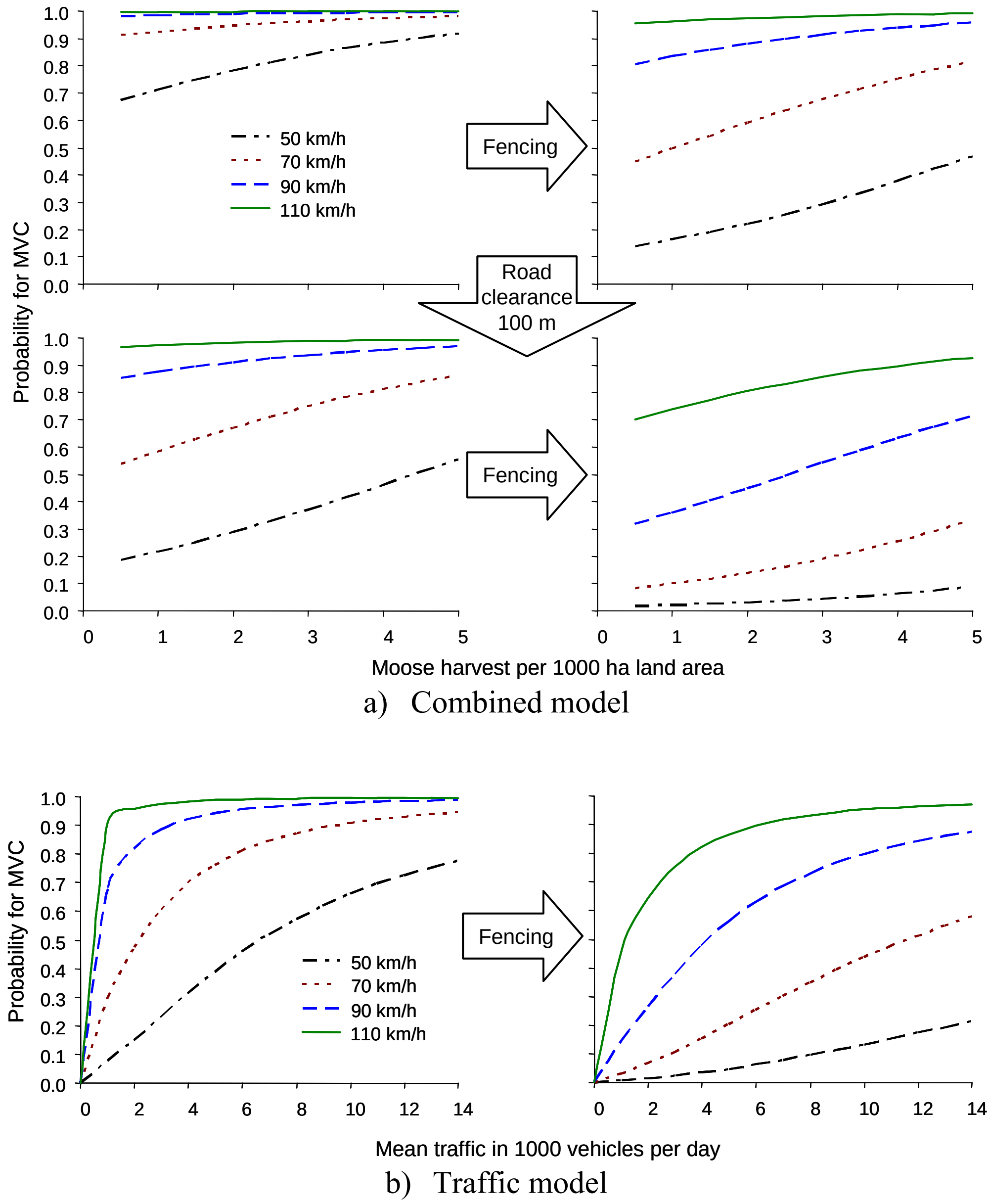


***Figure 7.5*** *Visualisation of the combined effects of vehicle speed, traffic volume, fencing, moose abundance and proximity of forest on the likelihood of moose – vehicle collisions to occur (one collision per kilometre during a ten-year period).*
*A) Predictions for roads with an average annual daily traffic of 5000 vehicles;*
*B) Predictions for areas with annual harvest of 3 moose per 1000 ha land. MVC: moose – vehicle collision. (From: Seiler 2005.)*

However, analysis of covariance between UVC (ungulate – vehicle collision) ratios, years and periods (1970–1979 and 1980–1999) suggests the ratio being at a generally higher level during the second period (Seiler 2004). The overall effect of 5000 km of fences was thus only marginal on the total number of moose accidents. On the other hand, the proportion of ungulate – vehicle collisions involving human injury or death in Sweden decreased from 5 % in 1983 to 2.2 % in 1999 (Swedish Road Administration database). This decrease contrasts the growing rate of human injuries in other, non-wildlife related road accidents (+20 %) and may approve for some beneficial effect of the mitigation efforts taken so far.

Logistic regression models that predict collision risks with moose suggested a significant effect of fencing at local scale, however (Figure 7.4). Traffic volume, vehicle speed, and the occurrence of fences appeared as the dominant road traffic factors determining collision risks. On a given road, however, landscape metrics such as the amount of and distance from forest cover, the density of intersections between forest edges, private roads and the main accident road, significantly affect collision risks (Seiler 2005).

## 7.4 Overview of compensatory measures

Compensatory measures comprise measures or actions taken to address a residual adverse ecological effect (ecological or other) which cannot be satisfactorily mitigated. The term compensatory measure should not be used as a synonym of "compensation" which usually involves the transfer of money to a stakeholder, *e.g.* a landowner affected by a road or railway scheme. Contrary to countries such as Denmark, the Netherlands and Switzerland (Trocmé *et al.* 2003), the principle of compensatory measures is, so far, not practised in the transportation sector in Sweden. Compensatory measures are also much practiced in Germany where the term "balancing" is used. Balancing comprises not only compensatory measures, however. In the German sense, balancing means to compensate the negative impacts of a project with mitigation and/or compensatory measures. German environmental protection laws stipulate that impacts on nature and landscape values should be avoided, and where they cannot be evaded the losses should be compensated for to the extent that a balance will be reached. The developer thus has to give back as much to Nature as he removes with the project. Nature here means natural resources and ecological functions. Landscape includes the cultural heritage as well as landscape scenery.

Swedish law stipulates that a project must not cause significant damage, or may only cause insignificant impacts. However, it does not say that remaining impacts have to be compensated for in order to strike a balance. In the absence of a balancing principle in infrastructure planning, one scheme after the other could, in the long run, create a non-sustainable situation of gradual impoverishment of a landscape housing more and more infrastructure.

The demand for compensatory measures has a valuable potential for rehabilitation of the landscape and is also a way to have the private market sector instead of the public sector and the taxpayers to finance the maintenance of landscape values.

This problem has three main perspectives: The legal perspective (statutory regulations), the planning process (administrative) and the scientific perspective, *e.g.* ecological, visual, social (professional).

So far, most of the Swedish research and development in this field deals with the legal perspective and planning process. (For more information, see: Grip *et al.* 1999; Skärbäck 1997 a, b, c, d).

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

There are no quality standards or minimum requirements in Sweden concerning mitigation measures for wildlife. However, initial proposals of minimum requirements for fauna passages have been made by the Swedish Road Administration and are currently subject to further refinement (Sjölund, personal communication).

## 7.6 Maintenance aspects

Maintenance plays an important role for the function of measures taken to counteract habitat fragmentation in connection with transportation infrastructure. In earlier times, maintenance was 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 to the verges of roads and railways. With more mitigation measures being taken in Sweden, more attention has to be given to the role of their maintenance to retain their efficiency over time.

Earlier having been managed by the Swedish Road Administration itself, the maintenance of roads has gradually been subjected to procurement since the mid-nineties. Since 1997, environmental requirements have been gradually introduced in the procurement of road maintenance. The following-up of the environmental requirements and the benefit to the environment of including environmental requirements are currently subject to a doctoral project (Faith-Ell 2000). The introduction of environmental requirements ("green procurement") has increased the environmental awareness among actors involved in road maintenance.

Railway maintenance in Sweden has just started to be subjected to procurement. A national inventory of the environmental impact of all activities of rail maintenance and operation has been made on a regional basis (Skeppström 2002).

### 7.6.1 Verge management

In ancient times, Swedish road verges were to a large extent mown annually for hay-making. Since many decades, this tradition has ceased. The road keeper cuts grass, herbaceous vegetation, bushes and tree twigs mainly for the sake of traffic safety and technical function of the road construction. With the dramatic decrease in the area of mown meadows in Sweden, much attention is being drawn to the biological values of road verges. The Swedish Road Administration has ambitious programmes for roadside management where the biological values are given high priority. With the exception of herbicides targeted at two single weed species, chemicals are no longer used for weed control along Swedish state roads.

The performance of verge maintenance is included in the above-mentioned doctoral study of Faith-Ell (2000). Her results clearly point out the importance of information on, *e.g.*, species-rich roadsides, to be spread to all involved actors in road management. This is especially important in a situation where various parts of the maintenance activities are procured out to different contractors.

Railway verges are also cleared from woody vegetation for technical and visibility reasons. Chemicals are still used for weed control along Swedish railways.

### 7.6.2 Management of other surfaces

The few Swedish fauna passages are maintained so as to keep the intended efficiency for the target species. Each fauna passage is maintained from its own characteristics, and no generally valid rules are at hand.

Culverts under roads and railways were up till some years ago managed so as to provide unimpeded water flow in order to avoid sediment formation and water-flow obstruction by obstacles in the culverts. Recognition of the fact that many culverts pose partial or definite barriers to the upstream movement and migration of many animal species has grown rapidly among road and railway keepers in recent years, however. Programmes for the ecological adaptation of existing culverts and recommendations for the construction of new culverts in a way that enhances the biological connectivity in and along watercourses are being implemented in the Swedish Road Administration and in the Swedish National Rail Administration.

### 7.6.3 Co-ordinating landuse in adjacent areas

The land adjacent to measures or installations to counteract habitat fragmentation has to be maintained in a way that does not destroy the function of the measure. This problem is little discussed in Sweden. For state roads in Sweden, the Swedish Road Administration is responsible for the management of the entire road area, including ditch back-slopes. Problems have been reported concerning roadsides with vegetation classified as species rich having been destroyed by a contractor not responsible for the roadside maintenance, or by a local farmer (Faith-Ell *et al.* 2006).

Apart from this, no specific information on the issue of co-ordination of landuse has been found.

## 7.7 Evaluation and monitoring of the effectivity of measures

So far, only few of the mitigation measures taken in Sweden have been studied and evaluated for their efficacy. Since monitoring is neither legally required nor scientifically validated, present follow-up studies vary greatly in quality. There is need for standardized monitoring methods that allow combining results from different studies to draw more general conclusions. In an on-going project commissioned by the Swedish Road Administration and the Swedish National Rail Administration, recommended methods for the following-up of environmental impacts of road and railway projects are being compiled in a handbook. The handbook will encourage the use of an information system comprising information on EIA follow-up programmes and follow-up results so as to make this information available for future EIA work and development (contacts: Lennart Folkeson or Inga-Maj Eriksson).

The paramount problem with evaluation is that efficacy must relate to an *a priori* defined goal or aim. Unless it is known or decided how frequent a fauna passage, for example, shall be used by wildlife to fulfil the ecological or economical goal, it is not possible to evaluate whether the fauna passage is efficient or not. It is surprising that this basic rule in monitoring has so far not been applied to any kind of mitigation measure for wildlife in Sweden. In most cases, there has been no intention to validate new mitigation measures. In only few cases, the use of fauna passages has been documented. This unprofessional attitude reflects the low status of mitigation measures for wildlife compared to other technical measures, but is also due to the failure of ecologists to provide civil engineers with necessary information.

Those few monitoring and follow-up studies that have been conducted so far are thus rather descriptive and usually without comparison of the pre-construction phase. Examples of research projects are given in, *e.g.*, Section 5.5.

# Chapter 8. Habitat Fragmentation and Future Infrastructure Development

## 8.1 Policies and strategies/trends

The environmental policy adopted by the Swedish Road Administration lays the grounds for developing the road transport system, including the roadkeeper's own activities, towards a situation in which the climatic impact of road transports is acceptable, the energy supply is environmentally sound, the level of vehicle emissions is acceptable, noise levels are tolerable, natural resources are being conserved and the infrastructure is adapted to the natural and cultural environment. Generally speaking, the road transport system shall be developed in a way that does not jeopardise the environment or public health and welfare either now or in the future.

To achieve that, the Swedish Road Administration is – among other aspects – obliged to locate and design roads, bridges and other structures so that they harmonise with the surrounding environment and are aesthetically attractive, and preserve cultural and natural landmarks that are of special value (Swedish Road Administration 2001).

Attempts to develop a landscape-ecological approach for use in strategic and project oriented EIA have been made (*e.g.*, Eriksson and Skog 1996; Seiler and Eriksson 1997) but have not yet been fully implemented (compare Section 4.7). This is partly due to poor analyses of the situation and problems. For example there is not yet any national geographical information on the extent of wildlife fences and no analysis of the effect of these fences altogether (compare Helldin and Seiler 2002). Environmental impact assessment is not applied for building such fences as a consequence of road upgrading or as an isolated measure.

As a means of enforcing the consideration of the natural and cultural values of the landscape in infrastructure planning, the infrastructure authorities, the Swedish Environmental Protection Agency, the National Heritage Board and the National Board of Housing, Building and Planning are jointly developing an approach called "Targets and indicators". The activities aim at developing tools and procedures which will secure an acceptable level of quality of the transportation system from, *e.g.*, an environmental point of view. The approach will also support the environmental follow-up of the activities of the infrastructure authorities and their reporting to the Government concerning the development with regard to the national environmental quality objectives (Swedish Road Administration 2001). A number of reports have documented the achievements of the project (*e.g.* Folkeson and Antonson 1999; Karlsson and Lundgren 2002; Swedish Road Administration 2001, Eriksson *et al.* 2005, Seiler and Sjölund 2005).

An approach to consider ecological aspects and landscape fragmentation in the strategic planning of roads has been to categorise landscape components in: protected areas, already strongly developed areas and other areas where these types of landscapes are expected to need extensive adaptation and compensatory measures down to the normal countryside where a certain minimum level of environmental adaptation will be required. Similar categories are now developed further in order to form a basis for classifying environmental quality of a road.

So far, landscape fragmentation has been a largely neglected aspect in the physical planning including transportation planning. Physical planning in the Greater Stockholm area may be stated as an interesting exclusion, however. During the recent decade, an increasing awareness of the ecological importance of the green structure in and surrounding the Stockholm area has been observed. Large attempts have been made to conserve the ecological network built up by the so-called green wedges extending deeply into the heart of Stockholm. This structure connects green areas in the urban area with the "natural" areas surrounding the Stockholm conurbation. The first national urban park in the world was founded in the city of Stockholm in 1995. The park comprises 27 $km^2$ and includes a range of various nature types. In recent years, an increase has been observed in the pressure from housing and infrastructure development on the green structure and even on the national urban park, however.

The issue of habitat fragmentation is nowadays treated in the Environmental Code. It was not until 1996, however, that knowledge on habitat fragmentation began to be utilised in the planning work. Fragmentation issues in connection with the strategic road and railway planning are to be dealt with using the section on EIA of the Environmental Code. The Code stipulates minimum requirements for the content of strategic environment assessment (SEA) and EIA. The amount or work for the assessment is to be adapted to the degree of the expected environmental impact. The county administrative board decides which environmental aspects that shall be treated.

It is the responsibility of the transport sector to improve the methodology for the evaluation and mitigation of ecological effects of infrastructure and transport. The growth of transport infrastructure requires continuous adaptation of concepts and methodologies that consider landscape-wide relationships. Increasing the scale of environmental consideration is crucial for the achievement of sustainable development in landuse. This demands, however, the adaptation of SEA and EIA to include:

- Aiming at an understanding of landscape processes and functions, instead of focusing on single landscape elements for protection
- Applying adequate ecological effect evaluations to all cases of infrastructural development
- Conducting follow-up studies, establishing ecological monitoring and making results available for future EIA
- Interdisciplinary co-operation when evaluating past and planning future development of landuse and environment

Thus, the need of development has been outlined and studies are currently conducted to provide the required background and methodology. It will take some more years, however, before evaluation tools and indices as well as the entire methodology will become operational in the SEA and EIA work.

## 8.2 Indicators/indices and models of fragmentation

So far, no indicators or indices have been applied nor fully developed in Sweden for evaluating fragmentation pattern due to infrastructure. The topic, however, is considered to be of great significance to planning. Initial suggestions of indicators have been made and work is in progress (*e.g.* Seiler 1996b; Seiler, unpublished; Nordström *et al.* 2003).

## 8.3 Data on transportation networks development

As in most countries, road traffic in Sweden has been steadily increasing with about 1–2 per cent each year (Figure 5.4) and is expected to do so for the next 15 years (Table

8.1). The largest increase is expected to occur in the traffic work (driven mileage) of trucks and lorries (2.5 %), whereas passenger cars will increase with about 1 % annually (SIKA 2002). This increase is only partly due to the increase in the number of vehicles: Over the past 25 years, the number of trucks has risen with about 30 % while the number of passenger cars has more than doubled since 1975 (Figure 5.5).

***Table 8.1*** *Predicted future road traffic in Sweden according to three alternative scenarios. NPVS: National road transportation plan, preliminary version (Road Administration). LTP: Proposed county-road transportation plan (Road Administration). (Sources: Bergström, personal communication; SIKA 2000.)*

| ***Scenario (2000-2015)*** | ***Overall traffic volume (billion km driven)*** |
|---|---|
| Present traffic volume (year 2000) | 72.0 |
| No road construction after 2003 | 84.3 |
| Only roads considered in the NPVS will be built | 85.2 |
| All roads in NPVS and LTP proposals can be realised | 86.7 |

To provide for increasing traffic, the Swedish Road Administration intends to upgrade several important trunk road linkages. However, the realisation of these plans depends upon economics, and no definite decision has so far been taken. Upgrading most often involves a widening of the existing road, although completely new constructions (of motorways) are necessary at several places. In most (if not all) of the new construction plans, special measures for wildlife are considered. Naturally, counteracing fragmentation effects on wildlife is easier in new roads as passages and other measures can be adjusted to wildlife already from the beginning. In maintenance or improvement of existing roads, however, counteraction is more difficult and rarely considered economically acceptable.

One important component of road improvement is the constructiuon of central wire-railings that separate lanes and reduce the risk of frontal collisions. On the other hand, there is evidence suggesting that railings may increase the risk for animal-vehicle collisions as the animals will be slowed down in the middle of the road. The Swedish Road Administration recommends therefore that wire-railings should be combined with exclusion fences where the risk of collisions with moose or roe deer is prevalent. Since this kind of road upgrading currently occurs at a broad scale on pratically all larger highways, the resulting fragmentation effects on moose populations and other larger wildlife may be considerable and need to be evaluated (compare Helldin and Seiler 2002).

## 8.4 On-going research and review of relevant studies

Many of the relevant studies have already been cited or described in earlier sections, especially in Section 5.5.

# Chapter 9. Economic Aspects

## 9.1 Planning of measures

For the planning of mitigation measures, the following statement could be a good principle: Planning in advance results in lower costs than taking corrective measures afterwards. Planning in an ecologically conscious way from the beginning only slightly increases the cost as compared to taking no environmental consideration at all. A road project concerning highway E4 in southernmost Sweden can be stated as an example: The cost of a 27 km motorway (dual carriageways) was estimated at 750 million SEK (ca. 82 million €). An alternative design including relatively good consideration of biodiversity increased the estimated cost by 3–4 % (not including the cost of wildlife fencing).

Putting the focus on traffic safety sometimes results in increased habitat fragmentation, *e.g.* where wildlife fences are to be installed. The cost of installation is currently ca. 100 SEK (ca. 11 €) per metre for each side of the road. The management of the fence (repair, vegetation clearance, etc.) costs c. 150 SEK (ca. 16 €) per 100 m of road (each side of the road) annually. To mitigate the effect of fences on the wildlife, especially large mammals, passage has to be provided at designated crossing points. For major roads, solutions are usually sought that combine provisions for wildlife with, *e.g.*, pedestrian tunnels or tunnels for local access roads. Extending bridges to allow for wildlife passages next to conventional roads is estimated to cost ca. 10,000 SEK (ca. 1,100 €) per $m^2$ bridge.

## 9.2 Wildlife casualties

In Sweden, ungulate-vehicle collisions produce a cost of more than 1 billion SEK (about 100 million €) annually, including 10–15 human fatalities and several hundred injuries (Table 9.1). While about 60 % of all police reported accidents were due to collisions with ungulates, their overall cost is only about 10 % of the cost for non-wildlife accidents.

However, these figures include the costs for material damage, human injuries and fatalities, but do usually not account for "external" costs such as the loss of meat or hunting opportunities, the call-out costs for vets, gamekeepers and police to deal with injured or dead animals, the costs for ambulances and any subsequent human medical costs, and the costs of traffic delays. For example, the pure meat and recreational value of an individual moose in Sweden has been assessed to ca. 7,000 SEK (about 644 €) in 1986 (Mattsson 1994). The touristic value of free-living moose, on the other hand, may even amount to 20,500 € per individual (Anonymous 2002). If losses of hunting opportunity, loss of meat and costs for the retrieval of injured animals are combined, another 300 million SEK should be added to the overall annual cost of ungulate-vehicle collisions (Karlsson 2005).

Despite earlier beliefs, also train – animal collisions can be costly. A recent study on train – animal collisions revealed that collisions with wildlife produce a considerable economic loss to the Swedish National Rail Administration, even if no human injuries or fatalities are included. Between January and June 1999, for example, collisions between trains and larger wildlife (117 moose and 643 reindeer) in the Northern railway region in Sweden charged more than 200,000 € due to train delays, repairs of trains, and costs for the loss of animals and the removal of the carcasses (Johansson and Larsson 1999).

Understanding the external costs of animal – vehicle collisions is crucial when assessing the monetary value of mitigation measures – and the funds that should be made available for further research. Estimations made so far are unsatisfactory and hardly applicable to road planning. With increasing internalization of external costs in the transport sector and increasing constraints on public spending, there is a great need to improve the economic models and methods for evaluating nature and wildlife (*e.g.* Cedermark and von Koch 2000).

***Table 9.1*** *Estimated annual cost (SEK) of road accidents with and with out wildlife involvement in Sweden. The costs have been adjusted to include the number of non-reported collisions. MVC: moose – vehicle collision; RVC: roedeer – vehicle collision. (Source: Andreas Seiler, unpublished.)*

| ***MOOSE*** | ***Material cost & Risk valuation**** | ***MVC** per year*** | ***Correction factor #*** | ***Total no. of accidents*** | ***Total costs per year (in 1000 SEK)*** |
|---|---|---|---|---|---|
| Human fatalities | 14 300 | 10 | 1.06 | 10.6 | 151 580 |
| Serious injuries | 2 600 | 59 | 1.27 | 74.9 | 194 818 |
| Not serious injuries | 150 | 384 | 1.27 | 487.7 | 73 152 |
| Damage to property | 13 | 4 007 | 1.60 | 6411.2 | 83 346 |
| **Sum** | *(in 1000 SEK)* | *4 460* | | *6 984* | **502 896** |
| | | | *average cost per accident* | | *72.00* |

| ***ROE DEER*** | ***Material cost & Risk valuation**** | ***RVC** per year*** | ***Correction factor #*** | ***Total no. of accidents*** | ***Total costs per year (in 1000 SEK)*** |
|---|---|---|---|---|---|
| Human fatalities | 14 300 | 2 | 1.06 | 2.1 | 30 316 |
| Serious injuries | 2 600 | 21 | 1.27 | 26.7 | 69 342 |
| Not serious injuries | 150 | 136 | 1.27 | 172.7 | 25 908 |
| Damage to property | 13 | 22 455 | 1.60 | 35928.0 | 467 064 |
| **Sum** | *(in 1000 SEK)* | *22 614* | | *36 130* | **592 630** |
| | | | *average cost per accident* | | *16.40* |

| ***NON-WILDLIFE ACCIDENTS*** | ***Material cost & Risk valuation**** | ***Reported accidents ***** | ***Correction factor #*** | ***Total no. of accidents*** | ***Total costs per year (in 1000 SEK)*** |
|---|---|---|---|---|---|
| Human fatalities | 14 300 | 372 | 1.06 | 394.3 | 5 638 776 |
| Serious injuries | 2 600 | 1 718 | 1.53 | 2628.1 | 6 833 011 |
| Not serious injuries | 150 | 4 993 | 1.75 | 8737.6 | 1 310 636 |
| Damage to property | 13 | 10 730 | 1.87 | 20064.9 | 260 844 |
| **Sum** | *(in 1000 SEK)* | *17 813* | | *31 825* | **14 043 267** |
| | | | *average cost per accident* | | *441.27* |

** from SIKA 2000:3*

*** from statistics of the Swedish Road Administration for the period 1990-1999*

*# from Almkvist et al. 1980*

## 9.3 Culverts

Culverts are important to aquatic animals including fish. Much development is in progress to enhance the ecological consideration in the planning and management of culverts. Granting free passage along the waterway in its entire stretch is the most efficient approach. This has to involve co-operation between all actors from various parts of the society. Each responsible partner will have to bear his own cost and the measures are to be taken in connection with the ordinary management.

## 9.4 Valuation of encroachment on landscapes

In infrastructure planning, the term encroachment is used to describe the sum of the effects that the infrastructure (with its traffic) causes on the physical environment. In the current practice of infrastructure planning in Sweden, encroachment on landscapes is in principle not included in the cost – benefit analysis (CBA). Some of the effects making up the encroachment are usually included, however: noise and air pollution emission (Matstoms and Björketun 2003). The fact that the rest of the encroachment aspects are not moneratised causes problems of how to treat these effects in relation to those environmental effects that are monetarised and included in the CBA. Much concern is therefore being raised regarding the possible lack of sufficient consideration of encroachment in current infrastructure planning. On the other hand, concern is being raised regarding too much societal recources possibly being devoted to avoiding or mitigating encroachment. This is an area of an intense debate among economists and infrastructure planners in Sweden. A recent report summarises the approaches to the question whether existing methods for the valuation of encroachment are trustworthy enough to be used in cost – benefit analyses in the transportation sector (Lind *et al.* 2002).

Several methods have been used in the search for monetary valuation of encroachment of infrastructure and traffic. One method uses differences in the market price of real estates to estimate the value of the environment in which the property is located (the hedonic price method). Another method is based on the travel costs of people visiting natural areas for leisure and recreation. A third group of methods seek to estimate people's willingness to pay for avoiding or being released from a nuisance from a road or railway in the area where they live or which they use for, *e.g.* out-door activities. The Contingent Valuation Method (CVM) is being used and further developed for application in the planning of road and railway investments in Sweden. CMV provides a monetary value of the encroachment caused by a planned or existing road or railway. Hitherto being an important impact not given an economic value, encroachment on landscapes and townscapes can in this way be included in the CBA preceding the infrastructure investment. The method is based on questionnaires to reveal people's willingness to pay for the avoidance of the encroachment. A number of case studies have been performed in Sweden to establish monetary values of barriers against water. In a typical example, a road forms a barrier between a residence and an inland lake or the sea. In three towns, people (aged 18–75 years) living in the vicinity of such a road were asked to put a value on the possibility of having the existing road relocated to a tunnel. Among the people living near the road, the willingness to pay for this possibility was found to be 610–4,180 SEK (c. 67–456 €) per person annually during 10 years. In addition to people living in the vicinity of the road, people in the rest of the towns were also included in the studies. In this way, a total value could be established for the willingness to pay by all inhabitants in the town. Calculations based on the various hypothetical values stated by people living at different distances from the roads resulted in total values between 13 and 160 MSEK (1.4 and 17 million €, respectively) for each of the three towns studied. This value is of course dependent on the number of inhabitants – in the three studied towns, the population was between 5,700 and 61,000. People living near the road were found to be disturbed in inverse proportion to the distance between the residence and the road. For the rest of the town's inhabitants, the willingness to pay for getting rid of the barrier was dependent on the frequency of their visits to the area next to the barrier (Grudemo *et al.* 2002).

The studies tried to establish monetary values of the barrier effect, the disturbance and the change in the scenic value caused by roads. Even though the studies were devoted to people's living environment, they can be used to give an indication of the magnitude of the economic value of natural areas being encroached upon by a road or a railway.

This type of methods to monetarise encroachment of infrastructure is being questioned. For instance, Lind *et al.* (2002) consider the hitherto used questionnaires unreliable because of problems with the econometry and the design of the questionnaires. The authors do not exclude the potential of such questionnaires, however, and recommend further methodological development including, *e.g.*, comparison between the hedonic price method, the travel-cost method and CVM. The authors conclude that the methods for monetarising encroachment on landscapes have so far not reached the maturity that they can producd trustworthy economic values. In principle, they consider it possible to establish such monetary values, however. Other researchers, *e.g.* Hesselborn (2002), claim the methodological problems to be so large that reasonable monetary values cannot be expected in a foreseeable future.

In addition, other approaches to establish monetary values of encroachment have been tested. The Swedish Road Administration has recently published an attempt to calculate the economic value of encroachment of roads on the natural and cultural value of the rural landscape (Cedermark and von Koch 2000). In the cost – benefit analysis currently used by the Swedish Road Administration to calculate the profitability of road investments, certain important factors are regularly excluded from the calculations. One of the most important of these effects is the encroachment on the natural and cultural landscape. The term encroachment includes effects such as landscape severance, barrier effect to humans and animals, scenery and aesthetical values. The study of Cedermark and von Koch (2000) is based on thirteen case studies where an initial provisional decision to construct a road was re-examined in favour of a road-stretch alternative that imposed less encroachment on the natural and cultural values of the rural landscape. The eventually chosen alternative was more considerate to the landscape values but less profitable to economics. Three different ways of calculation were used to estimate the economic value of the reduction in the encroachment on the landscape. All three methods were based on the estimated costs and benefits of the original proposal and that eventually chosen. For ten of the road projects, a comparison of the two alternatives differing in degree of encroachment produced estimates of the minimum economic value of the encroachment reduction. Three of the cases gave a direct economic value of the reduction in encroachment since the cost was caused by mitigation or compensatory measures taken to improve the situation ecologically or aesthetically. In the ten cases mentioned, the minimum estimated economic value of the reduction in encroachment thanks to re-routing the road stretch was found to be between 1 and 216 per cent of the total cost of construction of the road stretch chosen. The median value was 8–19 per cent. In the three other cases, the real cost of the mitigation/compensatory measures taken was 1–9 per cent of the construction cost of the road stretch (Table 9.2).

The study contributes a suggestion of an approach to monetarise the natural and cultural value of landscapes. However, this approach has been criticized, and the values arrived at using the calculations cannot be taken to represent any "true" value of a landscape.

***Table 9.2*** *Estimated value of the reduction in encroachment on the natural and cultural values of the landscape following the decision to choose less encroaching road stretches or taking mitigation or compensatory measures. Costs in million € and as a percentage of the total construction cost of the chosen road stretch. Range resulting from three alternative ways of calculation. The highways E4 (Höga kusten) and E6 (Fastarp–Heberg) and the road Lv 117 were the cases where mitigation/compensatory measures were taken. Here: 1 € = 8.25 SEK. (From Cedermark and von Koch, 2000.)*

| ***Road scheme (highways)*** | ***Value (M€)*** | ***Percentage of road-construction cost*** |
|---|---|---|
| Road E12, Kulla–Norrfors | 0.85–1.2 | 8–11 |
| Road E4, Yttervik–Tjärn | 1.2–2.4 | 5–9 |
| Road E4, Höga kusten | 30–33 | 8–9 |
| Road 55/56, Katrineholm | 13–17 | 23–32 |
| Road E18, Sagån–Enköping | 11–23 | 9–19 |
| Road E4, Markaryd–Strömsnäsbruk | 10–11 | 8–9 |
| Road 50, Ödeshög–Motala | 29–52 | 102–216 |
| Road 604, Stansgatan–Hyltan | 2.1–2.4 | 24–30 |
| Road E6, Håby–Rabbalshede | 0.85 | 1 |
| Road E6, Fastarp–Heberg | 1.5–2.9 | 1 |
| Road 117, Skogaby–Knäred | 0.5–0.8 | 3–5 |
| Road 19, Kristianstad–Broby | 52–55 | 116–123 |
| Road E22, Fjälkinge–Gualöv | 4.4–5.3 | 8–10 |

## Chapter 10. Conclusions and Recommendations

Transportation infrastructure contributes to the fragmentation of habitats. However, the long-term consequences to nature are difficult to quantify and evaluate. The Swedish Parliament has established environmental quality objectives against which the impact of infrastructure on nature can be evaluated. These goals are not yet sufficiently detailed to be operational in the planning of transportation infrastructure, however. Empirical research, modelling, follow-up studies and consequent monitoring are essential to tackle the problem.

The traditional way of thinking in nature conservation is reactive. Usually it is not until a completed plan for a new road or railway is presented that conservation interests become active. Protected areas and rare species are the usual arguments, but the understanding of the landscape context is missing. A new way of working could be to shift the focus from the object-oriented conservation perspective to a resource management perspective that views the problem in a more holistic way and includes other 'environmental' concerns such as traffic safety, economy, ethical or cultural concerns.

Public and governmental demands on the transportation sector to avoid, mitigate, and compensate for the impact on nature are increasing in Sweden. This must involve all planning and construction stages.

For instance, the construction of infrastructure within a site belonging to the Natura 2000 network requires both authorisation from EU and compensation of any significant effects. From a local perspective, habitats for amphibians and otter have received special interest and measures to reduce the conflict have been implemented.

To successfully plan and build wildlife crossings it is necessary to integrate their planning into the ordinary transportation planning process. As a rule these issues must be integrated at an early stage of the planning but consideration must also be given to the type of problem that is to be addressed. Introducing too detailed aspects at an early planning stage is as wrong as discussing general questions at the end. The relevant question needs to be defined and integrated at the appropriate planning stage.

However, arguments for mitigation measures still need to be developed. In addition, better arguments and more evidence are needed to improve the implementation of mitigation concepts. Many wildlife species that occur frequently among road kills are not immediately threatened by road traffic but instead are harvested or regulated through hunting. For such species, preventive measures are not of ecological or conservational importance but may very well serve to enhance traffic safety or meet ethical constraints.

Consequently, the following recommendations can be given:

- We need to establish specific and concrete targets which express a level of quality that transportation infrastructure shall achieve. These targets should be defined in conformity with the national environmental quality objectives, the national goals for a sustainable transportation system, *and* the operation of the road/rail transport system and its impact on the natural and cultural heritage. A quality level that is defined in this way should be based on state-of-the-art knowledge.

- Research should focus on understanding the environmental consequences of transportation networks and developing methods to support ecological impact evaluations already at early planning stages.
- Updated knowledge should be readily available and compiled in handbooks or on internet sites; international exchange of experience and knowledge is a crucial tool.
- The dialogue between ecologists, planners and constructors needs to be continued and improved to focus on the management and use of natural resources rather than on the conservation of designated species or areas. A management perspective may help to develop environmental quality goals that allow for evaluation of impacts.
- We have already sufficient knowledge to integrate ecological assessment into infrastructure planning processes. But there is a great need to improve the knowledge and to develop new methods in order to make the planning process and mitigation measures more efficient, thereby lowering the costs of ecological adaptations.
- The most effective way to gain necessary knowledge is to apply existing knowledge in practice and to improve it by co-ordinated and well focused follow-up studies. To be cost-efficient, the follow-up studies should be co-ordinated at an international level.
- Transportation infrastructure can provide important natural and cultural values, such as those found in historic routes, avenues or species-rich road verges. These values need to be appraised, properly managed and, where possible, enhanced.

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# 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. |

| Term | Meaning |
|---|---|
| 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'. |
| 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* 'Central reservation'*)*. |
| 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* 'Ecological corridor') serving as a conduit for species moving across the landscape. |
| Ecological network | System of ecological corridors (*see* 'Ecological corridor'), 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. |

| Term | Meaning |
|---|---|
| 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. |
| 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 landuse 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* 'Drainage'). |
| 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'. |

| Term | Meaning |
|---|---|
| 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* 'Gutter'*)*. |
| 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. |
| Land-take | Land used for highway or railway schemes (*in the context of this report).* |
| Land unit | The smallest functional element of the landscape. *See* also 'Ecotope, 'Habitat' and 'Biotope'. |
| Landuse 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 landuse type in a mosaic, characterised by extensive cover, high connectivity and/or major control over dynamics. |

| Term | Meaning |
|---|---|
| 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 context, 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* ’Central reservation’); 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* ’Mode’). |
| 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. |

| Term | Meaning |
|---|---|
| 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). |
| 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* 'Landuse 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* 'Environmental Impact Assessment') 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. |

| Term | Meaning |
|---|---|
| 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. |
| 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. |

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The present report is based on contributions made by different persons involved in the field of transport, nature and culture, here listed in their alphabetical order.

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Further information and /or written text has been provided by:

- Älgskadefondsföreningen (Association for Moose Damage) http://www.aelgen.g.se/en.htm
- Grimsö Wildlife Research Station http://www-grimso.slu.se
- National Board of Agriculture http://www.sjv.se
- National Board of Forestry http://www.svo.se
- National Land Survey of Sweden http://www.lantmateriet.com
- Swedish Environmental Protection Agency http://www.environ.se
- Swedish National Forest Inventory, http://www-nfi.slu.se
- Statistics Sweden http://www.scb.se

- Swedish Association for Hunting and Wildlife Management http://www.jagareforbundet.se
- Swedish Biodiversity Centre http://www.cbm.slu.se
- Swedish Institute for Transport and Communications Analysis http://www.sika-institute.se
- Swedish National Rail Administration http://www.banverket.se
- Swedish Road Administration http://www.vv.se
- Swedish Threatened Species Unit http://www.dha.slu.se
- Swedish University of Agricultural Sciences http://www.slu.se
- SWEIONET http://sweionet.environ.se
- Trafiksäkerhet och eftersök i samverkan (organisation for registration of wildlife-vehicle collisions) http://www.sesgruppen.se
- VTI http://www.vti.se
- Wildlife Damage Centre http://www.viltskadecenter.com

Home pages and internet sites that are cited in the report have been visited in August 2000 or May 2005.

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