COST 341

Habitat Fragmentation due to Transportation Infrastructure

WILDLIFE AND TRAFFIC
A European Handbook for Identifying Conflicts and Designing Solutions

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

COST

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Cover photo: Fauna overpass Woeste Hoeve over highway A50 between Arnhem and Apeldoorn in the Netherlands. It provides an ecological connection for all kind of habitats. (Photo by Luchtfotografie Slagboom en Peeters)

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Foreword

"Land is under continuous pressure for new transport infrastructure: between 1990 and 1998 some 33000 ha, about 10 ha of land every day, were taken for motorway construction in the EU. ... Most areas in the EU are highly fragmented by transport infrastructure. The average size of contiguous land units that are not cut through by major transport infrastructure ranges from about 20 km^2 in Belgium to nearly 600 km^2 in Finland, with an EU average of about 130 km^2." *(EEA, 2001)*

One of the most radical changes to the landscape of Europe over the past centuries has been the creation and subsequent extension of infrastructure networks. Towards the end of the 20th century, expansion of the major railway and road networks slowed, but did not cease. At the same time, an ever-denser network of minor roads (*e.g.* for forestry), tracks and trails has extended into the last wildernesses areas of Europe. Canals, pipelines, electricity and telephone networks have added to the exponential fragmentation of natural areas, while urbanisation has rapidly increased the built-up area. Researchers, nature organisations and authorities have expressed their concern over the impacts of fragmentation. Studies have highlighted the risks associated with reducing the size of remnant patches of habitat and, as a consequence, increasing the edge and barrier effects. Only during the past decade has there been sustained, international collaboration to review knowledge about the wider impacts of transport infrastructure in terms of fragmentation and especially about the means to avoid and mitigate it.

COST 341, which started in 1998, is one aspect of this effort. This handbook is a direct result of the concerted effort of 16 countries that have contributed to the COST 341 action. The handbook provides general advice on reducing the impacts of transport infrastructure on habitat fragmentation, and takes full account of the large differences in habitats and transport infrastructure context found across Europe.

When the need to mitigate against fragmentation effects leads to the construction of eco-ducts and other wildlife passages, the investment required can be quite substantial. If these solutions are also required on existing roads, project execution may not be simple and many agencies have found it very difficult to mobilise the resources needed. This underlines the importance of avoiding fragmentation in the first place, leaving existing habitats intact as far as possible, or contributing to their restoration. Infrastructure authorities and agencies need to maintain close contact with the local authorities and each other to ensure that purposely preserved habitats are kept intact and that the efficacy of wildlife passages is not diminished by other structures or landuse developments. The participants in COST 341 and the members of the Infra-Eco Network Europe expert group have made an important contribution both to knowledge and responsible practice. I am convinced that their work will proceed successfully and that it will significantly improve our manner of dealing with habitat integrity, and avoiding and mitigating against further fragmentation.

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

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

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1 Introduction

The Problem

The consequences for wildlife of constructing transport infrastructure include traffic mortality, habitat loss and degradation, pollution, altered microclimate and hydrological conditions and increased human activity in adjacent areas. All these cause considerable loss and disturbance of natural habitats. In addition, roads, railways and waterways impose movement barriers on many animals, barriers that can isolate populations and lead to long-term population decline.

Habitat fragmentation, the splitting of natural habitats and ecosystems into smaller and more isolated patches, is recognised globally as one of the biggest threats to the conservation of biological diversity. Habitat fragmentation is mainly the result of different forms of landuse change. The construction and use of transport infrastructure is one of the major agents causing this change as well as creating barriers between habitat fragments.

As transport systems have grown, their impact on fragmentation has become an increasing problem. The steady increase in animal casualties on roads and railways is a well-documented indicator of this problem. On the other hand, barriers causing habitat fragmentation have a long-term effect that is not that easy to detect.

To obtain an ecologically sustainable transport infrastructure, mitigation of these adverse effects on wildlife needs a holistic approach that integrates both the social and ecological factors operating across the landscape. Hence, one of the challenges for ecologists, infrastructure planners and engineers is to develop adequate tools for the assessment, prevention and mitigation of the impacts of infrastructure. This has been the task of the COST 341 Action to address the issues associated with *Habitat Fragmentation due to Transportation Infrastructure*.

Figure 1.1 - Transport infrastructure can fragment habitats, as with this example at the A36 interchange, Alsace, Forest of Hardt (Haut-Rhin), France. (Photo by J. Carsignol)

Figure 1.2 - Habitat fragmentation can be mitigated by building fauna passages like this overpass on the A36 motorway, Alsace, France. (Photo by J.Carsignol)

COST 341

Representatives from nearly 20 European countries in the Infra Eco Network Europe (IENE) have underlined the need for co-operation and exchange of information in the field of habitat fragmentation caused by infrastructure at a European level. IENE also recognised the need for support at a European governmental level. This led to the development of the COST 341 Action to address the issues associated with *Habitat Fragmentation due to Transportation Infrastructure*, launched in 1998.

COST 341 participants

16 countries and one NGO have been officially involved in COST 341

- Austria
- Belgium
- Cyprus
- Czech Republic
- Denmark
- France
- Hungary
- Norway
- Portugal
- Romania
- Spain
- Sweden
- Switzerland
- The Netherlands
- The Republic of Ireland
- United Kingdom
- The European Centre for Nature Conservation

COST 341 products

- National State-of-the-Art Reports
- A European Review
- A database of relevant literature and projects
- This European Handbook

COST 341 Habitat Fragmentation due to Transportation Infrastructure: ***The European Review*** (Trocmé *et al.*, 2003) 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. The review is built upon the National State-of-the-Art reports from the participating countries, and most of these are published separately in the countries themselves. The European Review and the National State-of-the-Art Reports are also available on CD-ROM.

The **database** offers online information on European expertise, data on existing literature, information about ongoing projects and project results, and a glossary of terms used in the field of infrastructure and habitat fragmentation. Access to the database is through the IENE website (**www.iene.info**).

The Handbook

The main topic of this handbook is the minimisation of ecological barriers and fragmentation effects of transport infrastructure. The primary target groups for the handbook are those involved in the planning, design, construction and maintenance of infrastructure (roads, railways, waterways), as well as decision makers at the national, regional and local levels. It is a solution-orientated handbook, based upon the accumulated knowledge of a broad range of experts from the participating countries and from numerous international contacts. The handbook takes the reader chapter-by-chapter through all the different phases, from the first steps of strategic planning, through the integration of roads in the landscape, the use of mitigation measures such as over- and underpasses, the lesser known field of compensatory measures, and to the use of different methods of monitoring and evaluating the chosen solutions. See Chapter 2 Users' Guide.

Roads, railways and waterways

As the title indicates, the solutions in the handbook are designed to deal with different kinds of transport infrastructure, not just roads. Railways can also have a big impact on nature and create barriers even though rail networks and traffic are far less dense than roads. In several European countries, there are massive networks of waterways used for transportation, comprised of both natural rivers and man-made canals. Nevertheless, it is the road network and road traffic that constitute the major pressure on wildlife. Although, the expression 'transportation infrastructure' is used throughout the handbook to cover all three transportation systems, most of the examples and the measures explained in the handbook are related to roads. Many of the measures are, however, equally suitable for reducing the impact of railways.

Measures described in the handbook

The mitigation of habitat fragmentation due to transport infrastructure is a relatively new field of knowledge, which combines engineering and ecology. The way infrastructure is placed in the landscape can be of great importance to wildlife. The handbook describes various factors that should be considered both in the planning of transport corridors and the integration of infrastructure in the landscape. Emphasis is placed on the building of fauna passages, over- and underpasses, pipes, culverts and bridges for several different species.

Partly due to different traditions, and partly due to different physical and ecological contexts, the design of fauna passages and other mitigation measures differs between countries. As a result, there are few general formal standards for the design, construction and maintenance of mitigation measures in Europe. To date, few evaluations of mitigation measures have been carried out. Further work is needed, including studies of the effects of measures at the population level. Based on experience and the evaluation of alternative structures, designs can be improved and eventually standards can be formulated. The ongoing exchange of knowledge and experience across Europe and beyond is necessary to develop these new standards.

New and existing network

While habitat fragmentation is increasingly taken into account when new infrastructure is planned, there remain many existing stretches of road and railway where mitigation measures are badly needed. The impact of existing infrastructure can change when new infrastructure is built, further increasing the need for mitigation measures. When designing measures to counteract habitat fragmentation, the focus should, therefore, be on the impact of the infrastructure network as a whole.

The European approach

This handbook is produced to cover the many different circumstances found across Europe. There are important differences between the countries regarding the cultural, political and scientific contexts of transport infrastructure development at local, regional and national levels. A good solution in one country may be less effective or suitable in another. Therefore, one of the big challenges in the production of the handbook was to deal with all these differences. There is a difficult balance between finding broad general solutions on the one hand, and more detailed local or regional solutions on the other. In most European countries there already exist more specific and detailed handbooks and guidelines on transport-related issues. A selection of these can be found in the list of handbooks and guidelines in the Annex, or through the COST 341 database.

With this background, it is important to emphasize that there are no 100% correct solutions. The advice provided in this handbook is based upon the accumulated knowledge of a broad range of experts from the participating countries and from numerous international contacts. It remains necessary to adapt and adjust measures to the geographical context, as well as to the specific needs and possibilities of the location. The Handbook is, therefore, no substitute for the advice of local experts such as ecologists, planners and engineers and should be used in conjunction with their advice.

2 Users’ Guide

How to use this Handbook

The barrier and fragmentation effects of infrastructure can be eliminated or minimised in different ways and during several phases of its development and use. Fragmentation problems can often be avoided if the right decisions are made in the early phases of planning. The barrier effect can be reduced by integrating the infrastructure into the surrounding landscape, or by building secure crossing points for wildlife. Objectives for existing infrastructure should focus on improving its permeability and on de-fragmenting the landscape.

The phases in an infrastructure's lifespan are usually more or less separate (*i.e.* planning, operation and decommissioning) and need input and expertise from different professionals. The parts of this handbook are structured to make it easy for people to find the relevant information on the different phases. At the bottom of each divider page is a lifespan diagram, which highlights which phase the chapter is related to (see Figure 2.1), and on the first page of each chapter there is a list of contents. Each page has the number of the chapter printed in the margin.

Chapter 3 briefly describes the different ecological impacts of transport infrastructure. These are habitat loss, barrier effects, fauna casualties, pollution and the key issue of the handbook, habitat fragmentation. **Chapter 4** explains how to develop integrated solutions and avoid fragmentation, and underlines the importance of early consideration of habitat fragmentation in infrastructure construction projects.

Chapters 5-7 provide advice on minimising fragmentation specific to the planning, design, construction and implementation stages of transport infrastructure development.

Occasionally, it is not possible to avoid fragmentation at the planning level nor can the effects be entirely mediated by special mitigation measures. In such cases ecological compensation measures should be considered. This is discussed in **Chapter 8**.

To identify examples of good practice and to provide the basis of good practice guidance, the various methods for mitigating habitat fragmentation need to be monitored. **Chapter 9** provides detailed guidance on monitoring the success of mitigation measures and advises on maintenance issues.

The Annexes include: 1) a glossary, 2) an explanation of abbreviations, 3) a list of participants in the project, 4) related internet links, and 5) a list of other relevant handbooks and guidelines.

Figure 2.1 - The infrastructure lifespan.

1 2 3 4 5 6 7 8 9 10

3 Effects of Infrastructure on Nature

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3.1 Defining habitat fragmentation

Transport networks divide natural habitats into small isolated patches and create barriers between the remaining patches. This can have two primary effects on species; firstly, it can reduce the size of habitat patches so much that they can no longer support viable populations of important species; and secondly, it can result in the remaining patches being so isolated from each other that individuals have a low chance of moving between patches. Being unable to move between patches renders species vulnerable to local and regional extinction. Through these processes, habitat fragmentation by transport networks and consequential secondary developments have become one of the most serious global threats to biological diversity. Although human activity started to fragment nature many centuries ago, the rapid increase in density of transport networks during the 1900s and the effect of increased accessibility have greatly accelerated this impact.

Figure 3.1 - In valleys such as in the Valle Leventina in the Swiss alps railway lines, motorways and other roads often lie close together at the valley bottom. Together they form strong barriers. (Photo by V. Keller)

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3.2 Ecological effects of transport infrastructure

Transport infrastructure has both primary and secondary effects on nature. It is possible to distinguish between five major categories of primary ecological effects that negatively affect biodiversity plus a group of secondary ecological effects: (see Section 3.4)

Primary ecological effects

1. Loss of wildlife habitat.
2. Barrier effects.
3. Fauna casualties - collisions between transport and wildlife.
4. Disturbance and pollution.
5. Ecological function of verges (edges of infrastructure development).

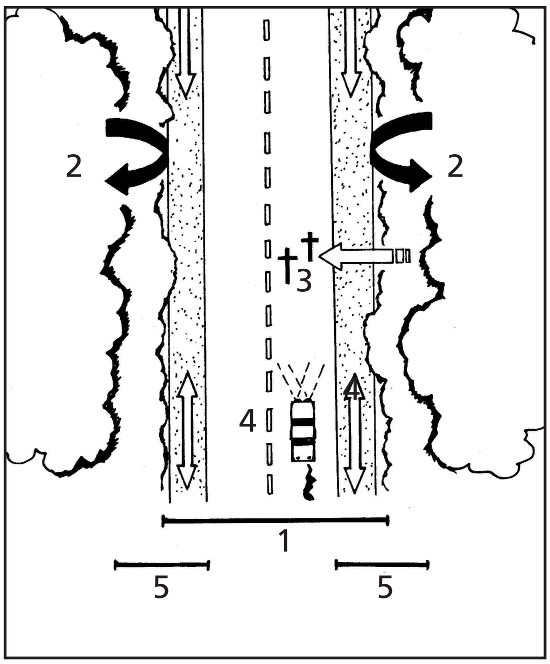

Figure 3.2 - Schematic representation of the primary ecological effects of transport infrastructure. The label numbers relate to the primary ecological effects listed above.

In practice, these effects usually interact and may significantly increase their negative impact through synergistic effects. The consequences of loss and deterioration of wildlife habitat, barrier effects, isolation, and disturbance can be summarised by the term fragmentation.

3.3 Primary ecological effects

Loss of wildlife habitat

The direct impact of road construction is the physical change in land cover along the route as natural habitats are replaced or altered by transport infrastructure. The impact of this net loss of natural habitat is made worse by disturbance and isolation effects that lead to an inevitable change in the distribution of species in the landscape. Roads and roadsides cover an area of about 0.3% of the land surface of Norway to more than 5% in the Netherlands. Thus, at regional or national scales, the direct land uptake by infrastructure may appear to be only a minor issue. Locally, however, the allocation of space for infrastructure will necessarily lead to conflicts with other landuses such as nature conservation, recreation, agriculture or human settlement.

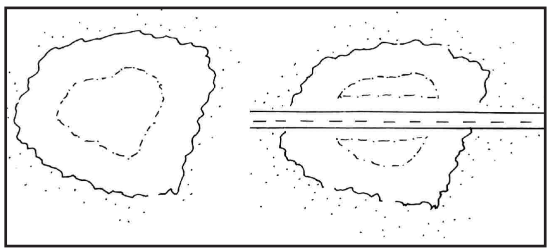

Figure 3.3 - Diagram showing the impact of infrastructure development on the interior core of habitat, important for its special flora and fauna. The area of core habitat lost is far greater than that taken by construction due to the increased edge effect along the route of the road.

Barrier effects

The barrier effect of roads and railways is probably their greatest negative ecological impact. The dispersal ability of individual organisms is one of the key factors in species survival. The ability to move around a landscape in search of food, shelter or to mate, are negatively impacted by barriers that cause habitat isolation. Impacts on individuals affect population dynamics and often threaten species survival. The only way to avoid the barrier effect is to make infrastructure more permeable to wildlife by means of fauna passages, adapting engineering works or by the management of traffic flows. Carefully selecting the route of the road through the landscape can minimise the barrier problem.

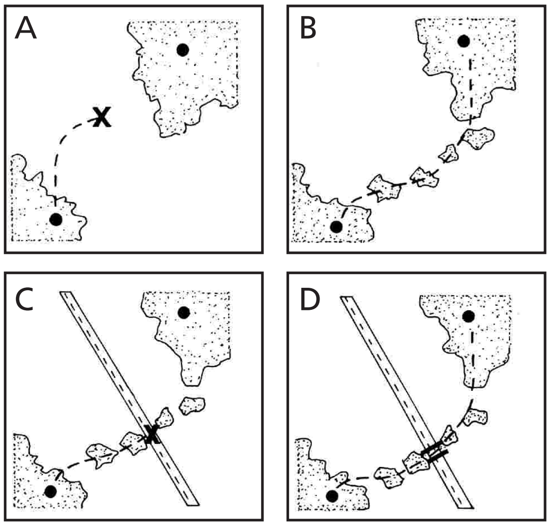

Figure 3.4 - The effect of ecological corridors and road networks on the movement of species across landscapes.

A. In open landscapes without ecological corridors, species may not be able to move between habitats.

B. Small fragments of suitable habitat may serve as stepping stones connecting distant habitat patches.

C. Ecological corridors in combination with roads may attract animals but direct them towards the road where they might be killed when attempting to cross.

D. Mitigation measures such as fauna passages can help to re-link ecological corridors.

Figure 3.5 - Traffic creates important problems for the otter population in the Czech Republic. Migrating otters (mostly males) often do not use small fauna passages and attempt to cross on the roads. (Photo by V. Hlaváč)

Physical barrier: For most of the larger mammals, transport infrastructure becomes a complete barrier only if fenced or if traffic intensity is high. For smaller animals, especially invertebrates, the road surface itself and road verges impose a considerably stronger barrier, either because the substrate is inhospitable or disturbance is too great.

Behavioural barrier: Many larger wildlife species are known to avoid areas near roads and railways related to the degree of human disturbance (traffic density, secondary development). Wild reindeer in Norway, for example, under-utilise their grazing resources within 5 km of roads. Other animals, such as small mammals and some forest birds, exhibit behavioural avoidance patterns particularly associated with crossing large open spaces.

Table 3.1 - The relationship between road traffic density and the barrier effect on mammals. Fences along infrastructure increase the barrier effect of infrastructure. However, fences near passages can be used to lead animals safely to fauna passages.

Traffic density	Permeability
Road with traffic below 1000 vehicles/day	Permeable to most wildlife species
Roads with 1000 to 4000 vehicles/day	Permeable to some species but avoided by more sensitive species.
Roads with 4000 to 10000 vehicles/day	Strong barrier, noise and movement will repel many individuals. Many trying to cross the road become road casualties.
Motorways with traffic levels above 10000 vehicles/day	Impermeable to most species.

The alignment of two or more forms of transport infrastructure along the same corridor (in close proximity) can be beneficial for some species as only one barrier is created. It is, therefore, often advantageous to place two or more parallel routes as close as possible especially in the case of multimodal transport corridors (roads and railways). The disadvantage of multimodal transport corridors is that they can strengthen the barrier effect to some species. There is documented evidence of combined solutions acting as a significant barrier, fragmenting mountain habitats and isolating reindeer populations. Where parallel infrastructures are not placed in a single corridor, the zones between them often suffer local/regional biodiversity declines.

Fauna casualties

Mortality is probably the best-known impact of traffic on wildlife. Millions of individuals of a wide range of wildlife species are killed on roads and railways each year, and many more are seriously injured. Large numbers of fauna casualties may not necessarily imply a threat to populations, but indicate that the species involved are locally abundant and widespread. Traffic mortality is considered responsible for just a small proportion (1-4%) of the total mortality of common species (rodents, rabbits, foxes, sparrows, blackbirds, etc.). However, for more sensitive species, traffic can be a major cause of mortality and a significant factor in local population survival. In Flanders, for instance, more than 40% of the badger population is killed on the roads each year. Such losses represent a very serious threat to the long-term survival of badgers at the regional level.

Numbers of bird casualties can also be significant. Major road schemes adjacent to or crossing wetlands can result in a high density and diversity of birds being forced to fly across roads thus increasing the risk of mortality due to traffic accidents. Large birds such as raptors and owls are attracted to the grassy road verges to prey on the small mammal and songbird populations that concentrate there. Large numbers of these birds become road casualties as they fly low over the road while hunting.

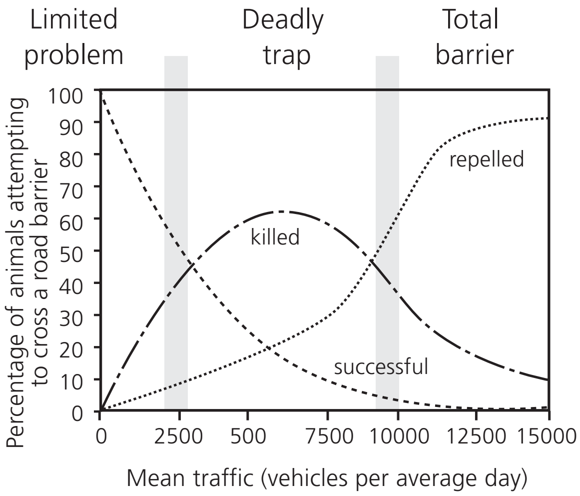

Figure 3.6 - At low traffic intensity (<2500) the small proportion of fauna casualties and animals repelled causes limited impact on the proportion of animals successfully crossing a road barrier. At medium traffic intensity (2500-10000) casualties are high, the number of animals repelled by the infrastructure increases and the proportion of successful crossings decreases. At high traffic intensity (>10000) a large proportion of animals are repelled and despite a lower proportion of fauna casualties there is only a small proportion of successful crossings. (Graph by Andreas Seiler, unpublished)

Species especially sensitive to road barriers and traffic mortality:

- Rare species with small local populations and extensive individual home ranges, such as large carnivores.
- Species that have daily or seasonal migratory movements between local habitats. Amphibians are especially sensitive to road mortality when their seasonal movement to and from breeding ponds crosses roads. Some deer species use different habitats at different times of the day and often cross roads or railways to meet this need.
- Species that have long distance seasonal migrations from summer to winter feeding grounds such as moose and reindeer.

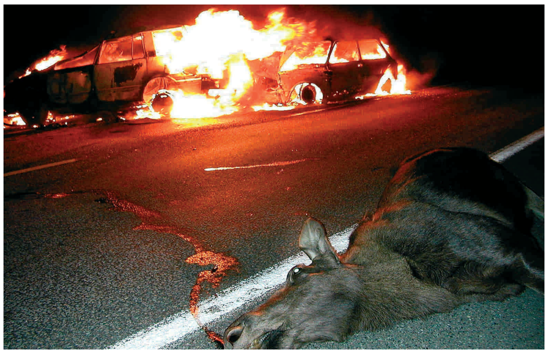

Figure 3.7 - A collision with large mammals such as moose can be dramatic, but these accidents are mainly a traffic safety issue. For smaller mammals and some birds, *e.g.* barn owls, road mortality can have a serious impact on local populations. (Photo (moose) by H. Corneliussen, Fædrelandsvennen and (barn owl) by G. Veenbaas)

Most of the measures taken to reduce the numbers of road casualties are taken for reasons of traffic safety. This is especially true for cases where larger animals such as moose, deer and wild boar are involved. The measures usually focus on stopping the animals gaining access to the road or the railway, but the need to lead animals to safe crossing points to minimise the fragmentation effect is often neglected.

The intensity and concentration of road and rail casualties varies with factors such as temperature, precipitation, season and time of day, and tend to follow the daily rhythms of traffic and animal activity. Seasonal variations in fauna casualties are influenced by breeding, dispersal, seasonal migration patterns and seasonal disturbances such as hunting. The landscape context of roads and railways also influences levels of wildlife traffic mortality. Roads that run parallel to or intersect the edges between forest and grassland are especially hazardous to the animals that move regularly between forest shelter and open foraging habitats.

Disturbance and pollution

Road and railway development and operation alter the ecological characteristics of adjacent habitats, which may induce changes in the way they are used by wildlife. Many of these changes can affect habitat quality at a significant distance from the infrastructure development. The following are the main types of disturbance associated with transport infrastructure.

Hydrological changes: Cuttings and embankments change landscape topography, and often induce large-scale changes in hydrology. Cuttings may increase soil erosion and drain aquifers. Embankments may change the water regime producing either drier or wetter conditions. These changes will affect vegetation, *e.g.* in wetlands and riparian habitats.

Chemical pollution: A wide range of pollutants are derived from road traffic and the road surface. Motor exhausts give rise to, for example, carbon monoxide, nitrogen oxides, sulphur dioxide, hydrocarbons including polycyclic aromatic hydrocarbons (PAH), dioxins and particles. Vehicles are sources of heavy metals such as lead, zinc, copper and cadmium. Sodium and chloride pollution comes from de-icing salt. The chemicals pollute surface and groundwater, soil and vegetation along roads. Compounds containing nitrogen and sulphur contribute to acidification and eutrophication. Pollutants can cause damage or disturbance to biological functions at several organisational levels, from cells through individuals to populations.

Figure 3.8 - Pollution by traffic includes secondary effects such as pollution from de-icing salts, which seriously damage roadside vegetation, as illustrated in this photo of a Norwegian road verge. (Photo by M. Smeland)

Noise and vibration: The disturbance from noise is mainly influenced by the type of traffic, traffic intensity, road surface properties, topography, rail type and the structure and type of the adjacent vegetation. Geological and soil characteristics influence the magnitude and spread of vibrations. Some species avoid noise-disturbed areas. For example, in the Netherlands, bird densities were shown to decline where the traffic noise exceeded 50 dBA, whereas birds in woodland were sensitive to noise levels as low as 40 dBA. Some species breed in normal densities in disturbed areas but with lower breeding success.

Lighting and visual disturbances: Artificial lighting can affect growth regulation in plants, disturb breeding and foraging behaviour in birds or influence the behaviour of nocturnal amphibians. Lights can also attract insects (mercury lamps) and, in turn, increase the local densities of bats along roads resulting in increased bat mortality. The movement of road and rail traffic is thought to disturb several sensitive wildlife species such as wild reindeer (see also Behavioural Barrier, page 5).

Ecological functions of verges

The value of infrastructure verges is a much debated topic. They can be important habitats for some species of wildlife, but they can also lead animals to places where mortality is increased or aid the spread of alien species. Verges can provide links in an ecological network and function as corridors for movement, especially in agricultural landscapes. Their function depends on their geographical location, vegetation, adjacent habitat, management and type of infrastructure. Positive values are more common in northern Europe and problems more often associated with southern Europe.

Habitat function: numerous inventories in highly urbanised countries indicate the potential of verges as habitat for a diverse plant and animal life. Through careful management, infrastructure verges may complement and enrich landscapes where much of the natural vegetation has been depleted. Nevertheless, verges are unable to fully replace natural habitat due to disturbance and pollution effects. As a result, the species composition in roadside communities is often biased towards a higher proportion of non-native and ruderal species.

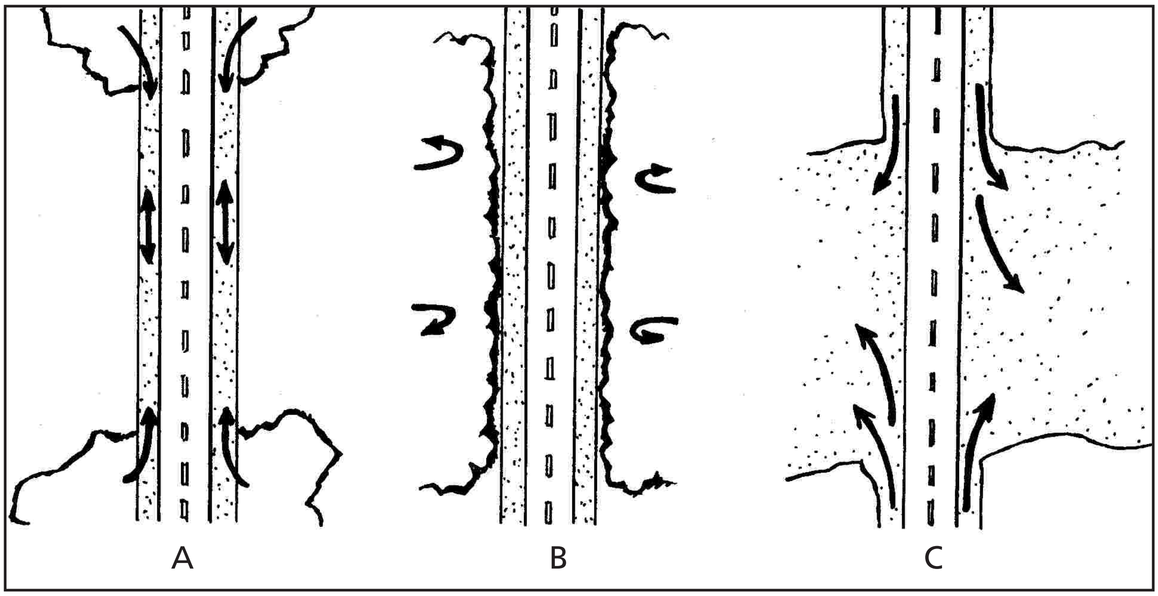

Figure 3.9 - The corridor function of road verges in different landscapes.

A. In open, agricultural habitats, vegetated roadsides can provide a valuable movement corridor and habitat for wildlife.
B. In natural landscapes, open and grassy road verges introduce new edges and can increase the barrier effect of roads to forest species, but increase the corridor effect or provide new habitat for others.
C. Verges may serve as sources for species spreading to new or re-colonising vacant habitats, but may also favour invasive alien species invading natural habitats or the spread of predators.

In more urbanised countries verges can be important wildlife habitat. In the Netherlands, 796 plant species (more than 50% of all plant species) are found in roadside verges. This includes not only widespread species, but also less widespread and fairly rare species.160 rare species (representing 10% of the national total) are mainly found in verges. Low to moderately fertilized grasslands are rare in the Netherlands due to intensive agricultural production and verges represent important refuges for species requiring this habitat. Verge management has changed from lawn management in the 1950s and 1960s, to mowing only 1 or 2 times a year. The result is more colourful verges which are habitat for 50% of Dutch butterfly species (*i.e.* 80 species). It is estimated that 22 of these species can survive in the network of road verges. Even some species under threat in the Netherlands (such as brown argus and small heath) can survive in the verges.

Figure 3.10 - Invasive weed species may spread along transport corridors. In Spain, narrow-leaved ragwort, a weed toxic to cattle, has spread along roads. (Photo by E. Bassols)

Verge management has a strong impact on the value of verges as wildlife habitat. Management operations that affect biodiversity include: tree and bush pruning, mowing grassy vegetation, ditch cleaning and management of culverts, tunnels, fences, fauna passages and other measures. The principles of ecological verge management include careful timing of mowing grassy verges to mimic hay meadows, planting of native bushes and trees, minimising disturbance in the breeding season and reducing the use of chemicals for weed and insect control. Ecological verge management can increase biodiversity locally, but without careful planning can increase traffic accidents or create ecological traps for some species. Hence, planning must be sensitive to local circumstances.

Corridor function: road and railway verges may function as wildlife corridors, enhancing the movement of species along the route. There are positive and negative effects of the corridor function of verges.

Positive: this effect has been observed mainly for small mammals and insects, but corridors also lead wildlife into urban areas, for instance, roe deer, foxes, badgers and reptiles.

Broad verges of low vegetation cut from forest may reduce accidents between road and rail traffic and large mammals by increasing visibility for both animals and drivers. Road verges are seen as important components of ecological networks in northern Europe.

Negative: alien species or weeds may spread along transport corridors through the wind disturbance caused by traffic, or by seeds and propagules transported by vehicles. The examples of rhododendron in the UK and narrow-leaved ragwort in Spain (a weed toxic to cattle) provide evidence of the way alien species can rapidly spread over large geographical areas with the help of transport infrastructure. Road verges can also be a major source of forest fires in the Mediterranean countries. In Spain, for example, more than 24% of forest fires in 2000 were attributed to fires started in road verges (often by cigarettes) and, to a lesser extent, railway verges.

Roads and railways can also function as wildlife corridors enhancing the movement of unwanted species through the landscape. The linking of offshore islands to the mainland by bridges can also initiate the spreading of predators such as mink, martens and fox to otherwise isolated bird colonies. The result is increased bird mortality through predation and disturbance effects.

Verges rarely have the same value as natural corridors, since habitat conditions in road and rail verges are rarely constant over longer distances, and may vary greatly in quality. Roads often intersect with other infrastructure and may lead animals towards these intersections where the risk of accidents is high. Broad roadside verges that contrast with the surrounding vegetation (for instance, grassy verges in a forested landscape) may add to the barrier effect of the road and increase the isolation of habitats.

3.4 Secondary ecological effects

Changes in landuse, human settlement patterns or industrial development induced by the construction of transport infrastructure are secondary effects. New settlements and housing estates may follow the construction of new regional roads and in turn induce the construction of local access roads. These secondary effects are usually outside the responsibility of the transport sector, but should be considered in Strategic Environmental Assessments (SEA) and Environmental Impact Assessments (EIA) (see Chapter 5). In areas where secondary linear development along existing road networks is a major threat to important wildlife conservation strategies, traffic calming measures or road decommissioning may be necessary (see Chapter 7).

One of the main secondary threats associated with infrastructure development is the increased degree of human access and disturbance. Networks of small forest roads provide hunters and tourists access to otherwise undisturbed wildlife habitats. Some design specifications have purposely not included car parking facilities and lay-bys to minimise disturbance to sensitive habitats such as coastal marshes important for waterbirds. However, once infrastructure development has occurred it is very difficult to limit access to adjacent land even if it is of high conservation value. Plans to manage increased access should therefore be drawn up during the planning stage and implemented in association with the infrastructure development.

3.5 Landscape ecology perspectives

Research on the effect of road networks at a landscape or regional scale is still embryonic. The study of large-scale ecological processes is landscape ecology, which is still a young applied science with new and developing methods, techniques and applications. It is very important to take into consideration the larger context of individual infrastructure plans as these larger processes are likely to have significant impacts on nature. However, it is difficult and demanding on resources to collect empirical data on the large-scale and long-term effects of fragmentation by transport infrastructure.

To study possible conflicts between nature conservation interests and infrastructure development, new tools such as computer simulations and spatial modelling are increasingly being used. In the future, they will be important in setting operational design criteria for infrastructure development. Remotely sensed landscape data combined with Geographic Information Systems (GIS) analysis provide promising resources to help place roads in the landscape with minimum negative effects on habitat fragmentation. The challenge for ecological studies is to predict the effects of transport infrastructure on individuals and populations at site, local and regional scales.

4 Developing Integrated Solutions: The Approach

Contents

4

Summary

This chapter introduces the integrated approach to minimising habitat fragmentation due to transport infrastructure which is developed in subsequent chapters. The scoping process, avoidance, mitigation and compensation are introduced and the importance of early consideration of habitat fragmentation and consideration of the different scales of integrated solutions are discussed.

4.1 Countering the threat of habitat fragmentation

The best practice approach promoted by this handbook for planning new or upgrading existing transport infrastructure adopts the following principles for coping with the threat of habitat fragmentation.

Avoidance

↓

Mitigation

↓

Compensation

The basic philosophy is that prevention is better than cure in avoiding the negative effects of habitat fragmentation. Where avoidance is impossible/impractical, mitigation measures should be designed as an integral part of the scheme. Where mitigation is insufficient or significant residual impacts remain, then compensating measures should be considered as a last resort. Although the focus is mainly on new roads, the principles should also be applied to existing roads where repair and maintenance, relationships with other fragmentation sources and the use of existing engineering works should be examined.

Within this system, two of the key questions to be addressed are when are measures needed and what are the criteria for success? This approach forces infrastructure planning to look outside the normal bounds of the transport corridor to examine the development of the whole infrastructure network and wider landuse issues including national and international spatial planning strategies. Measures within the infrastructure corridor must include a consideration of the adjacent landuse and planned development as this may severely reduce the efficacy of any mitigation or compensatory measures.

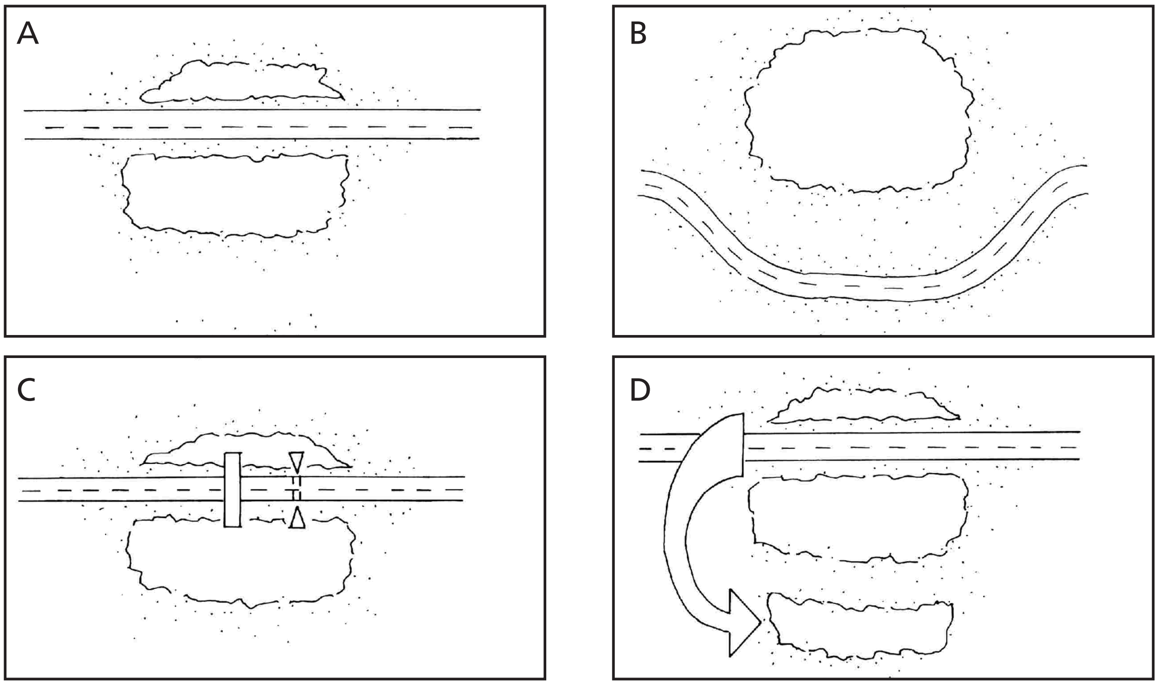

Figure 4.1 - Schematic representation of A) fragmentation, B) avoidance, C) mitigation and D) compensation

Figure 4.2 - Transport infrastructure can fragment habitats, like here at the A36 motorway, Alsace, France. This is an intersection with a minor road leading to fragmentation of the forest environment (Forest of La Hardt). (Photo by J. Carsignol)

Scoping: a process to identify areas to be avoided

The study area is evaluated for environmental interests and constraints to determine conservation issues. Criteria such as habitat diversity, rarity of habitats, conservation status, important landscape elements, species diversity, presence of red-list species and protected species may be used. This is explained in more detail in Chapter 5.

Conservation criteria are the basis for analysing the possible negative effects of the infrastructure route, and for identifying points of conflict between important natural features and the suggested alternative alignments. The sensitivity of habitats and populations to fragmentation, the mobility of animals, the size of their home ranges and their sensitivity to disturbance are all ecological factors that should be considered in this assessment.

All efforts must be made to maintain ecological structures connecting habitats and populations. Particular attention has to be paid to rivers, streams, riparian forests, wooded corridors, networks of hedges, and dikes, which can often be the last refuge for many species in intensively used landscapes.

It is important that transport infrastructure engineering work is co-ordinated at all scales so that all engineering works are sympathetic to habitat and species needs. Even at the detailed site level, minor changes in engineering specifications or design can have significant benefits for wildlife (see Chapter 7).

Avoiding or minimising fragmentation effects is a major consideration during the planning of new infrastructure, the upgrading of existing road and railway routes and the management of problems associated with existing roads and railways.

Avoidance of fragmentation

The avoidance of ecological impacts by not developing the proposed infrastructure may be the only solution to avoid fragmentation of vulnerable habitats. Adapting the alignment of the infrastructure to avoid bisecting vulnerable habitats, reducing the landtake of the road corridor or reducing disturbance to adjacent habitats minimise the impact but do not entirely avoid fragmentation. Avoidance of habitat fragmentation should become the first principle applied in the:

- Planning, design, construction and maintenance phases of infrastructure as well as the upgrading or closing of existing roads and railways.
- Wider involvement of interest groups, and collation of relevant data in the scoping stages of the EIA/SEA process.
- Co-operation between the relevant authorities and organisations.
- Commitment to an integrated multi-disciplinary approach within the planning framework where all affected interests are taken into account in the assessment of development plans.

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Figure 4.3 - The motorway A1 in Switzerland was planned to follow the southern shore of Lake Neuchâtel. This would have fragmented the largest wetland area in the country (area in the foreground). To avoid this, an alternative route was chosen further away from the lake. (Photo by V. Keller)

Figure 4.4 - Mitigation measures can be used to reduce the barrier effects of infrastructure. This is an overpass near Lipnik nad Becvou, Czech Republic, frequently used by a range of species including roe deer and wild boar. (Photo by V. Hlaváč)

Figure 4.5 - If mitigation is impossible, it may be necessary to compensate for loss of habitat by creating new habitats, as here at A46 Batheaston, UK. (Photo by Highways Agency, UK)

Mitigation

The barrier effect of transport infrastructure (see Chapter 3) can be mitigated by employing different kinds of measures, such as over- and underpasses aimed at maintaining landscape permeability through the use of animal crossing structures or adapting engineering works to act as fauna passages. A wide variety of measures are described in Chapter 7. The key questions related to mitigation measures are: 1) what is the problem and where is it located; 2) what kind of measures are appropiate to solve it; 3) what design is fit for the purpose?

Compensation

When fragmentation is unavoidable and mitigation measures are unable to compensate for the loss, damage or degradation of habitat, then compensation in the form of habitat creation may be the appropriate response to achieve 'no net loss' because of infrastructure development plans (see Chapter 8). The habitat creation scheme aims to provide additional habitat of appropiate quality and type to compensate for that lost or damaged by infrastructure development.

Monitoring

For all these approaches (avoidance, mitigation, compensation) adopted measures should be checked to ensure they conform to design and quality standards and that they work (see Chapter 9).

4.2 The importance of early consideration of habitat fragmentation

For new transport infrastructure developments, finding optimal alignment of roads in the landscape can minimise conflicts and the need for mitigation measures such as fauna passages. This requires involvement of ecological expertise at an early stage and throughout the process. Early involvement of local people and public awareness as well as co-operation between a wide range of organisations representing countryside interests are important actions in the planning of new routes to ensure the selection of the best possible solutions. Where mitigation is required, this should be an integral part of the planning and design process where all other aspects important in road planning are considered. Fragmentation effects thus have to be seen in the broader perspective of engineering constraints, costs, landscape, cultural heritage, recreation, agriculture and forestry as well as their impact on nature.

Evaluation of possible fragmentation or barrier effects at a very early phase of the planning process can significantly save costs. Mitigation measures are more likely to be more effective if integrated at an early stage of planning as well as being cheaper than measures built after infrastructure development. Special measures may be needed in urban situations where pressure is already high and the remaining areas of nature severely fragmented.

4.3 Integrated solutions

Finding integrated solutions to road planning is one of the great challenges. It requires information on how to plan the routes of transport infrastructure to minimise impacts within the constraints of cost and engineering. Assessment of new infrastructure will increasingly focus on integrated solutions and attempt to find the route and design which produce the least impact and greatest benefit for the greatest number of interests. Such solutions may involve various combinations of avoidance, mitigation and compensation measures. The integration process is especially difficult in geographic areas where the competition for space is very high such as narrow valleys and coasts. These areas, already under pressure from housing, farming and natural drainage, are fragmented into linear strips by road and railway development with negative impacts on most interests.

Integrated solutions to infrastructure planning can be viewed from several scales, namely from site, landscape and regional levels. Mitigation measures should be considered at all these scales when undertaking EIA/SEA:

- **The regional level**, where the potential routes are first developed in relation to topography, geology, terrain and drainage, as well as the existing infrastructure and settlement patterns. At this level, the total impact of the transport infrastructure network as well as individual plans is considered.
- **The landscape level**, where the routes of individual segments are planned to avoid serious conflict. At this level, land use, landscape, nature, culture and other interests are also taken into account. Landscape structure and the amount and spatial pattern of existing habitats will determine the impact of infrastructure developments.
- **The site level**, where specific engineering solutions are designed to meet the requirements of fitting the road to the terrain to minimise the potential impact. Physical and engineering constraints set the parameters for the design.

The following chapters provide details of methods that can be used to minimise the impact of habitat fragmentation caused by transport infrastructure.

5 Planning Tools

Contents

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5

Summary

This chapter deals with how to minimise habitat fragmentation due to transport infrastructure. Different ways of minimising and reducing habitat fragmentation are described in relation to the different phases of the planning process. Criteria for pointing out potential and existing points of conflict between infrastructure and nature are also discussed.

5.1 Planning to avoid and reduce fragmentation

Habitat fragmentation should be minimised when planning new infrastructure or the upgrade of existing infrastructure. Carrying out Strategic Environmental Assessments (SEA) on plans and programmes and Environmental Impact Assessments (EIA) on projects ensures that environmental considerations are taken into account at an early stage. SEA and EIA should be carried out according to EU directives and their national implementations (Sections 5.2 and 5.3).

The overall aim of the SEA and the EIA is to identify possible environmental impacts of plans and projects before a decision about implementation is made. Another aim is to ensure public consultation on the project. Before a plan or project is adopted and before any construction begins, all SEA and EIA are subject to a public hearing. At this stage, relevant authorities, stakeholders, NGOs and the general public can comment on the plans and influence the project before a final decision on implementation is made (Figure 5.1).

As some degree of fragmentation is inevitable when building a road or railway, mitigation measures must be taken into consideration to ensure permeability of the infrastructure in dispersal corridors and priority habitat areas. In situations where infrastructure crosses especially vulnerable areas or where mitigation measures are inadequate or impossible, compensatory measures may be necessary (Chapter 8).

Fragmentation issues relating to existing infrastructure are somewhat different. For a large part of the existing infrastructure, mitigation measures may not have been taken into consideration during planning and design. In these situations, the fragmentation brought about by the existing infrastructure may have already affected the area, and other sources of fragmentation, unforeseen at the time of the study, may have appeared. New evaluation may be necessary if the assessments that were originally made are outdated (Section 5.5).

5.2 At the strategic planning phase (SEA)

All new regional plans and programmes in the EU countries and other European countries are proposed to be subject to a SEA, according to Directive 2001/42/EC of the European Parliament and of the Council of 27th June 2001. The deadline for the implementation of national legislation is 21st July 2004. The SEA ensures that environmental considerations are taken into account in the development of large-scale planning policies. The SEA should comprise a general description of the plan or programme itself, its main objectives and its relation to other relevant plans and programmes. The SEA process integrates environmental considerations in the decision-making process prior to project-level EIA.

5.3 At the project planning phase (EIA)

All major projects, including infrastructure projects, are subject to EIA according to the EU Council Directive (97/11/EC of 3 March 1997).

An EIA relates to a specific project. The process ensures a detailed assessment of adverse and beneficial environmental effects for a range of alternative solutions, depending on the detail of assessments included in the SEA process, which varies between countries. The scoping process, described in Section 4.1, is the basis for the consideration of alternatives. These assessments are followed by recommendations for measures to minimise or compensate negative environmental impacts.

All environmental factors are also assessed for the situation where the project or the plan is not implemented. This is often termed the "do nothing" scenario. The future situation without the project should be described primarily for getting a reference.

The EIA is used as a basic document throughout the project planning and design phases and also as a common reference and communication tool.

5.3.1 Scope of the EIA

Assessments are made of all environmental factors, such as air, soil, surface and ground water, and take into account both physical and chemical impacts on ecosystems, flora and fauna, as well as effects on landscape and assets such as recreational value and cultural heritage. The EIA also addresses the interactions between these factors as well as the cumulative effects of separate projects or developments.

An EIA should provide at the very least:

- A description of the project including site information, the design and scale of the project at all project phases.
- An outline of the main alternatives explored by the developer or proposed by the public (including the "do nothing" option) and an indication of the main reasons for the choice, taking into account the environmental effects.
- A description of measures proposed for the avoidance, mitigation and reduction of significant adverse effects on the environment.
- A full description of the methodology and data used for the assessment, including an overview of parts of the assessment from which information is missing.
- A non-technical summary of the assessment.

5.3.2 Parameters of the EIA

As a basis for deciding where avoidance, mitigation or compensation are needed, the following parameters are used:

- Special areas for conservation (International sites, EU-habitat and Ramsar areas, etc.).
- Rare and endangered fauna species (*i.e.* species on the IUCN red-lists).
- Rare and endangered plant communities and vegetation types (forests, grasslands, wetlands, etc.).
- River valleys and wetlands (the objective is to remove all obstructions from wetlands).
- Undisturbed natural or cultural landscapes of high value.
- Important ecological networks.
- Dispersal corridors in areas which are already fragmented.
- Other types of important habitats.

In addition to these factors, technical design and traffic safety play an important role in influencing decisions on avoidance and measures for mitigation and compensation. Often the EIA is carried out in tandem with the project design as an iterative process involving planners, road engineers, environmentalists and architects. The public often contributes knowledge on the local distribution of important species and habitats.

For more detailed information on planning and construction see Chapters 6 and 7.

5.4 Fragmentation impact assessment of the new infrastructure and EIA

The approach should be analytical and include a substantial empirical element and should be performed by experienced ecologists, conservation biologists and landscape specialists.

Basically, the EIA consists of the following phases:

- Defining the study area.
- Inventory stage: mapping, field surveys and assessment of natural features.
- Evaluation of possible conflicts and assessment of risk of fragmentation.
- Discussion with road designers, planners, architects and environmentalists.
- Realignment and supplementary investigations.
- Selection of alternatives to be considered in the EIA process.
- Planning of mitigation and compensatory measures.

In practice, the EIA is an iterative process, which is more precisely described in Section 5.4.4 and in the Figure 5.1 opposite.

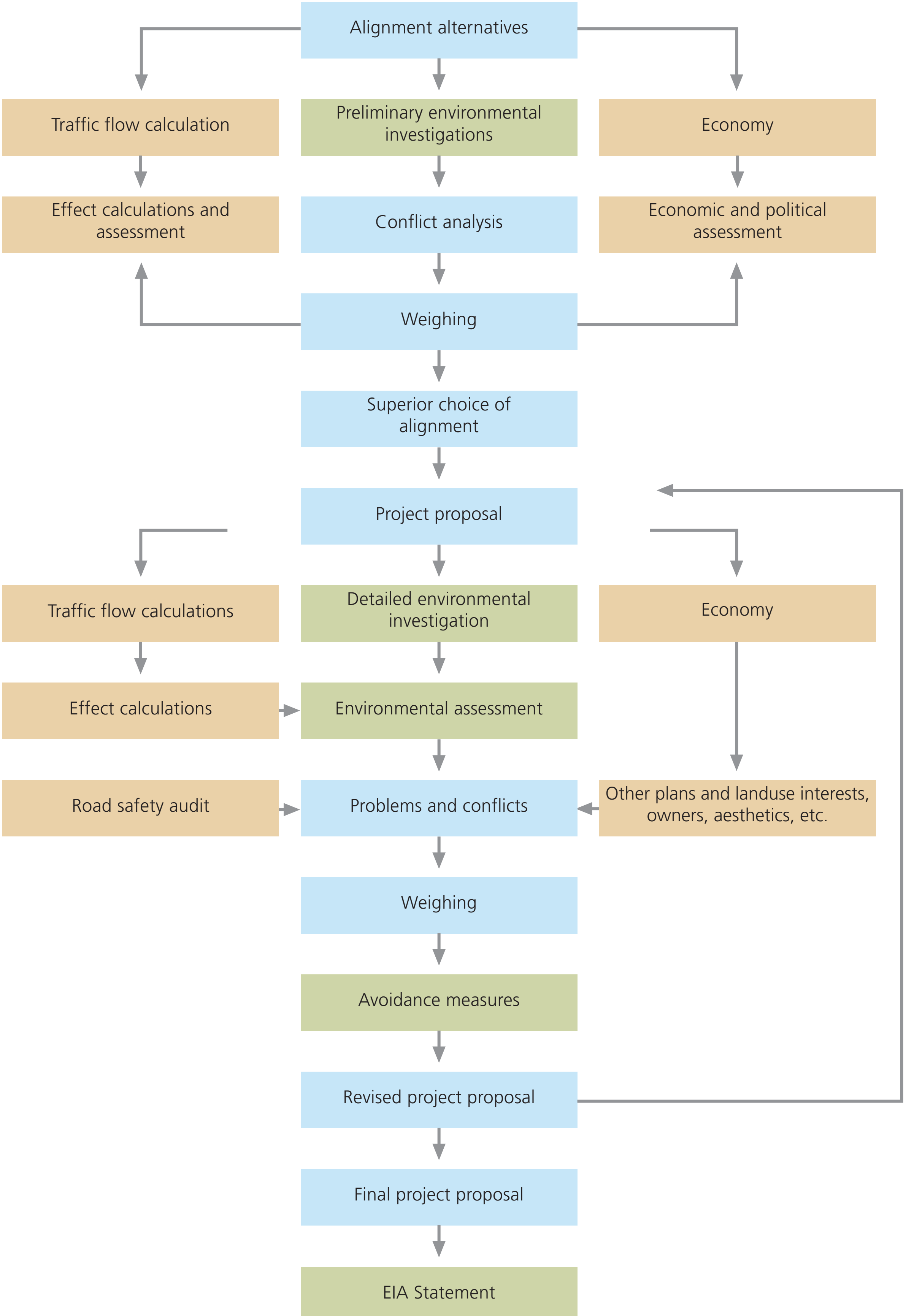

Figure 5.1 - The typical iterative process of an EIA.

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5.4.1 Defining the study area

Clearly defining the study area is crucial for a meaningful study of fragmentation issues. In general the study area must be much broader than the corridor within which the project is to be located, and is determined by the existing landscape structures, fragments and features which are sources of fragmentation. In defining the study area, different scales should be considered:

- **National scale**: observation of long distance migration routes, local bottlenecks and the connection of isolated populations - even when the target species does not permanently live in the area. 1:250000 may be an appropriate scale.
- **Regional scale**: focussing on the impact of the infrastructure, other barriers in the area, topographical connectivity, wooden areas, etc. An important objective is to describe the frequency and location of mitigation measures. 1:50000 may be an appropriate scale.
- **Local scale**: detailed studies of the area including populations, habitats and their locations. Useful information includes observations from local specialists, hunters, forestry personnel, etc. An important objective is to describe the exact frequency, location and dimensions of mitigation measures. 1:5-10000 may be an appropriate scale.

The size of the study area varies with the density of built-up areas and the infrastructure network. Normally the more sparsely populated an area, the larger the study area used. Several mapping scales may be used: an overall view of the area is necessary for analysing the fragmentation (*e.g.* 1:250000 and 1:100000) and smaller scales allow critical areas to be pin-pointed for decision making (maps or aerial photos of 1:25000 or even 1:10000).

5.4.2 Inventory stage

This stage involves a desktop study of planning documents, field inventories and mapping. The features mapped are:

- Landscape conservation designations, landscape elements, undisturbed landscapes and coastal and landscape protection zones.
- Legislative framework and regulations: special protected area maps and regulations, zones of special interest for flora or fauna (including dispersal corridors), areas designated by the Habitat Directive and the Birds Directive, forests, etc.
- Species: stands of rare or endangered plant species, sites of fauna value (*e.g.* breeding or wintering grounds).

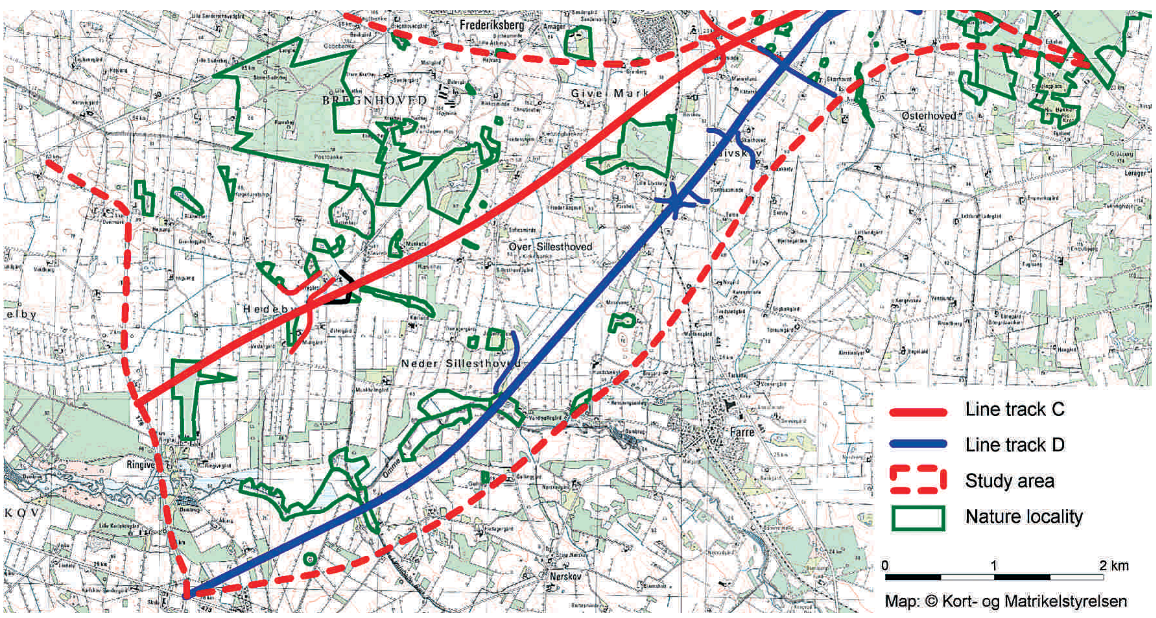

Figure 5.2 - Definition of the study area may vary from narrow corridors to whole regions when long distance migration routes are an important consideration. The figure shows an example of a study area expanded to include significant areas of nature conservation. (Danish Road Directorate 2001: VVM Brande-Riis)

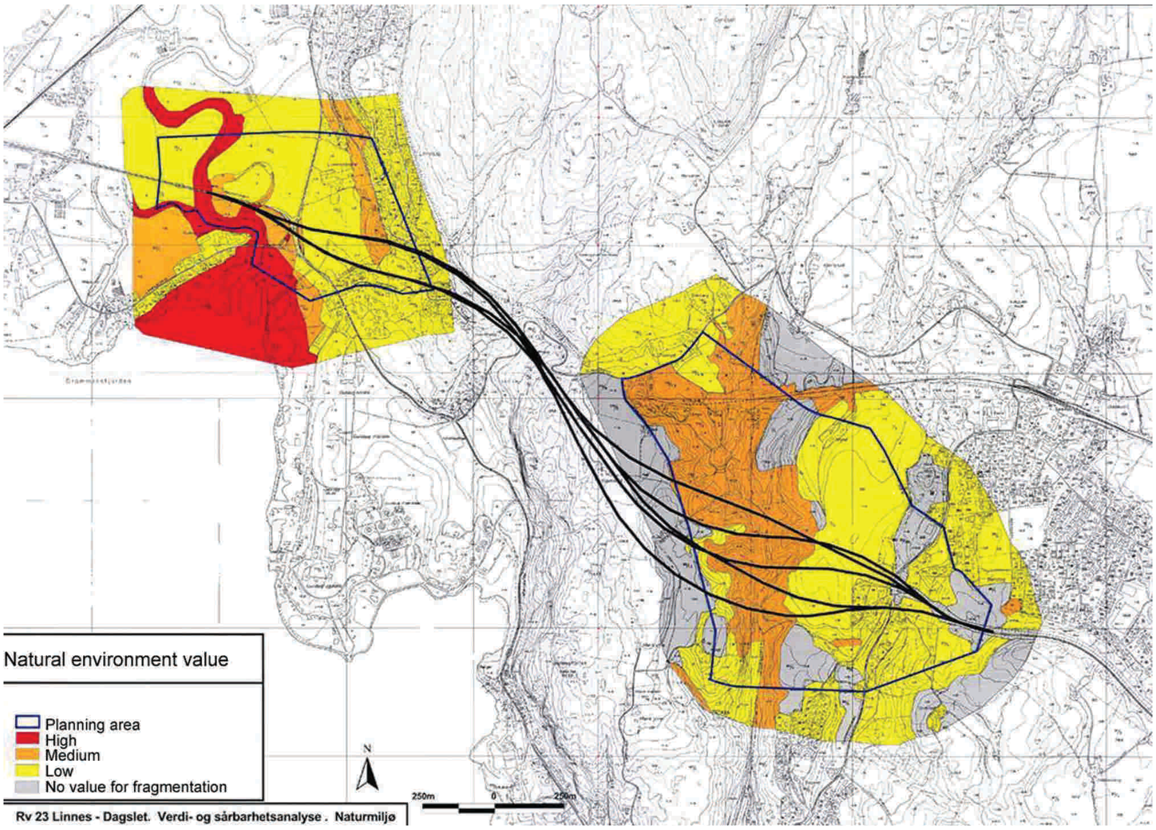

Figure 5.3 - The scale of maps is crucial. Different scales may be used in parallel for different purposes. The mapping must be detailed enough to include all relevant information. The above figure shows a Norwegian map of natural features. (Natural environmental value analysis Hw23 Linnes-Dagslet, Norwegian Public Roads Administration 2001)

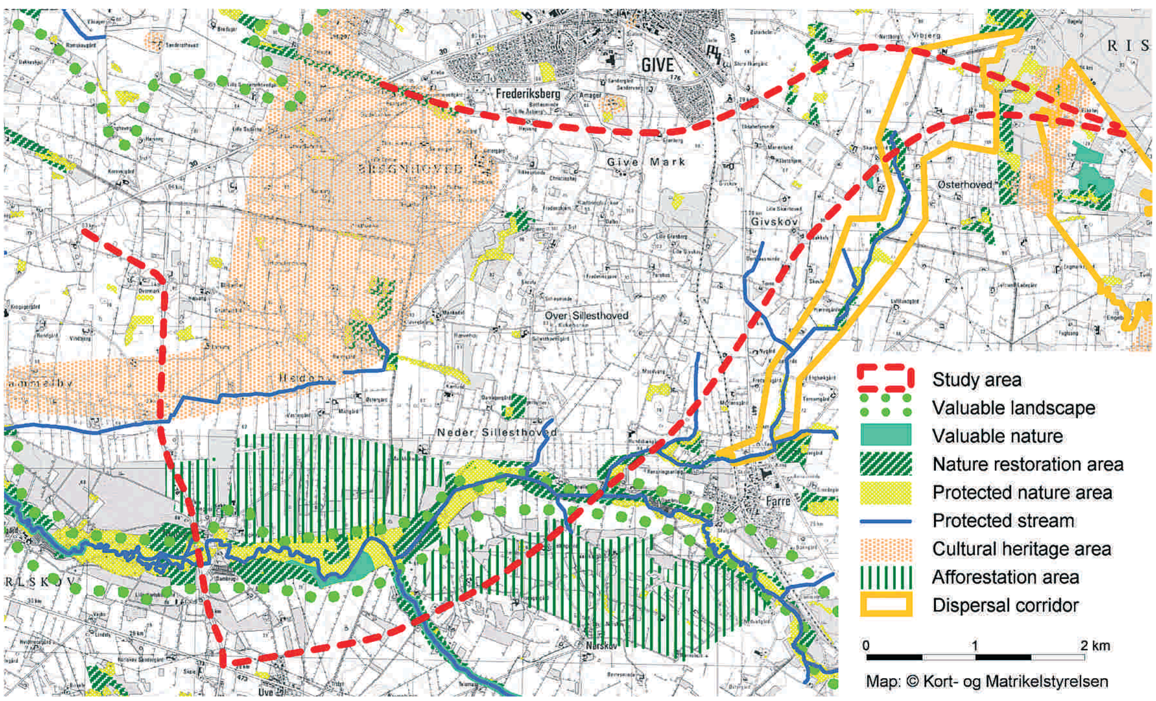

Figure 5.4 - Example of mapping spatial data. Relevant data should be mapped in a way that supports the iterative process of planning and impact assessment. The use of data layers and significant signs and symbols helps communication between the parties involved. (Danish Road Directorate: VVM Brande-Riis)

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All the layers of spatial information for environmental factors and the infrastructure network should be mapped, preferably using GIS. Mapping should include conflict points with migration routes, possible negative influences on vulnerable areas, fragmentation of valuable habitats, etc.

5.4.3 Ecological assessment process

The natural heritage in the study area is evaluated to identify ecological issues. The assessment should be based on the evaluation of:

- Habitat diversity.
- Habitat size.
- Degree of disturbance.
- Rarity of habitats.
- Conservation status, for example nature reserves or Natura 2000 sites.
- Important landscape elements.
- Species diversity.
- The presence of red-list species, protected species and species of the annexes of the Birds and Habitat Directives.
- Populations of game animals and emblematic species (*i.e.* species with strong cultural or emotional appeal).
- The importance and potential for recreational use and related disturbance to wildlife.

Each routing option is shown on a map which illustrates the route's impact and the sensitivity of the area. The illustrations should show:

- Size of the habitats and their location, including small and isolated biotopes located on either side of the route.
- Approximate size of populations on either side of the route (small, isolated populations are always vulnerable).
- Relative location, distribution and spacing of habitat fragments.
- Existing dispersal and migration corridors, including ecological and landscape connections and resting areas, which are not always natural habitats.
- Habitat restoration potential.
- Barrier effect of the infrastructure on small biotopes such as ponds with amphibian populations.
- Barrier effect of the infrastructure with regard to recreational areas and public access.

The maps form the basis for analysing the possible effects of the route and identifying points of conflict between natural features and the suggested alternative alignments.

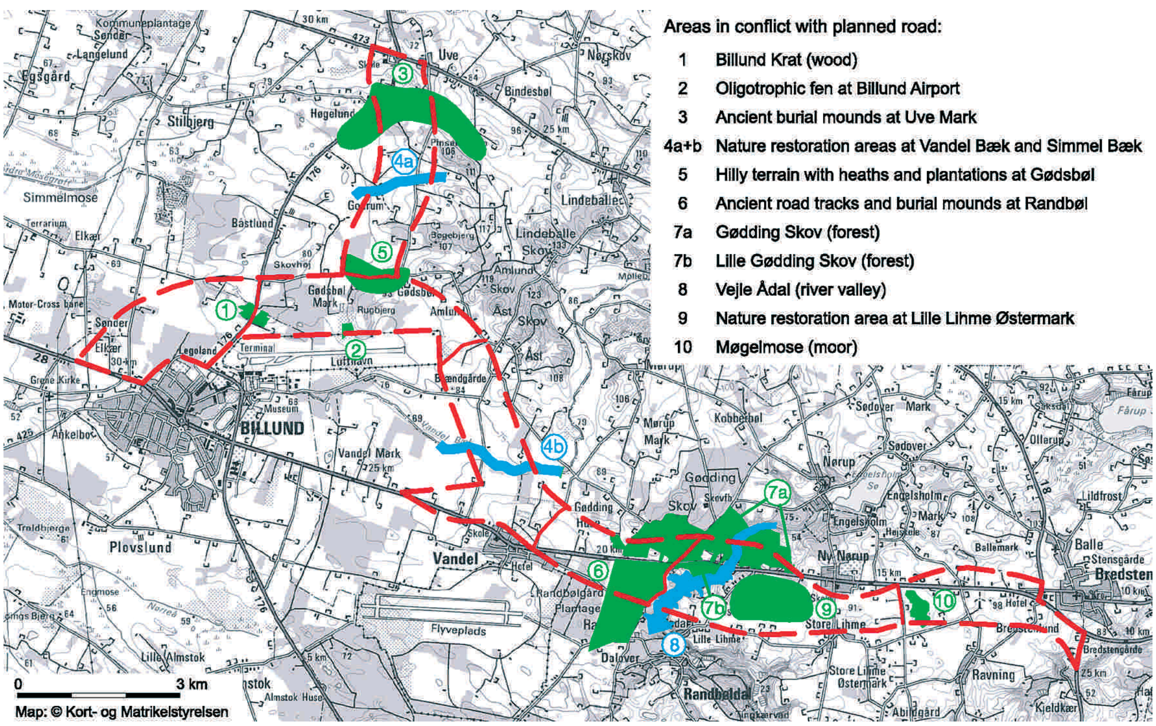

Figure 5.5 - Example of mapping conflicts in a corridor: landscape, recreation and biology. The graphics used should be chosen to highlight the issue; in this case, the fragmentation of habitats and the recreational landscape by a potential road alignment. (Danish Road Directorate: VVM Billund omfartsvej)

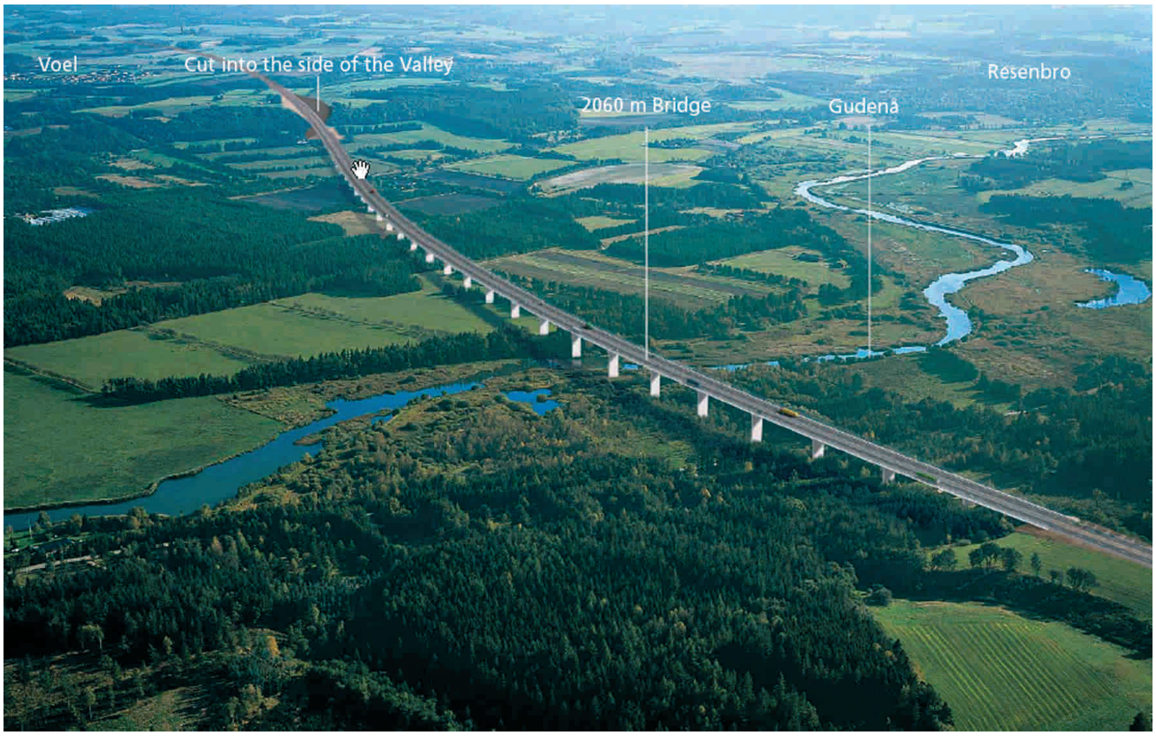

Figure 5.6 and 5.7 - Computer visualisations showing alternative options for a viaduct crossing the Gudenaa river valley, Denmark. (Danish Road Directorate: VVM Motorvejen Herning-Århus ved Silkeborg)

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Efforts must be made to maintain linear structures which connect habitats and populations. Particular attention has to be paid to rivers, streams, riparian forests, wooded corridors and networks of hedges and dikes, which in an intensively used landscape can often be the last refuge for many species. An assessment of the possibilities for crossing the infrastructure must be made: bridges, tunnels, culverts, etc. The density of mitigation measures should be based on vulnerability studies (for more details on density see Section 7.1).

5.4.4 Iterative process of project location and design

An iterative process is ideal if road engineers, planners, architects, conservation biologists, landscape ecologists and cultural heritage specialists have input on project location and design.

The multidisciplinary process will lead to changes of routing and alignments, planning of mitigation measures and other types of environmental adaptation. The process around project location and design is illustrated as part of the overall EIA in Figure 5.1.

The conclusions of conflict analysis made in the evaluation stage must be presented to the developers and road designers during the next stage of the process.

5.4.5 Consideration of alternatives

The selection and ranking of project alternatives must be based on the following considerations and guidelines (for more detailed descriptions see Chapter 6):

- Fragmentation should be avoided especially in areas of high conservation priority and in areas that are not fragmented.
- Functionality of dispersal corridors should be maintained. Relief (hills and valleys) often provides opportunities for decreasing the barrier effects of infrastructure. Rivers, watercourses, riparian forest, hedgerows and rows of trees should be taken into account.
- Infrastructure should be placed in development corridors (areas already disturbed by urbanisation, industrialisation, technical facilities and infrastructure) to avoid further fragmentation of undisturbed, pristine landscapes.
- The conservation of coherent landscape elements such as river valleys, coastlines and ridges.

Landscape and biological features must be weighed against technical, visual and aesthetic considerations: is the site of high ecological value (for instance part of the Natura 2000 network); could the routing be changed; is recreation or tourism important to the area; would it be possible to pay particular attention to the architectural quality of the passages?

Judicious decisions in the planning phase can do away with the need for measures to reduce the impact of the infrastructure later on.

5.4.6 Planning the monitoring programme

During the planning phase and the process of choosing appropriate measures, attention should also be given to monitoring and evaluation. Clear objectives for the chosen solutions as well as criteria for their evaluation should be described and implemented in the monitoring programme (see Chapter 9).

5.5 Existing structures

5.5.1 Improving ecological performance / solving conflicts

The construction of new infrastructure and in most cases the upgrading of existing infrastructure requires the consequences of habitat fragmentation to be taken into consideration, for example through the EIA. In contrast, there are no legislative rules to ensure that barrier problems in relation to existing infrastructure are solved.

Nevertheless, through the Habitat Directive (1992), EU member states are obliged to "*establish supervision of unintentional catch and killing of species mentioned in annex IVa*".

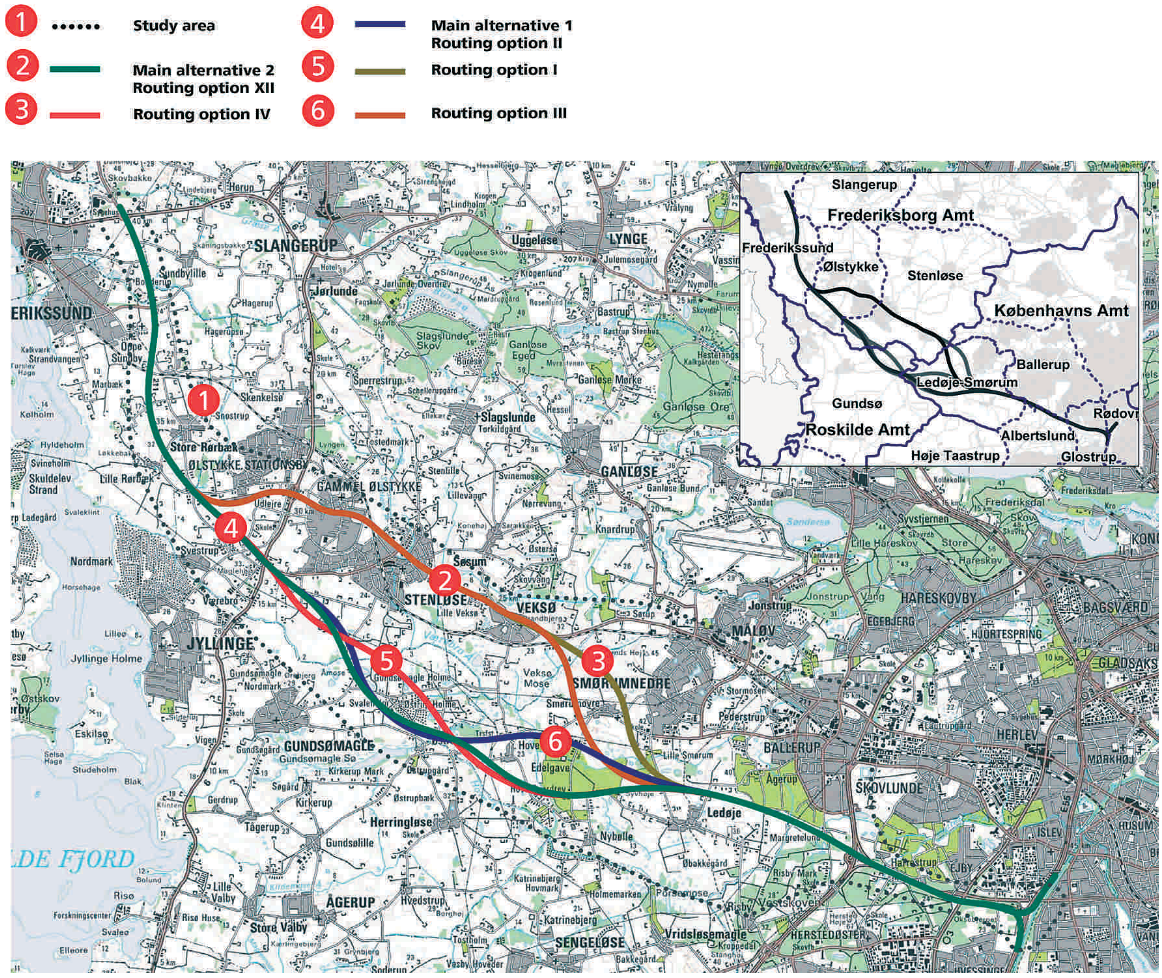

Figure 5.8 - Example of a plan to show alternative routing options and the study area. (Danish Road Directorate: VVM Frederikssundsmotorvej)

This includes traffic casualties and the Directive is therefore relevant to existing roads. The annex states that for those species where unintentional killing is known to have a negative effect, preservation measures must be taken.

5.5.2 Barrier mapping

The purpose of barrier mapping is to identify points or sections where the existing road conflicts with natural structures (rivers, river valleys, forests, etc.) that are part of the main dispersal network or are locally important habitats or dispersal areas. Furthermore, the aim is to point out where and how to improve existing measures and where it is necessary to establish new measures to compensate for the negative consequences of the road.

With simple methodology it is possible to get an overview of the barrier effect of existing infrastructure. The method should comprise:

- Identification and mapping of conflict points.
- Survey and description of conflict points.
- Recommendations of measures to reduce barrier effects.
- Prioritising tasks.

5.5.3 Identification and mapping of conflict points

The criteria for identifying conflict points are the same as mentioned in Section 5.4.3. The following must also be taken into consideration:

- Areas with a high concentration of traffic casualties.
- Existing over- or underpasses for transportation, recreational or agricultural crossings.

5.5.4 Survey and description of conflict points

Mapping should be followed by detailed descriptions of each of the surveyed localities and comprise descriptions of existing structures and features and their position, type and function. The condition of existing constructions, fencing, junctions, embankments and vegetation should be recorded. A visual assessment of the site should also be made to optimise the design for the specific situation and meet functional and aesthetic objectives.

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Example: Density of police-recorded vehicle collisions with moose and roe deer in south-eastern Sweden from 1995 to 1999.

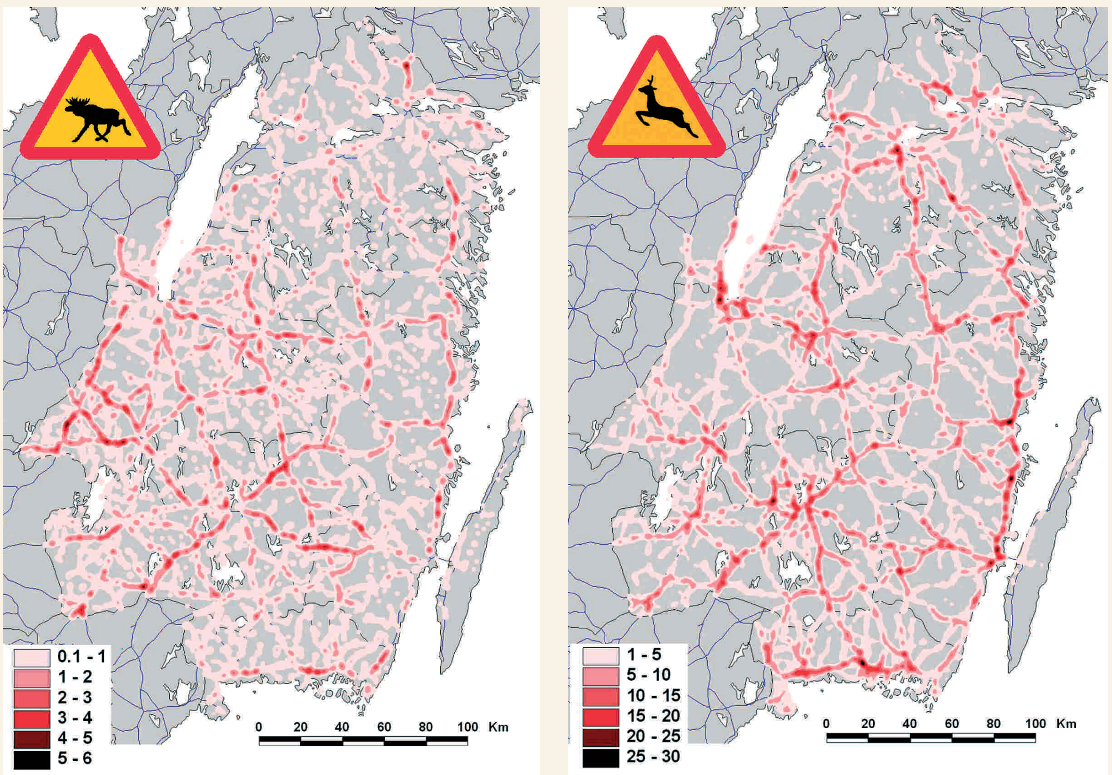

Figure 5.9 - The number of police-recorded vehicle collisions with moose (left) and roe deer (right), within a 2500 km radius over the 5 year period from 1995 to 1999 in the southeast region of the Swedish Road Administration. (Andreas Seiler, unpublished data)

Example: Identifying conflict points and sections in the Czech Republic.

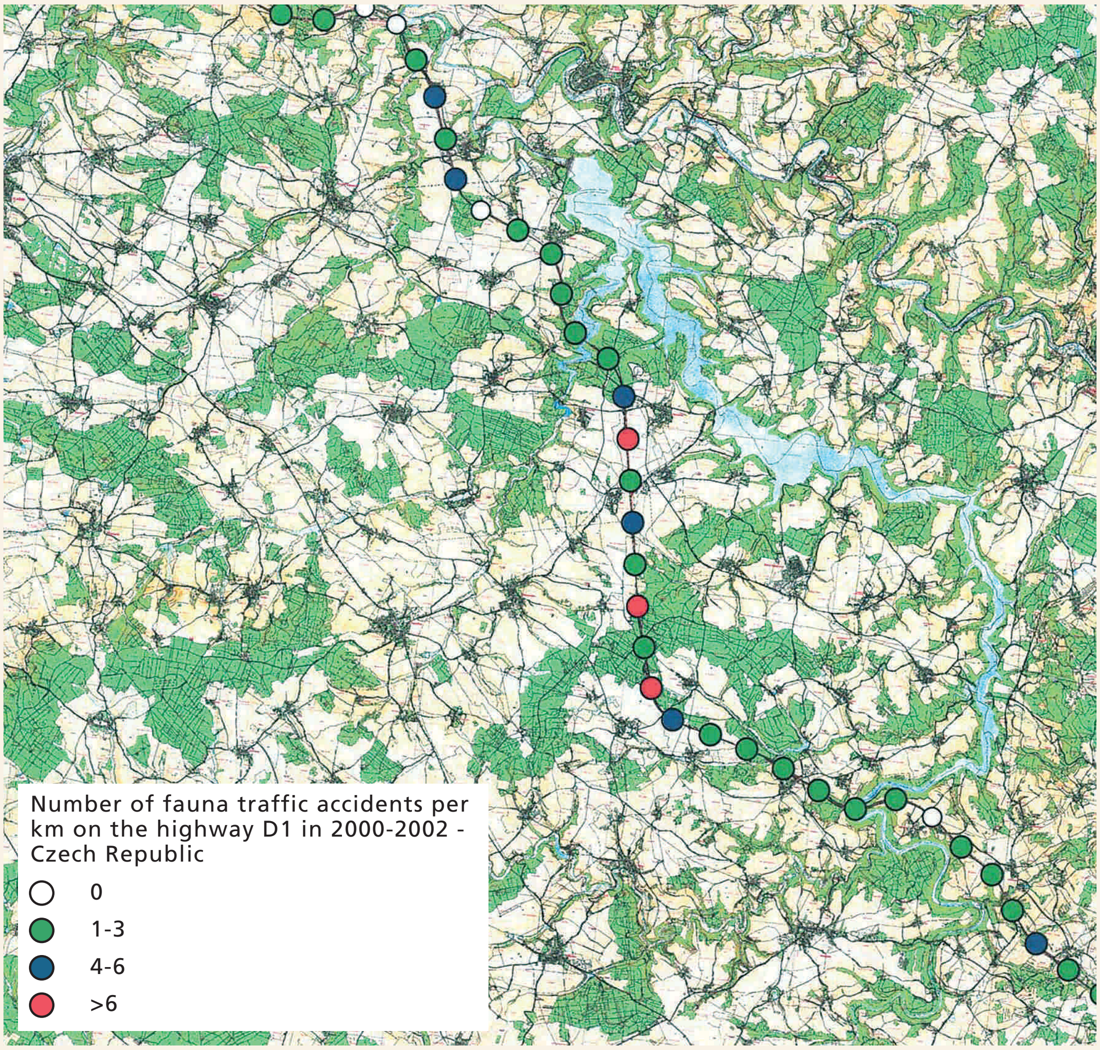

Figure 5.10 - All traffic accidents caused by wild animals were analysed and mapped on a 64 km section of the D1 highway in the Czech Republic. During three years (2000-2003) 145 animals were killed on this section (1 moose, 2 red deer, 18 wild boar, 2 fox and 122 roe deer). (Unpublished)

Example: Identifying and conserving wildlife corridors in Switzerland.

EIAs usually have a study area of only a few hundred metres around the planned infrastructure. It is clear that in most cases this is inadequate to judge the relative importance of a location for connecting habitats at a large scale. This Swiss study of wildlife corridors aimed at giving an overview of the situation for the entire surface of Switzerland, 41285 km^2. Expert knowledge was collected and integrated into habitat-based models. This led to the identification of wildlife corridors, *i.e.* bottlenecks defined as permanently bounded by natural or anthropogenic structures or intensively used areas. For each wildlife corridor the measures necessary to keep or restore large-scale connectivity were identified.

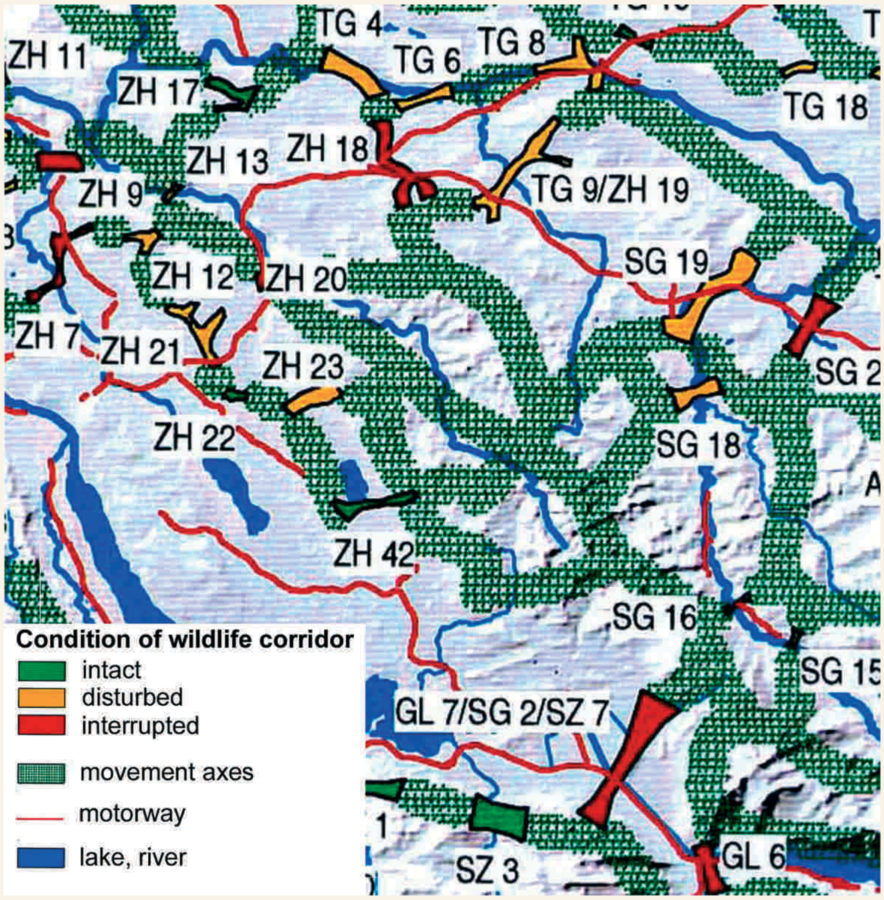

Figure 5.11 - This extract of the map of Switzerland's large-scale 'movement axes' (green dots) shows the connectedness and the most vulnerable or already impaired or interrupted parts of the wildlife corridors. The state of each wildlife corridor is indicated as intact, disturbed or interrupted. Work has started to restore disturbed or interrupted corridors, *e.g.* by building overpasses over existing motorways. (Holzgang *et al*., 2001)

5.5.5 Recommended measures and priorities

The assessment must be followed by recommendations of which locations and sections to improve to reduce the barrier effect. The recommendations will typically include modifications to existing tunnels, installation of new or additional tunnels and plantings and changes in maintenance practices.

Establishing passages across existing barriers is much more expensive than building passages during the construction of new roads and railways. For a large part of the existing infrastructure, bridges, culverts and other constructions can be adapted to provide mitigation measures. By making small adjustments, existing human passages may also be suitable for adaptation to joint-use passages.

Recommendations should include:

- A description of which criteria were used to identify the location as a conflict point.

- A description of objectives and targets (which are the target species and other species likely to use it?).
- A description of recommended adjustments (construction, dimensions and materials).
- Alternative possibilities.
- Rough estimates of costs.

For details about design and construction, see Chapter 7.

It is difficult to give general guidelines for prioritising tasks as regional planning and ecological conditions vary between countries. In the long term though, priority should be given to ensure the integrity of the overall ecological network. In some situations, nevertheless, it may be necessary to preserve local habitat for a single species. In other situations it can be practically impossible to improve conditions, for instance because of the road's position in the terrain. Furthermore, in most places it is appropriate to give priority to obvious, minor improvements of existing passages or to changes in maintenance routines.

As a basic guideline for the sections of infrastructure which require measures:

- Priority should be given to areas that meet several conflict-point criteria.
- The long-term benefits of mitigation measures must be weighed against costs.

5.5.6 Traffic calming

Traffic calming by reducing the dimensions of infrastructure may be an appropriate measure to reduce road kill and habitat fragmentation. In certain situations temporary or seasonal closure of roads is appropriate, for instance in order to avoid road kill of amphibians in their migration periods or to avoid large quantities of snow being removed from the road into peripheral areas. More details on traffic calming measures are given in Section 7.5.1.

5.5.7 Decommissioning of infrastructure

When new infrastructure is being built the removal of old parallel infrastructure should be considered. Possibilities of reducing the barrier effect by narrowing or removing the road or railway line should be considered by analysing the need for and utility of the old road.

In several examples, railways have been removed or partly removed and now work as valuable green corridors in heavily exploited urban or agricultural landscapes. In other cases old railway lines are used as recreational tracks. See Section 7.5.2.

5.6 Upgrading roads and railways

Upgrading infrastructure often increases the barrier effect. If existing infrastructure is not already built with mitigation measures, construction works provide an excellent opportunity to incorporate new measures. Establishing passages across existing barriers is generally much more expensive than building passages across new roads and railways.

Environmental studies that were originally made may be outdated and a new evaluation is often necessary: the fragmentation brought about by the infrastructure could have already affected the area and other sources of fragmentation, unforeseen at the time of the study, could have appeared. Usually upgrading existing infrastructure requires the preparation of an EIA similar to the process described in Sections 5.3.1- 5.3.4.

As before, this enables:

- Analysis and ranking of priorities by superimposing the infrastructure to be upgraded on maps of natural features and of the existing fragmentation.
- Identification of areas of conflict between natural features and the route.
- Discussion about the possible effects of the route. The sensitivity of the habitats with respect to fragmentation, the mobility of the animals, the size of their home ranges and how sensitive they are to disturbance, are all factors to be considered.

- The possibilities of increased traffic density and higher vehicle speed, as a result of a road upgrade must also be taken into account.

The endpoint of this analysis is to describe possibilities for limiting the fragmentation caused by the widened infrastructure or to consider alternatives, taking into account the following:

- Old highly curved roads may be difficult to widen and to adapt to the desired quality and modern standards of traffic safety.
- Broader barriers are more difficult to cross with underpasses, which may be longer and darker and require larger constructions.
- In some cases, building new infrastructure adapted to the landscape with bridges and ecoducts may be more environmentally friendly than mitigating old infrastructure barriers, which were placed without any consideration to landscape or habitats.

5.7 Costs and benefits

Planning new infrastructure or improving existing infrastructure includes economic considerations of the cost, effects and benefits of the investments. Although environmental effects are often difficult to calculate in simple monetary values, the principles of Cost-Benefit Analysis or Willingness-to-Pay methods are often used for this purpose. These methods are based on monetary calculations and should be complemented by a description of the non-monetary benefits to give a full analysis of investments and consequences.

Calculations and descriptions of cost and benefit vary a great deal from region to region and should therefore be based on local factors.

Economic considerations are further described in the COST 341 European Review Section 8.2 (Trocmé *et al.*, 2002).

5.7.1 Describing the costs

During the planning process multiple planning parameters are dealt with at the same time and the proposed solution is often a result of several functional, economic and environmental factors. It can be very difficult to isolate the costs that are related to fragmentation issues. An integrated approach and an iterative planning process will help develop effective solutions with low costs and high benefits. Frequently the choice of solutions determined by the topography can significantly reduce the costs of mitigation measures. In other situations the use of waste material to construct overpasses can be a low cost solution.

A description of costs related to fragmentation should include:

- Costs derived from avoiding fragmentation by choosing longer or more expensive routes and alignments.
- Costs derived from mitigation measures and fences added to the project for defragmentation purposes.
- Costs derived from the limitation to optimise on other functional aspects of the infrastructure.
- Costs derived from compensation measures caused by the fragmentation of the road or rail scheme.

5.7.2 Describing the benefits

A description of benefits related to fragmentation issues should include:

- Benefits derived from the long-term conservation of nature and biodiversity in general.
- Benefits from maintaining ecological coherence in the landscape.
- Benefits derived from preserving habitats for vulnerable species.
- Benefits from avoiding traffic accidents caused by wildlife.

The value of nature and biodiversity conservation can be described on the basis of a Willingness-to-Pay method. Interpretation of results from these methods should take into account that avoiding, mitigating or compensating for habitat fragmentation is a long-term benefit which is often irreversible. In other words, benefits will persist as long as the relationship between infrastructure and the ecological structure is under pressure. Often benefits could increase over time when new infrastructure has secondary effects on urbanisation or other landuse change which increase pressure on habitat fragmentation. The calculation of benefits should therefore take into account the long-term efficacy of avoidance and mitigation measures.

5.7.3 Small investments in existing infrastructure

Existing older structures on roads and railways can often function as mitigation measures with only small changes or adaptations. These investments are not always critical to habitat fragmentation but can strengthen the ecological coherence of the surrouding landscape. In this situation, even small costs can have significant benefits. The recommended planning method is described in Section 5.5.

5.7.4 Longevity of solutions

Longevity of avoidance, mitigation and compensation measures is crucial. Solid, persistent solutions and engineering constructions with a long life span are highly recommended. Wildlife can be very sensitive to temporary disturbance from the renovation of mitigation measures, which could increase the fragmentation effect. Cheap solutions may lead to more expensive maintenance and threaten long-term benefits. From a cost-benefit point of view, mitigation measures should be designed and constructed to last as long as the infrastructure itself.

5.8 Recommendations

When planning to minimise fragmentation, it should be considered that:

- Full incorporation of fragmentation issues into the SEA/EIA obtains the most efficient basis for decision-making with regards to programmes, routing options and design details.
- Comprehensive environmental and ecological information is needed to plan the minimisation of fragmentation caused by both new and existing infrastructure.
- Upgrading roads and railways also requires a comprehensive EIA similar to that used in the planning of new roads.
- Cost-Benefit Analysis based on monetary calculations should be complemented by analysis of the non-monetary benefits to give a thorough appraisal of investments and consequences.

6 Integration of Linear Transport Infrastructure into the Surrounding Landscape

Contents

6

Summary

This chapter describes the principles and key issues for the successful integration of highways, railways and waterways into adjacent landscapes and habitats. The emphasis is on those aspects of integration that are relevant to the minimisation of habitat fragmentation.

6.1 Introduction

6.1.1 Potential effects of infrastructure development on landform

The construction of new infrastructure can impact on landform in a number of ways:

- Habitat loss and fragmentation of nature.
- Changes to the water table and drainage patterns and systems.
- Physical barrier and visual intrusion due to:
  - i) the infrastructure itself;
  - ii) large earthworks;
  - iii) embankments crossing valleys and low-lying land;
  - iv) cuttings which fragment habitats and create scars on hillsides; and
  - v) unsympathetic junctions that can form barriers to wildlife movement and intrude into the landscape.
- Good alignment and sensitive design can be employed to minimise the magnitude of these effects.

6.1.2 Multi-disciplinary approach

The integration and minimisation of fragmentation effects of linear transport infrastructure is best achieved by employing a multi-disciplinary project team of engineering and environmental professionals. Decisions on design will require environmental constraints to be balanced against costs, but ultimately will be dependent upon engineering feasibility and safety considerations. However, consideration should be given to changing engineering standards to accommodate environmental constraints.

- The main design objective is to create a harmonious linear transport infrastructure that integrates with the natural environment.
- The infrastructure should have adequate connectivity above and below the highway, railway or waterway to maintain links and corridors for fauna and flora.

All the engineering elements of the infrastructure should be designed for minimum intrusion into natural habitats, *e.g.* use of a viaduct to cross a valley rather than a solid embankment.

6.1.3 Mitigation principles

The best mitigation involves the selection of the least damaging route alignment combined with sensitive scheme design. The underlying principles are avoidance of damage or direct effects or, if this cannot be achieved, mitigation of impacts. Where impacts cannot be fully mitigated compensation may be necessary. Particular attention needs to be given to the detailed design of earthworks - these are integral to successful mitigation of the scheme and can be blended with the adjacent landscape. Earthworks are considered in more detail in the following section. Other important mitigation considerations:

- Full use should be made of legal powers for the acquisition of land and/or procedures concerning the use of land under licence to install mitigation measures.
- Where a new or improved road or railway affects a site of European importance (*i.e.* designated under the EU Birds or Habitats Directives), land to support a compensatory habitat will need to be secured, developed and managed appropriately.
- Design for effective and long-term maintenance and recognise the limitations of prevailing site conditions.

6.2 Alignment

Route alignment and the design of earthworks should respond to the broad scale of the topography as well as to small-scale landforms. The guiding principle is to work with the topography using engineering elements to minimise habitat fragmentation by maximising the opportunities for connectivity below and above the infrastructure. Earthworks should respond to even minor changes in the geological characteristics encountered along the route. The design of each scheme should take into consideration the full range of vertical and horizontal alignment standards available. These standards will vary considerably according to the type of infrastructure. A single carriageway road in mountainous country that is lightly trafficked may have tighter radius curves and steeper gradients than a dual three lane motorway which by virtue of speed and traffic volume will require gentle gradients and generous radius curves.

A relaxation of standards can be used to good effect to avoid a nature conservation site without compromising the safety of the traffic.

The presence of protected or locally rare species or habitats may influence the choice of alignment and associated earthworks in the design solution. The need to limit incursions into valued habitat may require innovative design solutions such as the use of retaining structures where the road or railway is in a cutting, or the use of a shallow or low-level viaduct rather than an embankment.

Adopting an alignment following the natural contours is, in general, good practice. This helps to integrate a road within the landscape, reduces the need for earthworks and minimises disturbance to adjacent landuse.

Figure 6.1 - A4/A46 Batheaston/Swainswick bypass - within the Cotswolds Area of Outstanding Natural Beauty (AONB) and adjacent to the World Heritage City of Bath, UK. Landscaping was developed with highway design to ensure the best possible fit with the landform. There was extensive use of false cuttings and shallow embankments to screen traffic and blend the engineering slopes gently into the landform. (Photo by Highways Agency, UK)

6.2.1 Responding to ridges and valleys

An alignment that follows the foot of a major ridge will enable infrastructure to remain hidden from view. Even minor ridges offer opportunities for sensitive alignment; a rise of only five metres can be effective for screening purposes. The benefits to wildlife include lower noise levels, reduction of disturbance from vehicle lights and suppression of de-icing salt spray.

Although alignments on the skyline should generally be avoided, following the top of a major ridge can have environmental benefits by avoiding the valley bottom where it can have a major impact on sensitive wetland habitats.

Where infrastructure rises up or follows the side of a valley, the intrusion can be significant. In such situations earthworks need to be properly sited and designed. Major earthworks can be avoided by following the contours high up the valley side. Split carriageways and restored graded-out slopes are effective design solutions. Care must be taken not to grade out slopes where valuable habitats or species may be present.

There will be opportunities to place short sections of infrastructure on shallow viaducts in order to maintain an element of connectivity in the landscape. For further information see Section 7.3.1.

Following a valley bottom may be a satisfactory alignment only if the severance of watercourses and other linear features are avoided or minimised.

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Figure 6.2 - The A27 Brighton bypass runs through the edge of the South Downs AONB in Southern England. Grading the cuttings and embankments to 1:6 fits the road into the downland character. (Photo by Highways Agency, UK)

6.2.2 Alignment in flat landscapes

Flat landscapes vary greatly in character - good alignment and design need to consider landscape scale and context and the following principles:

- Habitat fragmentation should be minimised by integrating crossing points for the target species within the scheme design. On low-level embankments this may be through the use of culverts with dry ledges or the installation of dedicated tunnels such as those for badgers or amphibians. (See Section 7.3.5)
- All transport infrastructure should be kept as near existing levels as possible but should allow for an element of connectivity with sufficient headroom for crossings such as mammal tunnels/underpasses.
- Alignments using existing topographical features, drainage and vegetation are often the best.
- Flat landscapes, particularly wetlands, are often of high nature conservation value, so disturbance of soils should be minimised. The use of a low-level viaduct may be the best solution to cross a wetland area where this is unavoidable.
- Steep, intrusive embankments should be avoided. Viaducts are preferred as they maintain connectivity for species.
- Patterns of large existing features (*e.g.* ditches and hedgerows) should be followed.

6.2.3 Crossing valleys

Infrastructure can be carried across valleys on embankments or viaducts. Viaducts have environmental advantages subject to the choice of the appropriate crossing point.

Viaducts are suited to narrow, steep-sided valleys as they:

- Minimise landtake and fragmentation within a valley by allowing watercourses and any existing nature conservation interest to continue under the structure;
- Maintain connectivity for species movement; and
- Retain views up and down the valley.

For further information see Section 7.3.1.

Embankments are suited more to wide, shallow valleys as they:

- Can maintain some degree of connectivity through the use of appropriately sited and dimensioned culverts and underpasses. In other situations lower alignment may allow the construction of an overpass.
- Can be integrated with the adjacent landform by good use of earthworks and planting; and
- Offer more scope for screen planting.

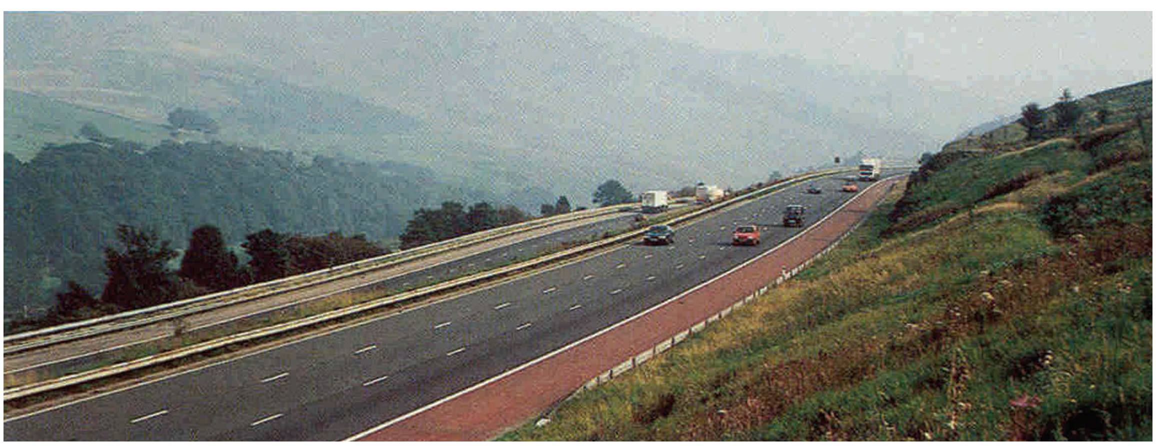

Figure 6.3 - M6, Cumbria in Northern England. The road follows a major ridge and avoids the river valley. Verges are restored to the classic upland vegetation types. (Photo by Highways Agency, UK)

Figure 6.4 - Viaducts minimise landtake and fragmentation within a valley by allowing watercourses and any existing nature conservation interests to continue under the structure. This viaduct carries the A9 highway over an important wetland surrounding the River Mino (Galicia, Northwest Spain). (Photo by AUDASA, Spain)

Figure 6.5 - M40, Cherwell Valley, Oxfordshire. The embankment is a dominant feature but care has been taken to retain the character and form of the river on both sides of the road. (Photo by Highways Agency, UK)

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6.2.4 Crossing watercourses

Diverting or crossing watercourses is often unavoidable and requires good design to ensure a good fit with the landscape and the minimisation of disturbance to the watercourse and the riparian environment. Watercourse crossings need to minimise impacts on the flow characteristics and vegetation and maximise opportunities for new habitat creation.

In general, new or modified watercourses should be wide with shallow margins to allow the establishment of appropriate marginal planting. Engineering design should respect the natural flow and substrate characteristics of the existing watercourse. A wide range of geotextiles and modular systems such as gabion mattresses can be used to create an erosion-resistant watercourse edge which can support riparian vegetation. Local materials should be employed within a site-specific design. It is important to ensure that animals can climb out of rivers, streams and ditches and so steep banksides and concrete elements should be avoided. Where it is absolutely necessary to use them exit steps or inset shallow slopes should be provided. Nature conservation opportunities include the planting of particular species associated with the water environment *e.g.* willow species or the creation of special features like nesting opportunities for birds, dry ledges and other bankside elements for small mammals.

6.2.5 Junctions and roundabouts

Highway junctions and roundabouts can be wildlife traps or islands and are very intrusive unless well sited and designed with earthworks at a scale appropriate to minimise the impact of any signs, gantries, lighting and overbridges. They should be designed to avoid fragmentation with good connections above or below the carriageways as appropriate for the species native to the area.

- Major junctions should be sited on low-lying ground screened by landform, wherever possible.
- Roundabout earthworks generally need to be low, simple and rounded.

Figure 6.6 - A73, Limburg, The Netherlands. The interchanges have been densely planted to minimise the degree of fragmentation caused to the woodland. (Photo by Rijkswaterstaat, Netherlands)

Land contained within junctions can be very extensive (up to 40 ha) and, in some cases, may offer opportunities for substantial planting and the creation of areas of nature conservation interest, *e.g.* species-rich grassland and wetland with balancing ponds. However, these areas should not be isolated from the adjoining land otherwise they become dangerous traps for fauna. They should not be considered for compensatory habitat creation.

- Connectivity between the segments of a major interchange may be important for the movement of fauna and can be achieved using culverts or tunnels.
- Fencing of the correct type may be required to prevent the larger mammals from crossing road carriageways and railway lines at these busy intersections, junctions and triangles.
- Exits from fenced areas should be provided for larger mammals.
- Whenever possible existing vegetation should be retained within the junction.

It is important to be aware of how these structures meet (crossing roads, railways and fences) to avoid confusing the fauna and unintentionally leading them onto the road.

6.3 Earthworks: cuttings and embankments

6.3.1 Siting

Where lateral views of the infrastructure are intrusive, a cutting is one of the best means of hiding it. However, cuttings may themselves become intrusive, fragmenting habitats, creating a notch in the skyline or taking the edge of one side of a hill leaving an ugly scar. A curved alignment over high ground and the careful siting of bridges can help reduce the impacts of a cutting on the skyline. Bridges can be adapted to provide a green connection for fauna and flora.

6.3.2 Varying gradients

Cuttings are usually constructed to a uniform gradient of 1:2 and contrast with natural gradients which are more varied and irregular. Good design can provide better integration with natural landforms and provide opportunities for a variety of habitats to be created.

- Different rock types give rise to different natural slopes and cuttings should reflect these where possible.
- Minor cutting faces especially in upland areas can produce rock exposures with potential nature conservation value.
- It is desirable to reveal the natural bedding plane of the rock to provide a stable slope that will not require for reasons of safety the use of catch fences, wire mesh or other unnatural engineering elements.
- In areas of woodland and rough pasture, an irregular cutting surface finish will provide better integration with the adjacent areas. They can provide niche habitats for certain plants and invertebrates.
- There are benefits in rounding off the tops of cuttings to a gentle profile to create a smooth transition to the natural landform.

6.3.3 Terracing

Terracing can be used to break up the sides of deep cuttings to overcome their visual dominance. It may benefit structural stability and facilitate the establishment of vegetation. It will also provide opportunity to create microclimatic niches for a range of fauna and flora. Terracing needs to work with the natural bedding planes of the parent rock.

6.3.4 Rock outcrops

Rock outcrops can be created in such a way as to provide a sense of place, passenger interest and nature conservation benefits. They are often preferable to attempts to establish vegetation on very steep slopes.

- A varied profile is needed for visual character and to allow vegetation to establish. Natural regeneration of plants is preferable.
- A safe distance must be left between the outcrop and the carriageway.
- Scree, soil and vegetation must be periodically monitored and stabilised.

Figure 6.7 - A6, Derbyshire. This rock outcrop, where naturally regenerated vegetation has become established and the characteristic form of the limestone is exposed, gives a very distinctive character to the road. The dry stone wall emphasises the outcrop. (Photo by Highways Agency, UK)

Figure 6.8 - Terracing breaks up deep cuttings and creates new micro-habitats for a range of flora and fauna, as illustrated here on the highway D1, Czech Republic. (Photo by V. Hlaváč)

6.3.5 False cuttings

False cutting is a means of screening the road from receptors (human and animal) in the surrounding landscape (a depth of 2 m is sufficient to hide cars). It is particularly appropriate in gently undulating ground where a natural cutting cannot be achieved. The best effect is obtained where the backslope is returned to the adjacent landuse. Such slopes can be used to screen nature conservation sites from the effects of infrastructure use, such as de-icing salt spray plumes and drift, lighting and noise.

6.3.6 Grading out cuttings and embankments

Grading out of earthworks can provide integration with the surrounding landscape, whilst ensuring the most efficient use of material. Prominent artificial features can be softened and restored to an appropriate landuse. Grading out of cuttings to slopes shallower than 1:2 helps avoid compaction of soils and makes it easier to establish vegetation.

It is often inappropriate to grade out major cuttings and embankments, either because the scale of the earthworks required makes it impractical or because the grading out would extend into areas of conservation interest. In these cases more attention should be given to the details of the top of cuttings and foot of embankments, variations in gradient and finished surfaces.

6.4 Design solutions

6.4.1 Tunnels

A tunnel may be the best design solution to protect high-value landscapes (see Chapter 5).

Though construction costs may be high the benefits to the natural environment will be incalculable (see Chapter 6). The scale of these benefits is dependent upon the method of tunnel construction. Bored tunnels allow sites of high nature conservation value to remain undisturbed and are least damaging environmentally. Cut-and-cover tunnels may be more appropriate for sites of lower conservation interest, but where the maintenance of connectivity between habitats is desirable. Methods of habitat restoration

Figure 6.9 - Bored tunnels leave the habitat above intact. They are particularly suitable in hilly areas like this example from Bavaria, Germany. (Photo by B. Georgii)

can be employed to provide safe crossing for a range of wildlife.

Siting of the tunnel portals, their landscape treatment, the alignment of the approach road and the design and siting of any ventilation shafts and control buildings are the major environmental design issues for any tunnels. They may intrude into habitats and cause disturbance and pollution locally for sensitive species.

The cut-and-cover tunnel

A cut-and-cover treatment may be a desirable alternative to the open cutting as it permits the landscape to be restored over the line of the infrastructure.

The landscape elements appropriate to the particular location should be carefully designed to be carried over the engineering structure, which must be capable if necessary of supporting large forest tree species. The reuse of the original soils should be considered if they can be stripped and stored in such a way as to minimise compaction and loss of structure.

The soil profile should be constructed to match the adjoining profile in order to reproduce the hydrological characteristics as well as the physical structure and chemical properties of the original substrates.

Where the cut-and-cover tunnel is to be used by a range of fauna, the natural vegetation type for the species' habitat should be planted over the tunnel and on the approaches.

6.4.2 Use of vegetation

At the design stage it is important to understand the type of vegetation and species composition that is appropriate to the setting of the new transport infrastructure. Integration with the landscape, nature conservation benefit and passenger interest are key considerations. Where possible, species included in planting designs should be locally indigenous (especially in rural areas) and occur naturally on the soil type adjacent to the route. They should not require irrigation for successful establishment. Where suitable, natural regeneration should also be considered as an alternative method for vegetating new landscapes. Allowing vegetation to regenerate naturally will produce a habitat most suited to the local surroundings. Some Mediterranean regions have special legislation to regulate the use of vegetation on verges. The high number of forest fires that begin beside roads has obliged highway authorities for example Catalonia in northeastern Spain, to forbid the use of pyrophytic plants such as rock roses on road verges. In the same region there is a requirement to prevent continuity of canopies between trees and shrubs on the verges and the forest trees on adjacent land.

Retaining existing vegetation

- The conservation value of existing vegetation, especially mature vegetation, should be respected since it will have associated with it a mature ecology including lichens, invertebrates, birds and small mammals (see Chapter 9).
- Existing vegetation should be retained where it is likely to remain viable and contribute both to nature conservation and to the integration of the infrastructure.
- Retaining mature trees provides a habitat for many species.
- Where infrastructure dissects an existing woodland the newly exposed edge trees should be thinned/coppiced to provide a more attractive and stable edge.
- Woodland edge species, predominantly shrubs, can be planted to increase the ecological value of the woodland.

Screening Function

- High planted screens may be used to provide a barrier to certain bird species that need to be discouraged from hunting along road verges such as the barn owl. A tall screen will lift their flight path over the road or railway above the area of turbulence from traffic (see also Section 7.3.6). Care should be taken to ensure species planted as screens or in the central reserve are not attractive to birds as a food source.
- A minimum thickness of 10 m is required for a tree screen; 5 m for shrubs.
- Vegetation needs to be at least 4.5 m

tall to screen heavy goods vehicles and large trees should be placed at a safe distance from the carriageway as determined by local or national regulations.

- Best practice design provides a screen of varied width and height while maintaining long distance views.
- In flat landscapes planting must be designed around existing features.
- Off-site planting may be useful for this purpose. (*i.e.* on land outside the immediate transport corridor.) Agreement with third party landowners will normally be required to establish and maintain the planting.

Establishing woodland

Woodlands are usually the product of a long period of management of self-generating trees and shrubs or of deliberate planting and do not have a natural distribution of species. New planting is an opportunity to create a more natural woodland type that will give a special character to the area and be of high wildlife interest.

Natural woodland structure is a mosaic of groups of the same species responding to local changes in soil, topography and drainage. In the Atlantic region for instance beech woodland, is almost entirely dominated by one species while ash and field maple woodland is more varied. Other trees may dominate over more confined areas in more specialised habitats such as willows and alders on wet ground and the elms on richer soils.

- Woodland structure and composition must fit in with any adjacent woodland.
- Species must be native to the locality.
- Correct planting distances are essential for good establishment.

Scrub and tree groups

Scrub communities can be as varied as woodland or they can comprise of large, uniform areas of common species such as hawthorn and blackthorn. Careful appraisal of local conditions is required and the arbitrary introduction of species should be avoided. For example, some Mediterranean countries have regulations or legislation that require a particular planting pattern to reduce fire risk.

- Scrub and small groups of trees are useful for softening the edges of woodlands and help to integrate the infrastructure into the landscape and enhance the wildlife interest.
- Intermittent planting of this kind is particularly important for landscapes like downland and wetland, where large-scale planting is usually inappropriate.

Hedges

Hedges should be provided where they are a feature in the landscape. They are important for nature conservation, especially as corridors for the movement of species such as bats, birds and small mammals. They should be sited in such a way that they can be accessed for maintenance. Hedgerow trees are an important component in the plant mix for hedgerows and should be incorporated in the design.

- Species composition should reflect that of neighbouring hedges and should be planted as a staggered double row of transplants.
- Fencing with light metal posts and stockproof wire will often be required whilst the hedge is establishing.

Grassland and heathland

Large-scale tree and shrub planting may not be the best landscape strategy for new infrastructure. Where screening is not an issue it may be appropriate to create grassland, heathland or scrub of nature conservation interest.

- Grassland should comprise of species of low maintenance requirement sown in moderate diversity into suitable soil conditions (preferably low fertility).
- Heathland, a rapidly dwindling resource, should be created where appropriate using locally indigenous plants or seed.
- A site-specific management regime is essential for ensuring the establishment of habitats of nature conservation value; frequency and height of cutting are key considerations.

The choice of seed for wildflower mixes is complex and should be undertaken with care to suit the site conditions and availability of

Figure 6.10 - M6, Cumbria. The road is absorbed by the strong pattern of the drystone walls which draw the eye away from it. (Photo by Highways Agency, UK)

seed. Where plants are used they should be of native origin.

The management of all vegetation types is an essential prerequisite to meeting the desired objective of maturity. This must be considered at the design stage and the choice of plant size, planting distance, soil preparation and detailed maintenance requirements need to be set out in the specifications for the work.

6.4.3 Fencing, walls and boundary features

Fences and walls may have serious barrier effects as well as a significant effect on the appearance of the road in the landscape. Their use should be restricted to locations where they are absolutely necessary. Technical details regarding these features are given in Chapter 7, but some general principles on integrating them into the landscape are set out below.

- Appropriate styles and alignments should be used to blend them into their surroundings.
- Hedge planting is often complementary to fencing and will have high nature conservation benefits providing both a habitat and a linking feature for mobile species.
- Fencing at bridge abutments and junctions needs particular attention to avoid gaps.
- Fencing and walls should reflect local styles and materials.
- Dominant fencing should be avoided wherever possible and it should not be located on the skyline.
- Fences need not follow property boundaries. Alignments which flow with the road and relate to the alignment of adjacent field boundaries are desirable. (See Section 7.4.1.)

6.4.4 Environmental barriers

Environmental barriers are structures aimed at minimising the impact of the road on adjacent property, *e.g.* earth mounding, continuous fencing, brick walls, concrete barriers, etc. It is important to provide fauna crossings where there are long lengths of barrier otherwise these noise and visual screens become major sources of fragmentation.

6.4.5 Lighting

Lighting should be designed for the minimum light spillage beyond the carriageway or railway to minimise its impact on fauna. For specific design details see Section 7.4.6.

6.4.6 Drainage

Site-specific ditch and drain designs are required in order to integrate the drainage with that of the surrounding land. Drainage elements should be concealed using geotextiles and vegetation cover rather than finishing with in-situ concrete or blockwork. Where the use of hard materials is unavoidable, these should be of local origin. Where appropriate, drainage features can be developed for landscape and nature conservation benefit. Ditches can also act as a useful buffer for adjacent sites of nature conservation interest.

Design must primarily take account of the need to protect watercourses and ground water from pollution, flooding and erosion. Settlement chambers and balancing ponds may be required in certain situations.

- Balancing ponds are opportunities to create features of landscape and wildlife interest provided that a site-specific design solution is used.
- Balancing ponds should have flowing, natural contours with shallow edges to allow for vegetation establishment, *e.g.* reedbeds and wet grassland, and the migration of amphibians.
- Wildlife will only become established if good water quality is maintained.
- Over-deepening of dry balancing areas should be considered to provide a wetland habitat all year round, where this is appropriate in a landscape context.

Filter drains, gullies and catchpits are potential traps for amphibians and reptiles. Care must be exercised to minimise this risk both in their design, maintenance and/or replacement. (For more details see Section 7.4.6.)

Maintenance operations on ditches and ponds to ensure their hydrological function will have to be planned and timed carefully to permit the associated fauna and flora to remain in an undisturbed part of the system.

Figure 6.11 - Balancing ponds provide an opportunity to create features of landscape and wildlife interest. (Photo by Highways Agency, UK)

6.5 Recommendations

Project teams should seek to:

- Choose a route which:
  - i) respects existing landform;
  - ii) requires the fewest large earthworks;
  - iii) minimises the extent of habitat loss;
  - iv) avoids sites of nature conservation interest and, where possible, protects non-renewable resources (*e.g.* ancient woodland); and
  - v) seeks to maintain connectivity through the use of structures that carry the landscape over the infrastructure or permit the landscape to flow under the infrastructure.
- Design profiles which reflect the local topography: embankments and cuttings need to be graded out to match the surrounding slopes and used to minimise noise and visual intrusion.
- Aim to achieve the most sustainable use of excavated material, *i.e.* create a balance of cut and fill material and minimise the need for off-site disposal.
- Ensure the new landform and its soil structure permits effective planting and/or restoration to an appropriate use.
- Planting design (pattern and species) should reflect the adjacent landscape and avoid the creation of a separate corridor of planting.
- Restore as much as possible of the pre-existing pattern of field boundaries, woodland, heathland, etc.
- Establish a clear design objective and maintenance regime for each element of the scheme design.

7 Fauna Passages and other Technical Solutions

Contents

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7.1 General approach

7.1.1 How to use this chapter

Description of measures

This chapter describes individual technical measures designed to mitigate the negative effects of transport infrastructure (see Chapter 3). For each measure a general description is given followed by important information on design and points for special attention. Technical specifications for materials and technical design details are presented if they are of particular importance to ensure the functionality of the measure. However, giving exact design instructions to the engineer would be beyond the scope of this handbook, which is intended for use throughout Europe. In several countries handbooks have already been produced, which deal with some of the issues presented here and which often provide more detailed information. In addition, technical design handbooks may be helpful to find appropriate solutions for construction. A list of national and regional handbooks can be found in Annex 5.

State of knowledge

Some measures have been well tested and considerable knowledge has been accumulated. Others are new and are still being developed and tested. The amount of information presented for each measure reflects this disparity, but best practice according to current knowledge and experience is presented. This means that some recommendations may be different from those in existing handbooks, especially the earlier ones. In some cases, recommendations in a particular country may differ from those presented here because they take into account regional issues such as a specific climate or habitat.

Measures that are not recommended

Some measures that are still widely used have been shown not be effective. Such measures are mentioned in the text, but no design details are given, since their use is not recommended in future schemes.

Relation to other chapters

This chapter should not be read in isolation. Minimising fragmentation starts with general infrastructure planning and avoidance is the first priority. Specific mitigation measures have to be viewed as small parts of an integrated solution. Before looking at the detailed description of a measure, the reader should look at Chapters 4, 5 and 6. Sections 7.1.2 to 7.1.8 provide more information on the relationship between different measures and how to choose the most appropriate ones. In these sections, the emphasis lies on fauna passages as they are the measures most specifically designed to mitigate habitat fragmentation.

Structure of the chapter

For clarity, different measures are described separately, but often a combination of measures is required. The chapter starts with fauna passages designed specifically for wildlife. Adaptations of infrastructure elements to enhance their use by animals are also described here. Fences and other measures that mainly aim at reducing the numbers of animals killed are then described. In this section, some related measures to protect animals alongside roads or railway lines are included as well as measures specific to artificial waterways.

7.1.2 Types of measures and their primary functions

Providing links versus reducing mortality

Measures to protect wildlife along transport infrastructure and to reduce habitat fragmentation can be divided into two groups (Figure 7.1):

- Measures that directly reduce fragmentation by providing links between habitats severed by the infrastructure, *e.g.* wildlife crossing structures or fauna passages (overpasses, underpasses etc.).
- Measures that aim to improve road safety and reduce the impact of traffic on animal populations by reducing traffic-related mortality.

In practice this distinction is often blurred. Measures may fulfil both functions but can also have an associated negative impact. For example, fences are a good means of reducing the number of collisions between large mammals and cars, but at the same time they increase habitat fragmentation. Thus, fences can be regarded as a mitigation measure for fragmentation only in combination with fauna passages that compensate for their negative barrier effect. As a further example, well designed underpasses for otters both link the habitats on either side and reduce the numbers of animals killed on the road or railway line.

Measures designed to reduce animal mortality also include the adaptation of engineering structures that may be fatal traps, particularly for small animals, *e.g.* drains, channels and gullies alongside roads.

Disturbance from roads or railway lines can significantly contribute to the effects of habitat fragmentation on wildlife (see Chapter 3). Measures to reduce disturbance are not dealt with here in detail, but they should be considered together with other measures to reduce traffic emissions (noise, light and chemical pollution).

Specific measures versus modified structures

A further distinction can be made regarding the objective of particular engineering measures. Fauna passages may be designed specifically for animals with human access prohibited. On the other hand, bridges, culverts or other structures built for people can be modified to increase the permeability of the infrastructure for animals. Again, there is no clear distinction between the two groups. A dedicated wildlife overpass, for example, can be combined with a forestry track where foresters occasionally need to cross the infrastructure. Modifying engineering works is often the most appropriate way to reduce the barrier effect of existing roads and railway lines. Many such adaptations are not costly but can significantly increase the permeability of the infrastructure.

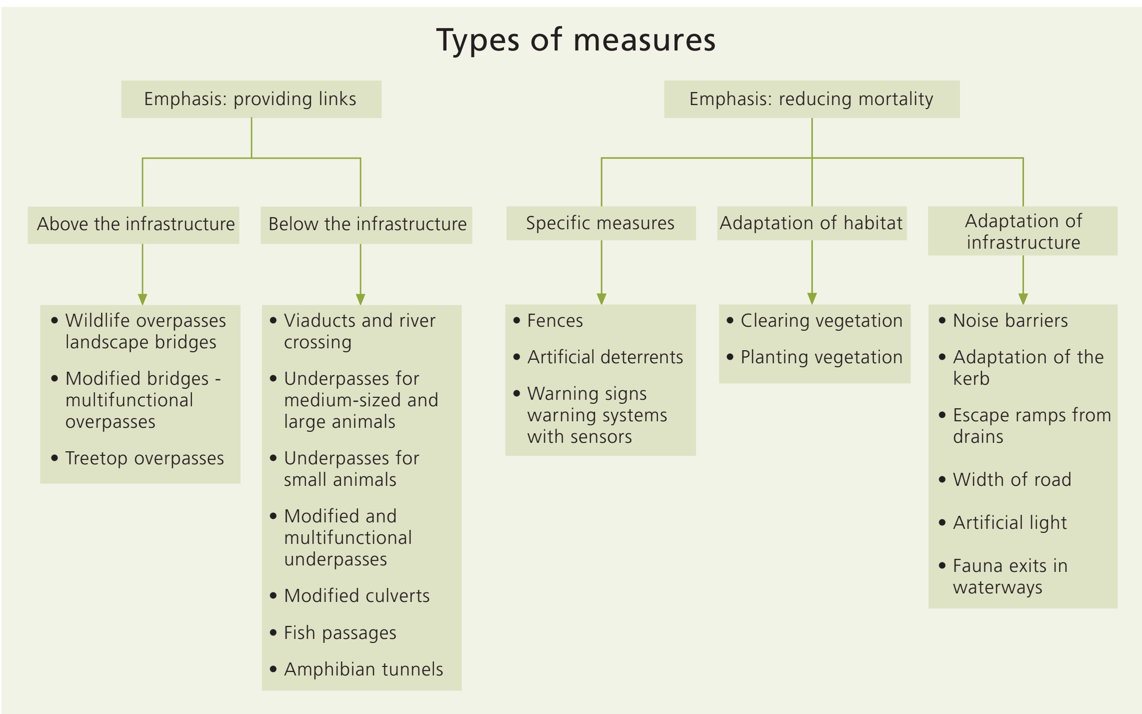


Figure 7.1 - Types of measures to mitigate habitat fragmentation.

7.1.3 Fauna passages as part of a general landscape permeability concept

Fauna passages and other structures adapted to increase the crossing of transport infrastructure by animals should never be considered in isolation. They should be part of a general 'permeability concept' to maintain connectivity within and between populations of animals. This concept emphasises connectivity between habitats at least at a regional scale and considers not only the transport infrastructure but also the distribution of habitats and other potential barriers such as built-up areas. Fauna passages can then be regarded as small but important elements used to connect habitats by enhancing the movements of animals across transport infrastructure.

At a more specific level, a permeability concept can be produced for a particular road or railway project. All connecting elements, such as tunnels, viaducts or elevated roads, stream and river crossings, culverts, and passages designed specially for animals should be integrated into the permeability concept. Again, the primary objective must be to maintain the permeability of the transport infrastructure for wildlife to ensure the connectivity of the habitats at a larger scale.

Mitigation measures, in particular fauna passages, are necessary if transport infrastructure bisects important patches of habitat, creates a barrier to migration routes and if avoidance by altering the route is impossible (see Chapters 3 and 4). Fauna passages are necessary for animals where:

- A road or railway line results in significant damage or loss of special habitats, communities or species.
- A road or railway line affects species particularly sensitive to barriers and traffic mortality.
- The general permeability of the landscape, *i.e.* the connectivity between habitats in the wider countryside, is significantly impaired by the infrastructure development.
- Fauna passages are considered to be a suitable solution for mitigating the barrier effect in the specific context.
- Other less costly measures are unlikely to be effective.
- The road or railway line is fenced along its length.

7.1.4 Choice of appropriate measures

Fauna passages and modifications to infrastructure that enhance the possibility of safe animal movements are the most important measures for mitigating habitat fragmentation at the level of a particular infrastructure. Many principles regarding, for example, the location or number of passages are the same for different types of passage. The following sections deal with these more general aspects.

Types of passages

The selection of the most appropriate type of fauna passage requires consideration of the landscape, habitats affected and target species. The importance of the habitats and species should be evaluated at a local, regional, national and international scale as part of an EIA (see Chapter 5). In general, the more important habitat connectivity is to the target species, the more elaborate the mitigation measures have to be (see Figure 7.2). Thus, where an internationally important corridor for the movements of large mammals is cut by an infrastructure development and this cannot be avoided, a large landscape bridge may be the only measure which can help maintain functional connectivity. In contrast, a small culvert may be sufficient to maintain a migration corridor for a locally important population of amphibians. In practice, however, there is rarely just one measure required to effectively mitigate habitat fragmentation. Instead, a package of integrated measures is required that address problems at specific sites and for the infrastructure as a whole. A combination of diverse measures suitable for different groups of animals will often be the best solution.

Overpasses versus underpasses

There are few general rules regarding whether one is more suitable than the other. The choice is partly determined by the topography. In hilly terrain it is often easy to construct either over- or underpasses, whereas in flat landscapes underpasses may be easier to construct, if the ground water level is not too high. Examples of over- and underpasses in different topographical situations are given in the respective sections. Overpasses have the advantage that it is easier to provide different microhabitats, because vegetation grows more easily than in underpasses. A wider range of species may therefore use them. On the other hand, conditions on overpasses are usually dry, and underpasses therefore seem to be better suited to animals requiring wet or humid conditions. The choice thus also depends on the adjacent habitats that are being connected. Monitoring has shown that, where overpasses and underpasses are close to each other, moose and deer prefer to use overpasses. For burrowing animals, the opposite may be true.

Choice of fauna passages in relation to importance of area / movement corridor

The higher the importance of an area / population / corridor, the more specific and larger individual measures have to be

Conservation importance: high	Conservation importance: medium	Conservation importance: low
• Area or species of national importance • Wildlife corridor of international/ national importance	• Area or species of regional/local importance • Wildlife corridor of regional/local importance	• Non built-up areas: forests, agricultural land, non-productive land
↓	↓	↓
Fauna passages • Specific • Large dimensions Combination of different measures to ensure maximum permeability	Fauna passages • Joint-use • Medium dimensions Combination of different measures to ensure maximum permeability	Modified structures to maintain general permeability

Figure 7.2 - The choice of different types of fauna passages depends also on the importance of an area or corridor.

Figure 7.3 - The Iberian lynx is threatened by extinction. Providing safe connections across motorways is an essential part of conservation action for this species, for which very large home ranges are typical. (Photo by Ministerio de Medio Ambiente, Spain)

Figure 7.4 - Collisions between moose and vehicles can have fatal consequences. Moose and other large mammals are therefore often target species for fauna passages, even when their populations are not threatened. (Photo by V. Hlaváč)

Figure 7.5 - Small vertebrates such as this tortoise, other reptiles and small mammals can be target species for fauna passages as well as non-flying insects and other invertebrates, which also need connections between their habitats. (Photo by H. Bekker)

Figure 7.6 - Common toads suffer from high mortality when they have to cross roads to reach their breeding sites. They are therefore often target species for specific amphibian passages. (Photo by N. Zbinden)

Target species

Any species native to the region can be a target species for fauna passages. Non-native species should not be target species for fauna passages, as they are not part of the natural ecosystem and their spread should not be encouraged. In practice, the expense of building fauna passages will mean that priority will be given to locally or regionally important species threatened by the infrastructure development. Identifying target species is an important step in the planning process where the location and design of fauna passages is, to a large extent, determined by the location and movement patterns of target species (see Section 5.3). Identifying target species is also important as a basis for the planning of monitoring procedures to evaluate the success of a measure (see Section 7.1.8 and Chapter 9).

Even if target species are important in deciding if and where fauna passages are necessary, the design of passages should not just consider one single target species. For example, an overpass across a motorway that is built to preserve a migration route for red deer should also form a habitat connection for populations of invertebrates (*e.g.* insects) or small vertebrates (*e.g.* lizards or mice). Nevertheless, experience has shown that some designs are better suited for particular species than others. Table 7.1 gives some indications that outline the appropriate type of passage for particular species or groups of species.

Table 7.1 - Suitability of different types of fauna passages for a selection of (non-flying) species or groups of species.

	Landscape bridges 7.2.1	Wildlife overpasses 7.2.1	Modified bridges/multi-functional overpasses 7.2.2	Tree-top overpasses 7.2.3	Viaducts and river crossings 7.3.1	Underpasses for large and medium-sized animals 7.3.2	Modified and joint-use underpasses 7.3.3	Underpasses for small animals 7.3.4	Modified culverts 7.3.5	Fish passages through pipes and culverts 7.3.6	Amphibian tunnels (small dimensions) 7.3.7
Ungulates											
Moose, red deer	●	●	—	—	●	○	—	—	—	—	—
Roe deer, chamois	●	●	○	—	●	●	○	—	—	—	—
Wild boar	●	●	○	—	●	●	○	—	—	—	—
Carnivores											
Brown bear	●	●	○	—	●	○	○	—	—	—	—
Lynx	●	●	○	—	●	●	○	—	—	—	—
Wolf	●	●	●	—	●	●	●	—	—	—	—
Fox	●	●	●	—	●	●	●	●	○	—	—
Badger	●	●	●	—	●	●	●	●	●	—	—
Otter	○	○	○	—	●	●	●	●	●	○	—
Marten	●	●	●	?	●	●	●	●	●	—	—
Small mustelids	●	●	●		●	●	●	●	●		
Genet	●	●	●	—	●	●	●	●	○	—	—
Lagomorphs											
Hare	●	●	○	—	●	●	●	—	—	—	—
Rabbit	●	●	○	—	●	●	●	●		—	—
Insectivores											
Hedgehog	●	●	●		●	●	●	○	—	—	—
Shrews	●	●	●	—	●	●	●	●	○	—	○
Rodents											
Red squirrel	●	●	●	●	●	●	●	—	—	—	—
Dormice	●	○	○	?	○	—	—	—	—	—	—
Mice, voles	●	●	●	—	●	●	●	●	○	—	○
Beaver	—	—	—	—	●	—	?	—	?	—	—
Reptiles											
Snakes	●	●	●	—	●	○	○	—	?	—	—
Lizards	●	●	●	—	●	○	○	○	—	—	—
Tortoises	●	●	●	—	●	?	?	?	—	—	—
Amphibians	●	○	○	—	●	●	●	○	○	—	●
Fish	—	—	—	—	—	—	—	—	—	●	—
Invertebrates (non-flying)											
Species of dry habitats	●	●	●	—	●	○	○	○	—	—	—
Species of humid habitats	○	○	○	—	●	○	○	○	○	—	○

● optimal solution
— unsuitable
○ can be used with some adaptation to local conditions
? unknown, more experience needed

7.1.5 Density and location of fauna passages

Density of passages

The density of fauna passages required to effectively maintain habitat connectivity is a major decision in planning mitigation measures. Deciding on the number and the type of measures required will depend on the target species and the distribution of the habitat types in the area. In some cases one or more wide passages will be appropriate whereas other problems will be better tackled by a larger number of smaller-scale measures. An additional argument for constructing several passages is to spread the risk in case a passage is not used as predicted.

In order to determine the number of passages required, the behaviour of target species can be used as a guiding factor. The catchment area of fauna passages, (*i.e.* the area where animals come from) is limited even for mobile species. For most invertebrates, if there are habitat corridors leading to the bridge, the catchment area is at most 200-300 m. For larger animals, individual home ranges and social interaction between individuals limit the range from which animals will be able to use a passage.

When determining the frequency of passages, all opportunities for animals to cross an infrastructure have to be considered, including the ones that may already be available, *e.g.* due to a road being led through a tunnel.

In general, the density of passages should be higher in natural areas, *e.g.* forests, wetlands and in areas with traditional agriculture, than in densely built-up or intensively-used agricultural areas. However, in areas where there are many artificial barriers due to transport infrastructure or built-up areas, fauna passages can be essential for maintaining the general permeability of the landscape. In such cases, solutions can be integrated with all remaining open corridors.

The density of passages required in relation to environmental goals has been poorly studied and more research is needed.

Figure 7.7 - The three-lane highway B31n in Southern Germany cuts off an area along Lake Constance. A high density of passages prevents the habitats from becoming isolated. Passages include wide wildlife overpasses as well as narrower ones combined with agricultural and forestry tracks. (Photo by V. Keller)

Example: Recommendations for the density of fauna passages for mammals in the Czech Republic.

The landscape in many parts of the Czech Republic is relatively unfragmented by infrastructure, and a patchwork of forests and agricultural areas offers good habitat for many mammal species. The motorway network will be enlarged in the coming years. In order to preserve landscape connectivity for mammals, the following steps have been taken:

1. Actual and potential distribution and movement corridors of large and medium-sized mammals were mapped.
2. Based on these data the overall importance of the different regions for mammals was classified (see Figure 7.8).
3. The use of different types of passages and the behaviour of mammals in the neighbourhood of the existing motorways was investigated.
4. Based on these results, recommendations were formulated on the density of passages (see Table 7.2).

Table 7.2 - Maximum recommended distances between passages for different mammal categories in areas of varying importance

	Categories of area		**Mammal category**	
Cat	Area	Red Deer	Roe Deer	Red Fox
I	Exceptional importance	3-5 km	1.5-2.5 km	1 km
II	Increased importance	5-8 km	2-4 km	1 km
III	Medium importance	8-15 km	3-5 km	1 km
IV	Low importance	Not necessary	5 km	1 km
V	Unimportant	Not necessary	Not necessary	1-3 km

(Source: Hlaváč and Andel, 2002)

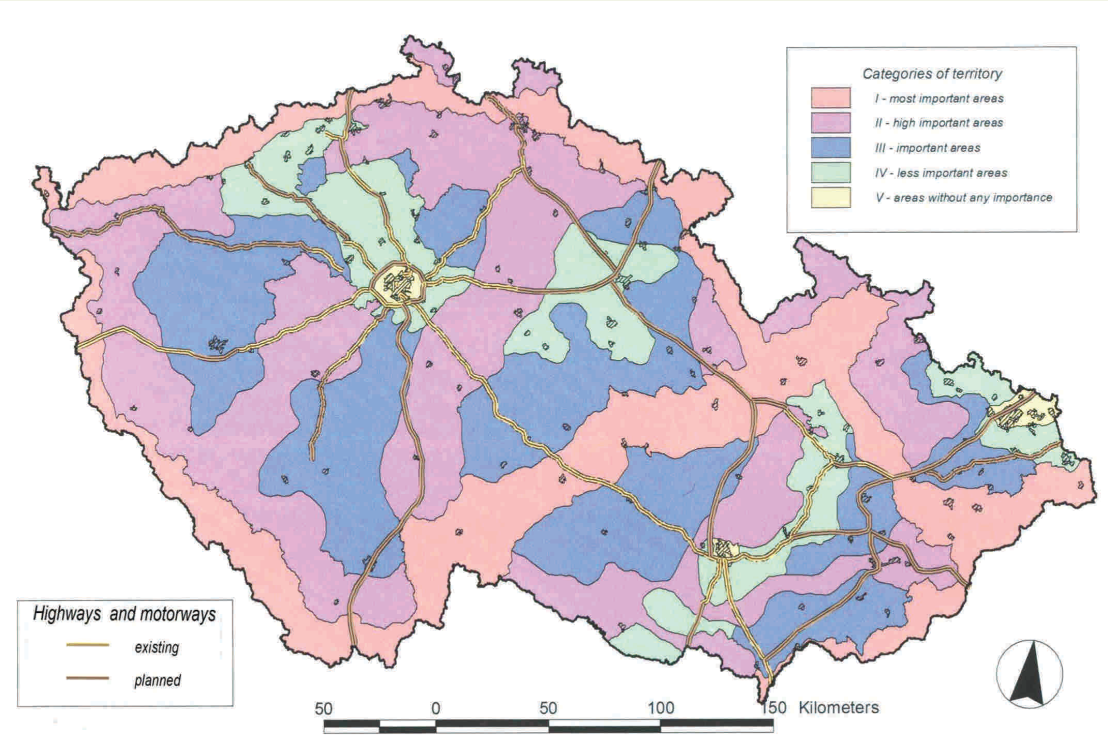


Figure 7.8 - Categorisation of the territory of the Czech Republic according to importance for mammals.

Location of passages

The location of passages has to be decided on the basis of sound knowledge regarding animal movements and the distribution of important habitats. Where clearly defined animal trails exist, passages should be placed as close to them as possible. Often topography and landscape structure can help to identify likely migration routes such as valley bottoms, streams, hedgerows, and continuous woodland. Where the principal aim of a passage is to link particular types of habitat, the passage has to ensure connectivity to suitable habitat on either side of the planned infrastructure. Other barriers existing in the surrounding landscape have to be considered when locating passages. Access to the passage must be guaranteed in the future.

Ensuring that passages are built at all known 'conflict points' (see Chapter 5) must be the first step in defining the location of passages. If this results in a density of passages considered too low to create the necessary level of permeability of the infrastructure in the particular region, additional locations should be identified.

Integration into the surroundings

Fauna passages should be well connected to their surroundings, either by way of habitat corridors leading towards passages for small animals or with guiding lines for larger animals. The probability of an animal encountering a fauna passage can be improved considerably with guiding structures. Barriers that prevent or hinder animals from reaching passages need to be removed or mitigated. Where other infrastructure elements occur in the vicinity, an integrated approach to defragmentation is required.

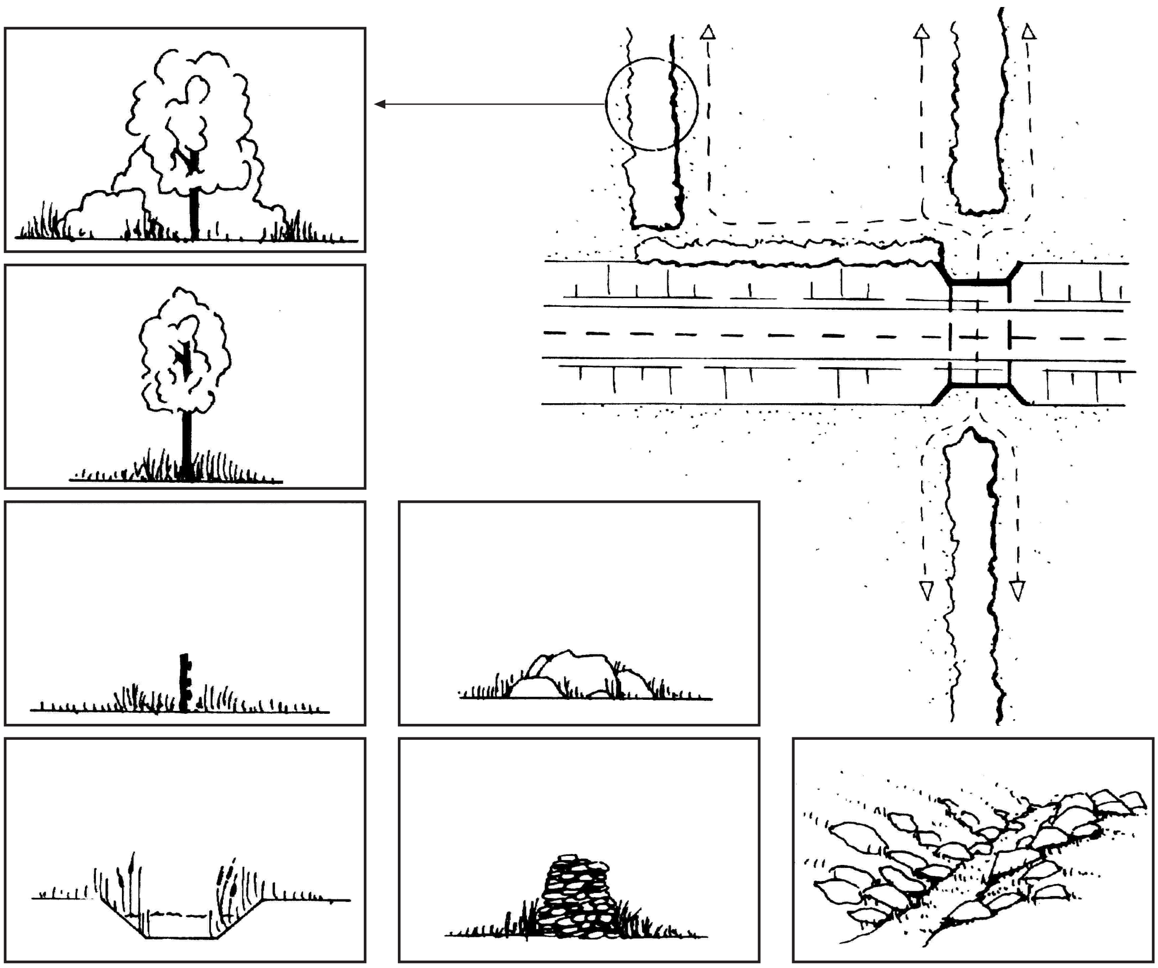


Figure 7.9 - The acceptance of fauna passages by animals depends on good guidance to the entrance. Linear (man-made) structures providing shelter improve the guidance. Some examples of guiding structures (from top left to bottom right): hedgerow, row of trees, cattle fence, ditch, heaps of stones, stone wall, small stream (after Oord 1995).

7.1.6 Adapting engineering works for use by animals

Engineering works are designed and constructed for crossings of two different flows. These can be two flows of traffic (*e.g.* one road crossing the other with an overpass), water and traffic (*e.g.* a culvert leading water under a road or an aqueduct leading water over it) and, more recently, traffic and fauna. Road bridges or culverts are mostly not used by animals to cross a road or railway line, because they don't fulfil the requirements for more demanding species. However, if the demands of animals are taken into account, these existing structures can often be adapted to serve as fauna passages. These passages, which combine the flows of fauna and traffic or fauna and water, are called joint-use passages.

For viaducts and other large structures, often little adaptation is needed for the structures to be a genuine alternative to specific fauna passages. At important sites, however, modified over- or underpasses are usually no alternative to specific fauna passages. Nevertheless, modified structures can help to increase the permeability of infrastructure at little additional cost.

Existing guidelines for the design of roads, over- and underpasses and culverts, etc. mainly focus on drainage, traffic safety and related issues. In many cases, provisions for wildlife at such structures can be implemented without compromising safety aspects. The planning of these structures has to be undertaken jointly by wildlife experts and engineers.

Integrating wildlife requirements in the planning phase of infrastructure development is the best and easiest way to develop cost-effective solutions. Nevertheless, many modifications can also be carried out at existing sites (see Section 7.1.7).

Many design principles relating to specific fauna passages are also applicable for modified and joint-use passages. Some general considerations may however improve joint use by animals and people:

- Both the ecological and engineering requirements have to be known and possible conflicts identified.
- Larger dimensions facilitate joint use.
- As far as possible the flow of human activities (traffic, pedestrians) and the flow of animals have to be separated.
- Providing shelter for animals may reduce disturbance and increase levels of use by animals.
- Lowering the amount of traffic permanently or at certain times (*e.g.* at night) may increase the use by animals.

7.1.7 Solving problems on existing roads and railway lines

In Europe, thousands of kilometres of motorway, other road and railway line have been built before people became aware of the potential problems they caused for wildlife. An obvious need for adapting existing structures arises when there is a high number of collisions between animals and vehicles. High levels of animal mortality, and the need to re-establish movement corridors may require measures to be taken while a road or railway line is in use.

When planning adaptive measures for existing infrastructure the general principles discussed in this handbook should be considered, not just the particular local situation. This is particularly the case when fences are installed to reduce the number of collisions between vehicles and animals. Fences will increase the barrier effect and should never be installed without accompanying measures (see also Section 7.4.1). Most measures described in Chapter 7 are also suitable for existing infrastructure or may be adapted accordingly (see in particular Section 7.1.6).

The principles for dealing with existing infrastructure can be summarised as follows:

- Construction of new engineering works (passages, etc.) above or below existing roads may give the best results but is often more expensive.
- Adaptation of existing engineering works that have been designed for other purposes (*e.g.* water, forestry) is often not an optimal solution, but is in general less expensive. A large number of adapted passages may, in some cases, give better results than constructing one new specific

passage for the same price.

- Modification of maintenance procedures (*e.g.* treatment of vegetation) may improve the situation.

7.1.8 Maintenance and monitoring of mitigation measures

All mitigation measures have to be routinely inspected and maintained to ensure their long-term functionality. Maintenance considerations, including cost, have to be considered at the earliest possible stage, *i.e.* when a measure is designed. Planning should define the type and frequency of maintenance procedures and the organisation of and responsibility for maintenance. In most cases maintenance will be carried out by road maintenance teams, but giving a mandate to nature conservation organisations and farmers, etc., has proven to be a good alternative for certain types of measures. Specific maintenance aspects are dealt with in the sections on the different measures.

The maintenance and monitoring of measures are closely linked. Monitoring procedures are mainly designed to check whether a measure fulfils its purpose, but at the same time they can identify maintenance deficits and needs. Monitoring requires clear definition of the objectives of the measures, and programmes should be planned in parallel with the design of the measures themselves. Monitoring procedures are dealt with in Chapter 9.

7.2 Reducing the barrier effect: overpasses

Overpasses include all fauna passages that cross roads or railway lines above the level of the traffic. In general, the term 'wildlife overpass' refers to connections at the population/meta-population level and 'landscape bridge' refers to connections at the landscape/ecosystem level. Even though there is a continuum between these two extremes, the different terminology helps to distinguish between the different levels.

The main difference between the two types of overpasses is the width, because the larger an overpass the more functions it encompasses. The distinction between the two types is artificial and is defined by a recommended width. Deviations above or below the recommended width should be justified.

Landscape bridges and wildlife overpasses can be designed in various ways, for example as cut-and-cover tunnels or by adapting the design of bridges for traffic. Bored tunnels often have the same function as landscape bridges. They avoid habitat fragmentation by keeping the natural habitat intact. They are therefore not dealt with in this chapter (see Chapter 6).

7.2.1 Wildlife overpasses and landscape bridges

General description and targets

Wildlife overpasses and landscape bridges are purpose-built bridges, usually built over a road with several lanes and/or high-density and fast-driving traffic, over high-speed railway lines or over a combination of both. They are a costly but effective means for minimising, at least locally, the fragmentation effect of transport infrastructure for all terrestrial groups of animals. Several techniques have already been applied and these are described below.

Width, design and vegetation depend largely on the target species, which are usually ungulates or smaller mammals although invertebrates, reptiles and amphibians are also possible target species. For small animals, a bridge must be wide enough at its narrowest point to function as a habitat corridor. For larger mammals, the width and location of an overpass are more critical than the design details, substrate or vegetation. Overpasses have also been shown to act as guiding lines for birds, bats and butterflies, both enhancing the movements of flying animals that may be reluctant to cross open surfaces and reducing mortality.

However, costly constructions like overpasses should not be built just for one or two target species. In most cases the aim should be to connect habitats at an ecosystem level. This requires the simulation of the habitats on either side of the infrastructure on the overpass, taking into account vegetation and environmental factors such as soil type, humidity, temperature and light. This means, for example, that the connection between forests requires at least elements of similar forest habitat on the overpass.

Location

The location of overpasses must be oriented to the occurrence and behaviour of the target species (see also 7.1.5).

- For large mammals, an overpass should be located along paths traditionally used by them. The paths can be determined with the help of fieldwork, *e.g.* mapping tracks in the snow or on marble dust, night censuses using spotlights, census of road kills, or by asking locals using specific questionnaires.
- Avoid areas where human activity causes disturbance.
- Avoid sections with large differences in level or embankments.
- Choose the location in relation to other crossing possibilities for animals.
- Where target species rely on a particular habitat type, the overpass and habitat must both be within reach of the animals.

Dimensions

The width of an overpass is given here from the perspective of the user of the overpass. Road constructors usually call this the length, i.e. the stretch of the road/railway line that is covered by the overpass.

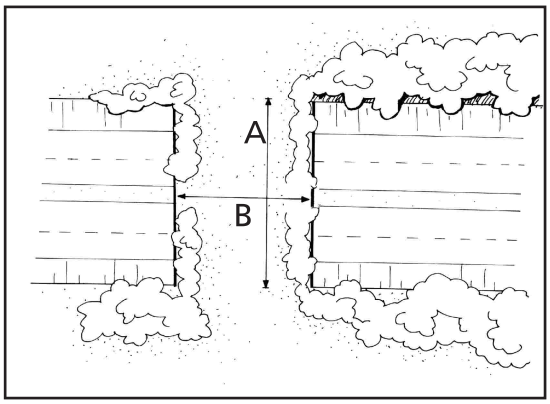


Figure 7.10 - Terminology used for defining length (A) and width (B) of an overpass. In this handbook length and width are defined from the point of view of the animals using the overpass.

General recommendations

Wildlife overpasses:

- In general, larger mammals require wider overpasses than small vertebrates. On the other hand, small vertebrates and invertebrates rely more on the provision of special habitat features, which can only be provided on relatively wide passages.
- A standard width of 40-50 m (between the fences) is recommended. This width can be lowered to a minimum of 20 m if the aim is only to provide a movement corridor for not very sensitive species such as roe deer, or where the topography has a channelling effect leading the animals directly onto the crossing.
- A width below 20 m is not recommended. Experience with mammals has shown that individuals used to the local situation may use narrower overpasses, but frequency of use is generally lower than on wider overpasses. It is also not known how inexperienced animals react to narrower overpasses, *e.g.* young individuals during dispersal. In some cases, funnel-shaped overpasses with a minimum width below 20 m but a width at the entrance of c. 40 m have been shown to be used, for example by roe deer.
- The required width increases with the length of the overpass, *i.e.* an overpass across a six-lane motorway has to be wider than one over a two-rail high-speed railway line. The minimum width to length ratio should be greater than 0.8.

Landscape bridges:

The recommended width for landscape bridges is >80 m. This enables the establishment of different habitats to provide a connection at the ecosystem level (Figure 7.4). The optimum width depends on the diversity and conservation importance of the habitats that have to be connected. In areas of high importance a landscape bridge may need to be several hundred metres wide to preserve the connectivity of the landscape.

Vegetation

- The aim is to guide the target species and a variety of other animals across the overpass.
- The vegetation on the overpass should reflect the habitats situated on either side of the infrastructure.
- Only plant species native to the local area should be used.
- Sowing grass/herb vegetation is not always necessary. Spontaneous establishment can lead to good results.
- An alternative to using expensive seed mixtures may be the transfer of seed bank material (hay, topsoil) from areas adjacent to the overpass.
- Hedge-like structures across the bridge provide a guiding line, cover and protection from light and noise from the road, especially for larger mammal species.
- Where small vertebrates and invertebrates are concerned, the vegetation is designed to resemble as much as possible that adjacent to the bridge, forming a suitable habitat corridor.
- Plant species which are preferred food sources can be used to attract herbivores to the overpass.
- Roots of trees can create maintenance problems on an overpass. The choice of suitable tree species should take maintenance and traffic safety into account.

Soil cover

- Soil is a prerequisite for vegetation and depth depends on the habitat types.
- Recommended topsoil depths:
  Grass/herbs: 0.3 m
  Bushes/shrubs: 0.6 m
  Trees: 1.5 m
- Topsoil or special mixtures can be used.
- Depending on the type of vegetation to be favoured, soil depth can be varied, giving a varied micro-relief and lowering costs.

Figure 7.11 - The overpass Schwarzgraben in southern Germany (B31neu, 50 m wide, combined with local road) is densely covered with bushes and small trees since it aims at connecting the adjacent forests. (Photo by V. Keller)

Figure 7.12 - On the landscape bridge Weiherholz in Germany (B31neu, 80 m wide) only the bushes were planted. Otherwise spontaneous growth of herbs and grasses was allowed, which was later managed by mowing. (Photo by V. Keller)

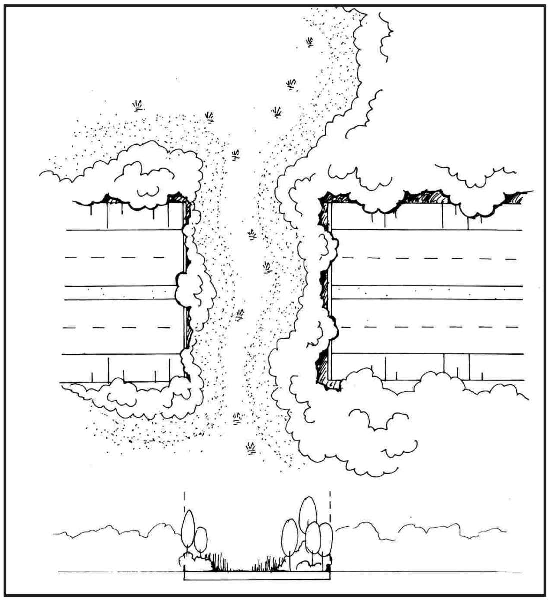


Figure 7.13 - Different habitat types, used by different groups of species, are connected to the overpass from both sides (after Oord 1995).

7

Screening

Screening aims to reduce the disturbance of animals by light or noise. Artificial screens are more important on relatively narrow overpasses. On overpasses of 50 m upwards, hedges on either side, preferably on small mounds, are sufficient.

- The height of side screens should reach about 2 m. In that case, no fences are needed on the overpass.
- On overpasses <20 m wide (recommended only in special situations, see paragraph on width) high screens should be avoided as they may create a negative tunnel effect for animals.
- Screens are probably more important in areas where the only light emissions are from the infrastructure the overpass crosses than in areas where there are other emissions in the vicinity.
- To maximise the width that can be used by the animals, the screens are better placed at the outer edge of the construction.
- Screens have to be properly connected to provisions like noise screens along the road.
- Earth mounds at the outer edge of the overpass and extending along the transport infrastructure make good screens. They are particularly suitable for wide overpasses and landscape bridges.
- Dense hedges used as screens are best placed on a low earth mound.

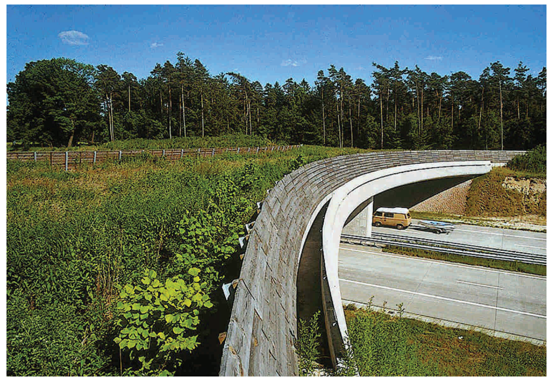


Figure 7.14 - The example of the Boerskotten wildlife overpass (the Netherlands) shows a screen made of wood. The screens have to be as close to the outer edge as possible to ensure a maximum width for wildlife. The ledge on the outside is designed to allow safe access for maintenance. (Photo by H. Cormont)

Fences

Fences are needed to guide animals to an appropriate fauna passage. Design and specifications are given in detail in Section 7.4.1.

- Fences are essential on the outer edge of an overpass if no screens are constructed.
- When screens are built as solid walls, a fence is not necessary.
- Fences on the overpass need a tight connection to fences alongside the infrastructure.

Figure 7.15 - In this example from Hungary the motorway was not cut into the surroundings. The access had therefore to be levelled out. The fences guide animals along the road verges to the overpass. (Photo by P. Farkas)

Design

There are many construction types available. The choice depends mainly on topography, subsoil stability, cost, aesthetics and local design traditions. The following examples are chosen to provide ideas to the construction engineer. They are not intended to provide all the technical details, but to highlight features which are important to ensure the effectiveness for wildlife.

Construction principles relevant for wildlife:

- Leading the infrastructure through a natural or artificial cutting allows an overpass to be built on the level of the adjacent land. See also Chapter 6.
- Where the level of the overpass is higher than that of the adjacent land, the access ramps should not be too steep and should be well embedded in the adjacent landscape. So far there is little knowledge on the maximum gradient tolerated by different animals. In hilly areas steeper gradients may be more acceptable than in flat regions. Some existing overpasses that are used by animals have gradients from 16% in a flat landscape (Hungary) to 25% or more in mountainous regions.
- Shape and materials should ensure that the necessary features (soil cover, vegetation) and the connection to the adjacent land can be achieved.
- On existing roads the use of prefabricated arches reduces construction time at the site.

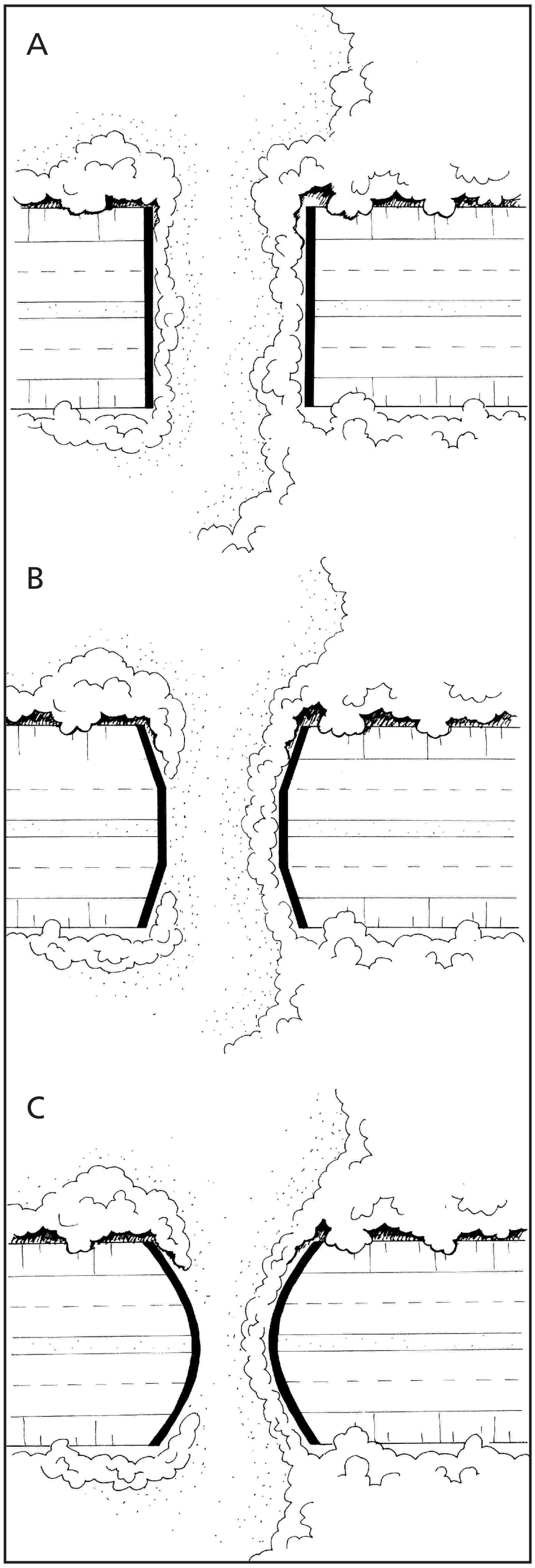


Figure 7.16 - Different shapes of overpasses in plan. A parabolic or funnel-shaped design (B, C) is often chosen to lower costs, which increase with the surface area of an overpass. The construction of a pure parabolic shape (C) is more difficult and costly than a funnel-shaped design with straight lines (B).

7

Figure 7.17 - The side view of Terlet north of Arnhem (the Netherlands) shows a straight concrete construction on pillars. The road level has been lowered to allow the overpass to cross at the level of the adjacent land. (Photo by V. Keller)

Figure 7.18 - The wildlife overpass Harm van der Veen (Kootwijk, the Netherlands) was built in 1998 over two separate parts of the motorway A1. This was a significant milestone, because it was the first overpass in the Netherlands to be built across an existing motorway. (Photo by H. Bekker)

Figure 7.19 - This wildlife overpass in Banff national park on the Trans Canada Highway was built with prefabricated elements across an existing road. (Photo by H. Bekker)

Figure 7.20 - The shape of the 80 m wide landscape bridge Hirschweg (B31neu, southern Germany) takes up the slope of the hill and leads animals across the road, which has been placed in a cutting. The picture was taken before the bushes planted as screens had grown. Nevertheless the overpass was intensively used by mammals as soon as it was covered with earth. (Photo by V. Keller)

Figure 7.21 - Wildlife overpass in the Czech Republic with two prefabricated arches made of concrete. (Photo by H. Bekker)

Figure 7.22 - Corrugated steel elements were used for the overpass Schindellegi in Switzerland (40 m wide), which was constructed across an existing road which was widened. This allowed traffic flow along one lane during the whole of the construction phase. (Photo by O. Holzgang)

Figure 7.23 - A wildlife overpass east of Vienna (Austria), one of five in a row across the A4. (Photo by H. Bekker)

Figure 7.24 - This picture shows the same overpass Schindellegi as in figure 7.22 after it was finished. The slope on the right-hand side is very steep, but as the overpass lies on a mountain slope, red deer and other animals use it frequently. (Photo by V. Hlaváč)

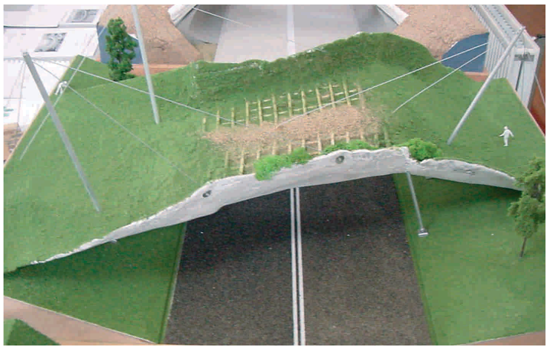
Figure 7.25 - A wildlife overpass across a high-speed railway line in Norway (44 m wide) preserving an important migration route of moose. (Photo by L. Kastdalen)

7

New design alternatives

Even though the costs of a wildlife overpass usually make up only a small part of the total cost of a road or railway development project, they belong to the more expensive nature conservation measures in a planning scheme. The development of alternative less expensive designs should therefore be encouraged. Some ideas for new designs are presented here.

Figure 7.26 - Until now, overpasses constructed with wood have rarely been built. At one overpass in France problems arose due to high maintenance costs. This photomontage from Switzerland shows what a modern construction of a wooden overpass could look like. (Illustration by Marbach & Marbach, Eich, Copyright Swiss Ornithological Institute)



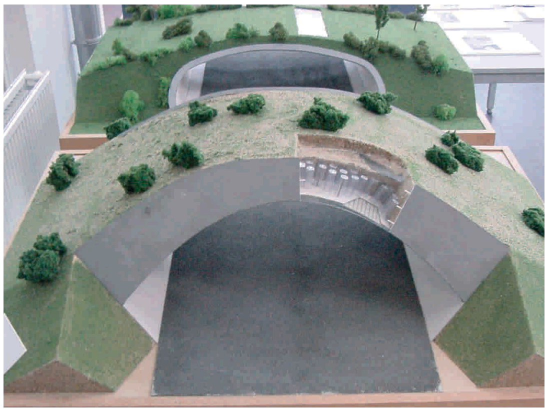


Figure 7.27 - Design ideas elaborated by students from the Department of Civil Engineering and Architecture of the Technical University of Delft (the Netherlands). (Photo by K. Saathof)

Points for special attention

- Overpasses are meant to be in use for a long time. Engineering works are developed for a period of 50 to 100 or more years. Safeguarding a corridor which allows access to the overpass has to follow a similar time frame and should be part of spatial planning at local and regional scales. A proper maintenance plan should be developed.
- In particular, no development (housing, local roads, industrial areas) should be permitted that reduces the functioning of the overpass.
- Hunting should be forbidden on the overpass and in its surroundings. There is little experience of the size of the no-hunting zone required, but a distance of 0.5 to 2 km may be appropriate depending on the local situation.
- Specific overpasses (for the exclusive use by wildlife), are recommended as a general rule and especially if important daily or seasonal migrations of larger mammals have to be restored.
- The use of an overpass by vehicles or walkers has to be planned carefully. Joint-use overpasses are discussed in Section 7.2.2.
- Where access by walkers is foreseen, it is preferable to provide a narrow path, which concentrates their movements, than to provide no path which can lead to them using the whole width of the passage.
- Extra shelter at the overpass can be important for a wide variety of species. When it takes time to establish tall vegetation on the overpass, tree-stumps, a heap of branches and stones can provide shelter.
- Sand beds created to monitor tracks of animals leave a gap in the continuity of the vegetation and may pose an obstacle for invertebrates. They should only be left for a limited period of time while monitoring takes place.
- Roads and forestry tracks which run parallel to the infrastructure may obstruct access to the overpass. They should be routed so as not to block access for small animals, in particular invertebrates.

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Figure 7.28 - Boulders were placed on this overpass on highway 64 in France to block access for cars. (Photo by H. Bekker)

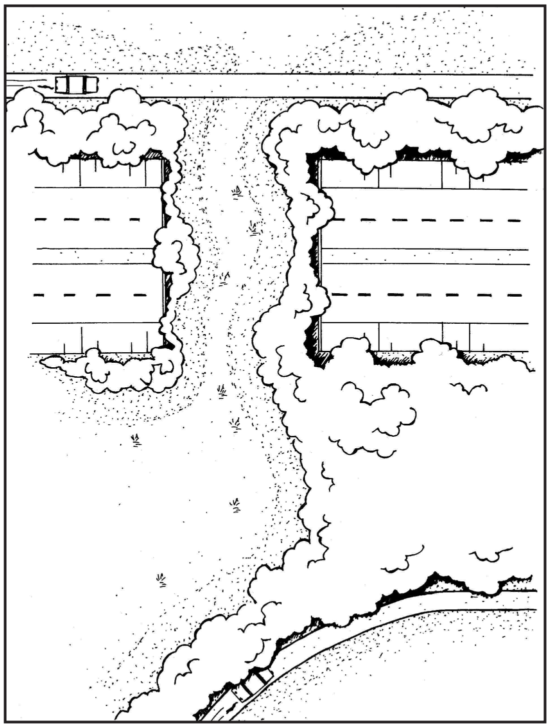

Figure 7.29 - Roads parallel to the motorway hinder access to the overpass for animals (top). Roads in the vicinity of overpasses should be placed some distance from the overpass and leave a corridor for access to it (bottom).

Maintenance

- The responsibility for maintenance has to be organised during the planning phase. Where maintenance is handed over to persons or organisations that were not involved in the planning process (*e.g.* farmers, foresters, nature conservation organisations), a close collaboration with the people responsible for road maintenance has to be ensured.
- The people responsible for maintenance have to be properly instructed. They have to be aware of the purpose of the overpass and a maintenance procedure has to be developed together with them.
- Maintenance procedures in the first two to three years should be planned during the construction phase of the overpass. Later it should be decided on an annual basis depending on the results of the inspection.
- Regular inspection of the structure and seal and drainage system is essential and should be part of ordinary infrastructure maintenance procedures which should also dictate the frequency of inspection.
- Vegetation should be maintained in accordance with the original targets of the overpass.
- Care should be taken that maintenance of vegetation does not damage the technical functioning of the bridge.
- Particular attention has to be paid to any misuse of the overpass and its surroundings that may hinder its functioning as a wildlife passage (*e.g.* fences on adjacent land, recreational installations, etc.).

7.2.2 Modified bridges over infrastructure: multi-functional overpasses

General description and targets

There are large numbers of bridges for local roads, forestry or agricultural tracks. They are usually covered with concrete, asphalt or tarmac and are hardly used by animals. With the simple addition of an earth-covered strip an improvement can be achieved. Such earth-covered or vegetated strips are used by invertebrates, small vertebrates, carnivores and occasionally by ungulates. They favour the dispersal of animals. They are no alternative for specific wildlife overpasses, but an additional measure to improve the general permeability of infrastructure barriers. If all local bridges outside built-up areas were equipped with an earth-covered strip, this would contribute to a mitigation of the barrier effect at little additional cost. Wider overpasses can be combined with local roads or forestry tracks as long as traffic intensity is low.

Cut-and-cover tunnels which are constructed for example for aesthetic reasons to preserve the original aspect of the landscape (see Chapter 6) can often be adapted to function as wildlife passages at the same time.

Design requirements

Road bridges with vegetated strip

- For the vegetated strip a minimum width of 1 m is recommended.
- Soil cover does not have to be deep (0.3 m).
- In most cases spontaneous vegetation is sufficient and no seeding is required.
- The road surface on lightly-used bridges should not be tarmacked.
- The modification of bridges with strips is recommended only when traffic intensity on the bridge is low.

Joint-use overpasses

- Roads, cycle paths and forestry tracks, etc. should only be combined with a wildlife overpass if traffic intensity is low.
- The width of any road on an overpass has to be added to the width required for the fauna passage, *i.e.* joint-use passages in general have to be wider than specific overpasses.
- Any paths or forestry tracks should be placed towards one of the outer edges of the overpass to ensure a maximum width of vegetated and undisturbed area (Figure 7.31).
- Access for the animals onto the overpass must not be hindered by roads at the entrance to the overpass (see also Figure 7.29).
- On landscape bridges, a lateral road that is likely to be the source of disturbance may be separated from the vegetated part of the overpass by an earth wall. Where a lateral road is used very lightly separation is not necessary.

Figure 7.30 - A cut-and-cover tunnel in Spain improved for use by animals. (Photo by C. Rosell)

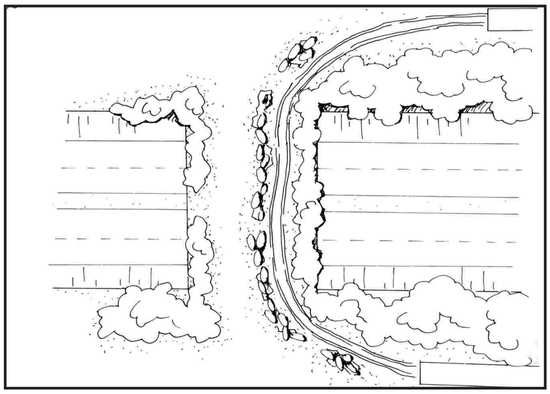

Figure 7.31 - Tracks or small roads on an overpass should not be paved and should be placed at the side to leave the maximum possible width for the vegetated part of the overpass. Screening the road from the rest of the overpass with boulders, etc. is not always necessary.

Figure 7.32 - A vegetated strip alongside a forestry track can enhance the permeability of infrastructure for small animals. A bridge across the high-speed railway line near Oberderdingen in Germany. (Photo by B. Georgii)

Figure 7.33 - A forestry track can be considered, if other motorised access is forbidden. (Photo by J. Carsignol)

7.2.3 Tree-top overpasses

General description and targets

For climbing mammals special types of passages may be needed. Squirrels or pine and stone martens readily cross roads and railway lines and fences are not obstacles. Where traffic is heavy this may result in high traffic mortality. Edible and garden dormouse on the other hand rarely descend to the ground and prefer to cross roads at points where the branches of trees get close to each other.

Wildlife overpasses will be readily used by squirrels and martens, whereas they may only be suitable for dormice when there is adequate tree cover. However, passages designed or adapted to allow climbing animals to cross the infrastructure above the traffic may be a good alternative to reduce the number of traffic victims. In a few countries these tree-top overpasses have recently been constructed or are planned. So far there has been limited research and clear recommendations cannot yet be given. The first indications are, however, that these passages are indeed used by squirrels and dormice and in other parts of the world by monkeys or possums.

Location

Tree-top overpasses should be considered:

- In wooded areas with important populations of dormice, red squirrels and pine martens.
- Where traffic mortality of target species is concentrated.
- In large parks in towns and cities where traffic mortality of squirrels is high.

Special requirements

- Tight enough for animals to walk on.
- Safe from predators.
- Places for small animals to hide.
- Good connections to trees and bushes on either side of the infrastructure.
- Safe in relation to road users.

Design

The design of the tree-top overpasses depends on the type of road. On minor local roads the crowns of trees are often close enough together to enable climbing animals to move from tree to tree. When the distance is too big, a rope, rope ladder or other walkway can provide a connection. On wider roads and in other situations where the distance between tree crowns is too big, the connection needs more stability. Ropes and also constructions of steel cables with a small pathway in between have been implemented. These provisions have to be wide enough for animals to walk on.

- Squirrels will use ropes with a diameter of 4-10 cm.
- Rope ladders with a width of 30 cm have been installed in some locations.
- Walkways of two steel cables with a net between (20-30 cm) have also been implemented.
- Planting of trees and shrubs and additional ropes and planks can facilitate access to the overpasses for the animals.
- On broad motorways the installations for traffic signs over the road can be adapted with a wooden walkway, shelters and hiding places.

Point for special attention

- Protection from predators is an important accompanying measure. On an open rope or walkway an additional thin rope above the passage can prevent attacks by birds of prey.

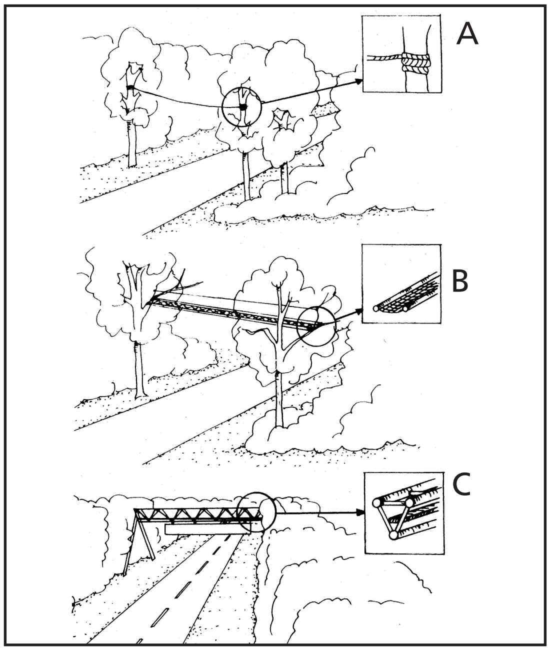

Figure 7.34 - Climbing mammals can use constructions over roads. Design details of A: a rope, B: a walkway of two steel cables with a net between, and C: adaptation of motorway signage.

7

7.3 Reducing the barrier effect: underpasses

Underpasses for wildlife include all types of fauna passage built as a connection under the level of the traffic. Many underpasses are built for other purposes, from culverts to allow the passage of water to underpasses designed to lead a forestry road under a motorway. With only limited adaptations these can function as fauna passages.

This chapter starts with viaducts, which are usually not built specifically for wildlife, but which can provide large and suitable passages for wildlife. For wildlife-specific underpasses a distinction is made between underpasses for large and medium-sized animals, *i.e.* mammals from the size of moose and red deer to roe deer (7.3.2), and underpasses for small animals, *i.e.* mammals from the size of foxes and badgers down to small mammals such as voles, shrews, reptiles or invertebrates (7.3.3). Separate sections give recommendations on how to adapt underpasses (7.3.4) and culverts (7.3.5) built for other purposes to make them better suited as fauna passages. Passages for fish (7.3.6) and for amphibians (7.3.7) are described in separate sections.

7

7.3.1 Viaducts and river crossings

General description and targets

In hilly areas a viaduct is a good technical solution to lead a road or railway from one side of a valley to the other. Valley bottoms are preferred routes for many animals, in particular when there is a watercourse present. In these cases measures for wildlife only have to ensure that previously existing movement corridors of animals are preserved or enhanced.

When a road or railway line crosses a valley or other area which lies slightly lower than the target level of the infrastructure, a low viaduct is an ecologically preferable alternative to an embankment. Viaducts are particularly valuable to preserve ecosystems. They are favourable for invertebrates and small vertebrates, which are strongly linked to particular vegetation types and hardly use underpasses without plant cover.

From an economic point of view, embankments are often preferred, especially where excess material from other parts of a development can be used. However, the preservation of the particularly valuable ecosystems and corridors found in floodplains and river valleys usually outweighs the short-term economic benefit.

Figure 7.35 - This viaduct in northern England leaves the river valley intact. (Photo by Highways Agency, UK)

Figure 7.36 - Instead of building an embankment, the motorway A20 in northern Germany was built on pillars. This low viaduct preserves the floodplain and marshes below. (Photo by DEGES)

Figure 7.37 - A long viaduct on a slope as opposed to an embankment preserves the habitat and allows animals to move freely, as with this example of a Swiss motorway. (Photo by H. Bekker)

Figure 7.38 - This large viaduct in Spain (road C25 near the Natural Park of Montseny) shows different zones under the viaduct: roads, natural vegetation, etc. Spatial planning has to ensure that the parts suitable for the passage of animals remain so in the long term. (Photo by C. Rosell)

In general, even low viaducts provide better links and are suitable for a wider range of species than small underpasses. The microclimate in the vicinity of the infrastructure is less affected than by an embankment.

Location

- Viaducts can be built everywhere where lower-lying ground has to be crossed. They are particularly recommended where a watercourse has to be crossed.
- Wetlands (marshes) should only be crossed if they cannot be avoided, but when crossing a wetland is unavoidable, viaducts are preferable to embankments.

Design requirements

- In general, the surface areas beneath the viaduct should be kept or designed to be as natural as possible.
- Vegetation cover should be encouraged where possible. Where watercourses are crossed the vegetation has to be continuous in the aquatic, amphibian and terrestrial parts of the area.
- To allow continuous plant cover, a viaduct should have a minimum height of 5 m. In wooded areas the minimum height should be 10 m.
- Viaducts can have a length of several hundred meters.
- Where rivers are crossed, the width of the viaduct should allow at least 10 m on either side of the water to allow the growth of river bank vegetation.
- Natural floodplains should be spanned completely by a viaduct.
- In the case of wide roads or motorways a separation of the two causeways by a wide gap provides extra light to the ground under the viaduct. However, narrow gaps between the lanes should be avoided, as they lead to sudden bursts of noise from passing vehicles.
- A lack of water and light may limit the growth of vegetation. Where this occurs the ground should be covered with earth and not with gravel, stones or tarmac.
- For larger mammals open unobstructed ground should be provided.
- Watercourses under the viaduct should be kept in a natural state including the riverbed and river banks. Banks should allow the free movement of otters and other riparian species.
- Under wider viaducts the zoning of land use is recommended.
- Roads under the viaduct with night traffic should be screened off from movement corridors of animals to reduce the impact of car lights.
- Rows of tree stumps and heaps of twigs or stones can provide cover for small vertebrates and act as a link between bushes or hedges on either side of the viaduct.

Maintenance

Regular checks must ensure that the area under the viaduct is not obstructed or used for wrong purposes.

Points for special attention

- The area under the viaduct must not be used for storing equipment or be blocked by agricultural machinery, parked cars, fences or other obstructions. Placing large rocks can help to avoid misuse of the passage.
- Long-term connection to the adjacent land must be ensured.

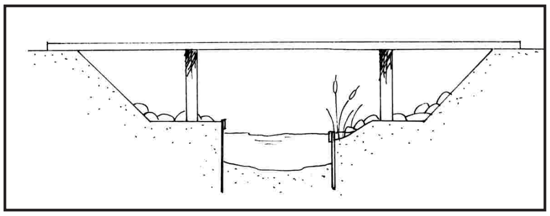

Figure 7.39 - Modified embankments under a bridge over a river.

Figure 7.40 - In this example of the RN59 in France, the function of a viaduct to preserve movement of animals is lost, since access is blocked both by a fence and by stored material. (Photo by J. Carsignol)

7

Figure 7.41 - In Banff National Park (Canada) two parallel structures were constructed to minimise the length of the underpass and to provide increased light below. (Photo by H. Bekker)

Figure 7.42 - Tree stumps were used as shelter for animals under the Zandheuvel viaduct on the A27 in the Netherlands. The screen which separates the road from the stump walls can be seen in the background. (Photo by H. Bekker)

Figure 7.43 - A river crossing in France which preserves the natural river bed and has dry banks for movements by terrestrial animals. (Photo by J. Carsignol)

7.3.2 Underpasses for large and medium-sized animals

General description and targets

Underpasses for large animals are primarily constructed as safe crossing points for mammals. They are a suitable solution particularly in hilly areas or where the infrastructure is built on an embankment. Target species are usually mammals such as deer, wild boar and large carnivores (lynx and wolves). Smaller mammals may readily use these underpasses as well. Underpasses are less suitable for some flying species and for species guided in their movements by light (many invertebrates). Underpasses are also less suitable for connecting habitats, because of the lack of light and water, which allows only limited growth of vegetation.

Location

- An underpass should be located along paths traditionally used by the target species. The identification of such paths is part of an environmental impact assessment (see Chapter 5).
- Where underpasses cannot be constructed directly on the animal paths, linking the passages to the paths is essential.
- Underpasses should be located at sites where local topography channels movements towards the passage.
- Areas where human activity causes disturbance should be avoided.

Dimensions

The dimension of an underpass is defined by height, width and length (Figure 7.44). The length basically corresponds to the width of the road or railway track and is therefore fixed. However, the width and to a lesser degree the height can be chosen according to the requirements of the animals. For a description of the dimensions of an underpass an index of relative openness is often calculated, defined as width x height / length. An underpass with a width of 12 m, a height of 4 m and a length of 25 m would therefore have a relative openness index of 1.9. However, relative openness should never be used as the sole measurement. An underpass with a width of 57 m, a height of 2 m and a length of 60 m would have the same openness index, but a height of 2 m would clearly be insufficient for large species like red deer or moose. Therefore minimum values have to be set for height and width. Relative openness can then be used as a value that reflects the fact that the longer an underpass is, the wider and higher it has to be.

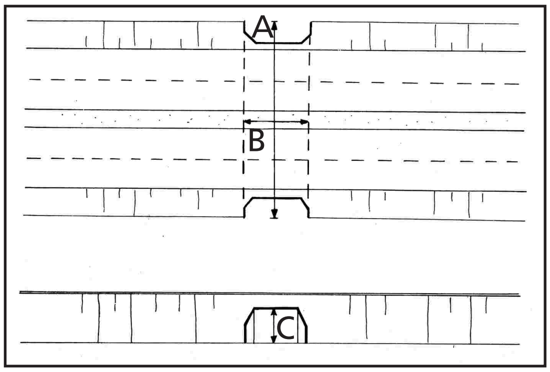

Figure 7.44 - Terminology used for defining length (A), width (B) and height (C) of an underpass. In this handbook length, width and height are defined from the point of view of the animals using the underpass.

Experience indicates that mammals may learn to use underpasses situated in their home ranges. Inexperienced animals, in particular young animals in the dispersal phase or animals that use the underpasses only infrequently during seasonal migration may be more sensitive to dimensions. There has been little research in this area, as monitoring programmes usually focus on the use by animals resident in the vicinity of the underpass. The recommended dimensions take this uncertainty into account.

General recommendations for dimensions:

- Minimum width: 15 m
- Minimum height: 3-4 m
- Openness index (width x height / length: >1.5)

Vegetation and soil cover

- The ground inside an underpass should be natural, *i.e.* covered with soil.
- Due to the lack of light and water, vegetation will normally not grow inside an underpass, but should be encouraged where possible.
- The vegetation at the entrance of an underpass should be attractive to the target animals.
- Bushes around the entrance may be planted both to guide animals towards

the underpass and to provide screening against light and noise disturbance from the road or railway line.

Fences

- Stretches of road or railway where underpasses for large mammals are built ought to be fenced in.
- Fences should be constructed to lead animals towards the underpass.

Points for special attention

- Specific underpasses, *i.e.* for the exclusive use by wildlife, are recommended as a general rule.
- The joint use of an underpass by animals and vehicles or walkers is possible where traffic is light. Points for special attention for joint-use underpasses are listed in Section 7.3.3.
- A watercourse leading through the underpass may be positive for the acceptance by wildlife.
- Hunting should be forbidden in the vicinity of an underpass in particular where important movement corridors of animals are concerned. There is little knowledge of the size of the no-hunting zone required, but a distance of 0.5 to 2 km may be appropriate depending on the local situation.
- Underpasses must not be used for storing material.
- Access to the underpass should be levelled out and free of obstacles for small animals.
- Design and materials must ensure that standing water does not accumulate in the underpass.
- Places to shelter inside the underpass encourage its use by smaller animals (*e.g.* logs, rocks, piles of dead wood).

Figure 7.45 - This underpass is below a high-speed railway line in France and has a good openness index, suitable for large mammals. (Photo by SETRA)

Maintenance

- The responsibility for maintenance has to be organised during the planning phase. Where maintenance is handed over to persons or organisations that were not involved in the planning process *(e.g.* farmers, foresters, nature conservation organisations) a close collaboration with the people responsible for road maintenance has to be ensured.
- People responsible for maintenance have to be instructed appropriately. They have to be aware of the purpose of the overpass and a maintenance procedure has to be developed in collaboration with them.
- Regular inspection can be carried out in combination with general maintenance routines.
- Waste accumulating in underpasses has to be removed at regular intervals.
- Attention should be given to the drainage: even after heavy rain the interior of an underpass should not remain covered by water.
- Particular attention has to be paid to any misuse of underpasses, *e.g.* for storing material or for parking agricultural machinery.
- Vegetation at the entrances to the underpass should be maintained in accordance with the underpass' design objectives.

Figure 7.46 - This passage under a road which crosses a protected wetland in Spain (Natural Park Aiguamolls de l'Empordà) was constructed with a dividing wall to reduce costs: Dimensions of each section: 10 m wide (5 m each section), 2 m high, 28 m long. It is used by mammals, *e.g.* otter, polecat, badger and wild boar, but also by some birds from the adjacent wetland. (Photo by C. Rosell)

7

7.3.3 Modified and joint-use underpasses

The joint use of underpasses by humans (traffic, pedestrians) is only recommended for underpasses >10 m wide. However, improvements are also recommended for smaller existing underpasses, where the length of the underpass is no greater than 25-30 m. With joint use, the potential for disturbance is higher, which means that demanding species like ungulates may be hindered by traffic noise and light.

On the other hand, existing underpasses for human use can be improved to increase the probability that they are used by animals at a local scale. The number of underpasses and of other engineering works is enormous and adapting them could have beneficial effects at a large scale.

7

Design requirements

- Many of the requirements mentioned in 7.3.2 are applicable to joint-use underpasses as well.
- The adaptation of underpasses for wildlife is only to be considered if traffic density is low.
- Underpasses with lightly used local roads or forestry tracks can be improved for wildlife.
- Underpasses with streams are particularly suitable for improvement.
- Unsurfaced roads in the underpass are recommended.
- An earth-covered strip at the side of the road can improve the movement of animals.
- Shelter inside the overpass (tree stumps, heaps of branches) is recommended for wide underpasses. These elements can be placed in the strip(s) on the side of the road.
- The entrance to an underpass may have to be redesigned.

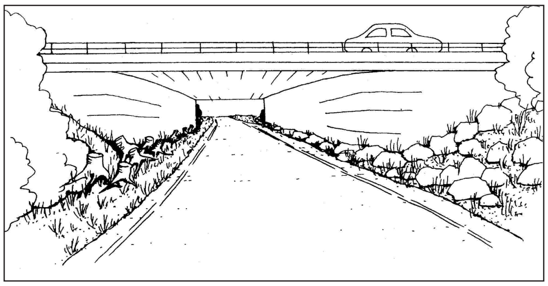

Figure 7.47 - The entrance design of an adapted underpass. Stones and/or bushes offer extra shelter for small animals.

Figure 7.48 - If bridges over streams are built wide enough to preserve the natural banks of the river, they can be used as underpasses by animals, like in this example from the Czech Republic. (Photo by J. Dufek)

Figure 7.49 - This underpass in Denmark has a diameter of 13 m with 8 m clearance, and is 87.5 m long (at the top), 115 m (at the bottom). It is regularly used by fox, badger, marten, stoat and polecat - as well as by humans and horses. For ungulates the openness index would be too small. For underpasses under motorways the layer of soil above the overpass should be thicker to reduce noise inside the underpass. (Photo by B. Wandall)

Figure 7.50 - An underpass below a railway line in the Czech Republic. It is combined with an agricultural track which is not tarmacked. Its height also makes it suitable for large mammals. (Photo by J. Dufek)

Figure 7.51 - The main purpose of this underpass at the A10 in France is water management in a wetland. The dimensions and the integrated ledge allow movement of small and medium-sized mammals. (Photo by H. Bekker)

7.3.4 Underpasses for small animals

General description and targets

Underpasses for small animals consist of pipes or rectangular tunnels with a diameter/width of usually 0.4-2 m. In contrast to culverts, which are primarily built to enable the flow of water under the road/railway line, they are built primarily as passages for small animals like small mustelids. However, there is potential to combine the two functions. Ways to make water culverts suitable as fauna passages are described in Section 7.3.5.

Where culverts are built at frequent intervals, the most appropriate solution is to improve their design to make them suitable as fauna passages. However, where there is no need to build water culverts, additional small passages should be considered to increase the general permeability of the infrastructure. This is important to allow species dispersal. Specific small passages may also be needed where animals regularly cross an infrastructure and suffer from high mortality. This is the case particularly for species such as badgers or otters that move along clearly defined tracks. In some countries, *e.g.* the Netherlands, tunnels for badgers have been built in many places. A lot of specific knowledge has therefore accumulated. The most important features are listed in a separate box. Another box provides information on otters, another species where specific information is available. In most cases, however, tunnels for small animals are built for a variety of species.

Location

- Tunnels for small animals are appropriate where a road or railway line across natural areas is built on an embankment. However, they can also be built where the transport infrastructure lies at surface level.
- Underpasses for small animals are particularly necessary in areas of high species diversity.
- If the target animals are species which use clearly defined paths, the underpass should be placed as closely as possible to the site where the path crosses the infrastructure. (See also box on badger tunnels).

Dimensions

- A diameter of 1.5 m for pipes, or 1-1.5 m side length for rectangular tunnels is suitable for a variety of species. A diameter of 0.3-0.5 m may be acceptable for badgers, but is not suitable for a 'multi-species' passage. Maintenance is more difficult with smaller diameter tunnels.
- The diameter of a pipe has to be large enough to allow the bottom part to be filled in to provide a movement surface.

Figure 7.52 - A pipe in Germany (B31neu) designed as passage for small animals. The bottom is filled in with earth, but with a diameter of 1 m it is rather small. (Photo by V. Keller)

Figure 7.53 - A rectangular underpass for small animals, (1.2 m wide, 0.8 m high and 40 m long; A50 near Hernen, the Netherlands). This underpass is often used by badgers. (Photo by H. Cormont)

Design

- Rectangular tunnels are preferable for amphibians, and possibly other species, because the vertical walls provide better guidance. Rectangular tunnels are preferred for new roads and railway lines.
- Pipes are often cheaper than rectangular tunnels and easier to build under existing roads.
- Pre-fabricated concrete elements are appropriate for rectangular tunnels. The connection between elements has to be smooth.
- Concrete or metal pipes can be used, but metal surfaces are avoided by some species, *e.g.* rabbits and some carnivores.
- The bottom surface of the pipe should be filled to provide a 'horizontal' movement surface.
- Design solutions should be adopted that will prevent the tunnel from becoming waterlogged. To allow a free-draining tunnel, the minimum gradient is 1%. The maximum gradient should be 1:2. Surfaces with a gradient should be rough.
- The bottom of the tunnel should at all times be above the level of the ground water.
- The floor of the tunnel should be as natural as possible: sand, rocks, no asphalt or tarmac.
- The tunnel entrance should be kept free from human disturbance. Artificial light should be avoided.
- Tunnel entrances should be located in recess along the fence line so that animals are guided to them.

Points for special attention

- Shelter and guidance for small animals (mice, invertebrates) could be provided with two strips of plants or other material (tree stumps or stones).
- The tunnel should be accessible for inspection.
- Access for animals to the underpass has to be unobstructed.
- Tunnel entrances have to be placed outside any fences which run alongside the transport infrastructure.
- No roads or tracks that interrupt the habitat connectivity adjacent to the underpass should be built parallel to the road or railway line.

Maintenance

- The inspection of tunnel and fences around the entrances is necessary 2-10 times a year, depending on the situation. Water or street litter in the tunnel is often a problem.
- Proper maintenance is vital for ensuring long-term effectiveness of the underpass.
- The vegetation around the tunnel entrance needs to be well maintained.

Figure 7.54 - Entrance to an underpass for small animals at the A8 in Switzerland (diameter 1 m). Stone walls, which in this mountain region are a common feature, guide animals to the passage. (Photo by A. Righetti)

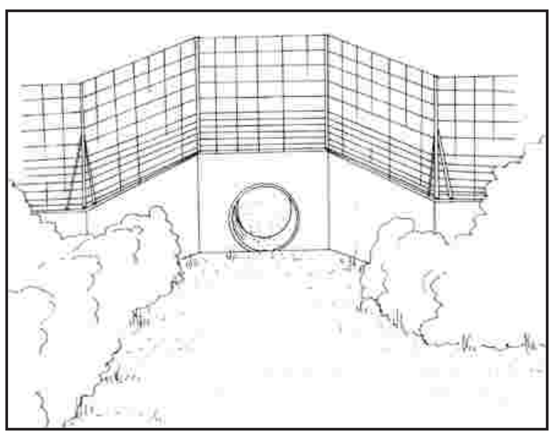

Figure 7.55 - Entrance design of an underpass for small animals. Stones and/or bushes offer guidance to the entrance and extra shelter.

Badger tunnels

Badgers are nocturnal animals, which live in family clans in setts which are sometimes used for hundreds of years. On their daily movements between the sett (in bushes and wooded areas) and feeding ground (pastures) they follow established trails which usually skirt woods or run along hedges. When badgers have to cross roads to reach their feeding areas, they are frequently killed. This may lead to whole clans being wiped out, resulting in a decline of the overall population, since areas isolated by transport infrastructure are not easily re-colonised. Badgers have received a lot of attention in some parts of Europe and a lot of knowledge on badger tunnels has been accumulated particularly in the Netherlands.

Location

Badgers use trails within their home range. Placing a tunnel on or as near as possible to an existing badger path is therefore essential. As a general rule, two tunnels per clan territory or a tunnel every 200-400 m in areas with high badger densities should be sufficient.

Design

- Fencing is necessary to guide badgers to a tunnel and to prevent them from getting onto the road. Special badger fences are needed at either side of the crossing point and on both sides of the road. The length depends on the situation. At some sites it is enough to have a length of 10 m at either sides of the entrances. In other cases the whole area, specially feeding grounds, along a highway should be fenced. The advice of a badger expert should be sought.
- Badger fences should have a small mesh (25.4 x 50.8 mm) and be galvanised spot-welded. The fence should be dug into the ground to prevent badgers from digging underneath it. Where this is not possible, folding out the fence and fixing it to the ground is an alternative.
- An exit is necessary for badgers that are caught on the wrong side of the fence. Badger gates may act as a disincentive, but these gates have a tendency to malfunction. An elevated section or ramp on the road side of the fence which allows the badger to jump over the fence is preferable.

7

Accompanying measures

- Badgers may be encouraged to use new tunnels by laying syrup or peanuts at the entrance or by laying scent trails by using dung produced by the relevant social group
- Shelter around and guidance to the tunnel entrance is very important. Shelter and guidance should be provided by planting hedges and bushes, excavating gullies and avoiding of human activity.

Figure 7.56 - A small fauna underpass in the Netherlands with a badger. This kind of tunnel may be used by small carnivores, mice and amphibians (Diameter: 0.3-0.6 m, length: 5-60 m). (Photo by Vereniging 'Das en Boom')

Figure 7.57 - This tunnel in the Netherlands has been filled with sand and water. The lesson learned from this example is to construct a tunnel above the ground water level and to build stable slopes around the entrances. (Photo by H. Bekker)

Otter tunnels

Otters live in streams, but often use the banks for movement, too. When they reach a road and the stream is led through culverts not adapted for animals, they often prefer to cross the road at the surface. This may lead to high traffic mortality.

A lot of the information on badger tunnels is suitable for otters as well. However, due to their 'amphibian' lifestyle some requirements differ. In several countries special tunnels for otters have been implemented. Passages for otters can also be provided by adapting ordinary culverts (see 7.3.5).

Location

- Under roads near watercourses used by otters.
- At sites where otters regularly cross roads. These sites are often marked by spraints (faeces).
- Near bridges and dams where otters cannot pass.
- At the shortest connection between two watercourses used by otters.

Points for special attention

- Fences are necessary for 25-50 m on either side of a watercourse, depending on the location
- Although otters are very good swimmers the tunnels have to be (partly) dry inside, or provided with a lateral ledge (sometimes called an 'otter walk' or 'cat-walk').
- A good connection between the passage, the ledge and the embankment is important.

Figure 7.58 - Otters don’t like to use water-filled culverts without dry parts. Small pipes placed above normal water level parallel to culverts, such as these ones crossing under a main road in southern Czechia, are used regularly. (Photo by V. Hlaváč)

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7.3.5 Culverts modified for use by terrestrial animals

Culverts are designed to allow the flow of water and may contain small streams or drainage water. Some culverts carry water all year round, others only temporarily, *e.g.* after heavy rainfall or during the period of snow melt. When culverts are dry terrestrial animals may use them; this often requires only little adaptation. In culverts which carry water extra installations for terrestrial animals are usually needed. Modified culverts have been shown to be used by small mammals in particular, including the smaller carnivores (in addition to fish and other aquatic species). In situations where culverts are big and dry during most of the year (*e.g.* in Mediterranean areas) they may also be used by larger mammals.

Culverts connecting streams have to be designed to allow the passage of fish. Requirements for this group of species are discussed in Section 7.3.6.

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Adaptation of culverts and drains

- Where culverts are built to lead a stream under a road or railway line, the design has to be such that the whole ecosystem is led through, not just the water. The same principles apply as for river crossings (see Section 7.3.1).
- In corrugated steel drainage pipes the bottom should be filled with concrete or other material to provide a more suitable surface for animal movement.
- Lowering part of the concrete bottom to channel small amounts of water may provide a guiding line for small animals.
- If the culvert frequently contains water, the bottom must be adapted to keep a part of it dry at all times. This can be achieved with a lateral embankment or ledge (*e.g.* a wooden board) above the water level.
- Prefabricated rectangular culverts can be designed with an integrated ledge.

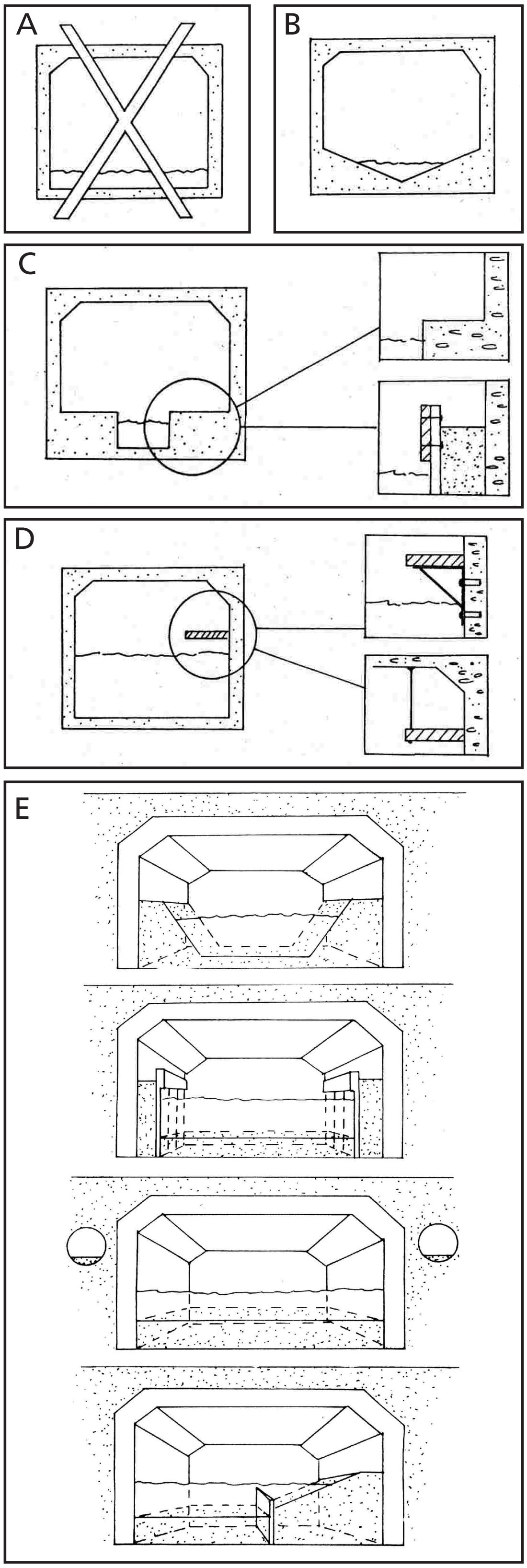

Figure 7.59 - Small terrestrial animals can use culverts, if dry walkways are provided. A: not suited for terrestrial animals, because water covers the whole bottom part of the culvert. B and C: prefabricated concrete walkways above the water level. D: a wooden board above the water level, fixed to the side wall. E: design perspectives.

Figure 7.60 - Two prefabricated culverts in the Netherlands (A35, A1) with integrated ledges used by small animals. (Photos by G. Veenbaas and H. Bekker)

Figure 7.61 - A large culvert made of corrugated steel in Spain designed to allow the drainage of water after heavy rainfall. Filling the bottom with concrete allows it to be used by mammals. (Photo by C. Rosell)

Figure 7.62 - A board placed inside the culvert is regularly used by otters in this Czech culvert. (Photo by V. Hlaváč)

Figure 7.63 - An adapted culvert under a railway in the Netherlands. The ledge needs a good connection with the embankment, a width greater than 0.7 m and to be made of concrete, stone or wood. The design should be as open as possible. (Photo by H. Bekker)

Culvert exits

Culverts often have stepped exits to reduce the erosive force of water on embankments or slopes. They can be a trap for animals using the culvert as a passage and should be modified with structures to reduce the height of the steps. Different modifications can be made, *e.g.* to open the lateral walls of the stepped channel or substitute the steps with a ramp.

Note:

- The ramps should have a rough surface to provide a good grip, *e.g.* by combining stones and concrete.
- The recommended slope for the lateral walls of the stepped channel is 30°, with a maximum of 45°.

Figure 7.64 - Stepped exits of drains are traps for small animals (top). The two exits in Spain (centre, bottom) have been adapted so that animals passing through the drainage culverts do not get trapped. (Photos by C. Rosell)

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7.3.6 Passages for fish and other aquatic organisms

General description

Fish passages include bridges, fish ladders and culverts. This chapter focuses on culverts and pipes, which are often chosen as the solution to lead smaller streams under roads and railway lines. The traditional purpose of pipes is to transport water, but in most cases new pipes can be adapted to create passages for fish and other aquatic animals at little extra cost. Adapting small existing pipes is difficult so the only effective solution will in many cases be to replace the existing pipe with a new specially designed one. Fish have to be able to move freely both upstream and downstream. Barriers to fish occur mainly for upstream movements, which are particularly important for fish migrating to their spawning grounds.

The requirements of fish are very specific. A lot of knowledge has been gathered for fish passages in general. Consulting a specialist is required in any case. In this handbook only some general points can be described.

Location

Fish passages should be constructed whenever infrastructure crosses fish habitats like rivers, streams and lakes. The optimal location for a fish passage will be where the passage has the same water flow and bottom substrate as the main water course and is accessible for the target species. The design of the passage is usually determined by the location and the chosen solution is often a compromise between the following criteria:

- Not too long.
- Not too steep.
- Not too narrow.
- No outfall drop, or at the very most only a small outfall drop (if cyprinids, juvenile salmonids and invertebrates are expected to pass, there must be no drop at all).

When new stream crossings are planned, attention should be paid to finding a location that will best meet these criteria. The location of fish passages should optimise alignment relative to the upstream and downstream channels and the length of the passage. A culvert at an extreme skew (greater than about 30° to the channel) will affect the success of fish passing through by increasing inlet contraction and turbulence at high flows. In-channel deposition and bank scour often occur upstream of pipes/culverts with excess skew. The engineering purpose of increasing culvert skew is usually to reduce the length of the culvert. On the other hand, an increased pipe/culvert length can increase the difficulty of providing fish passage and increase habitat loss.

Design requirements

There are five issues of fish passage design which have to be avoided:

Excess drop at passage outlet

Barriers can be caused by scour pool development at the outlet of a culvert. The scour pool may be a good habitat in itself, but it can create a barrier to upstream migration. For most species drops of 5-10 cm obstruct passage. Technically, the barrier is created by the drop from the water level inside the pipe to the level in the plunge pool. However, even if the culvert is backwatered, *i.e.* the bottom of the culvert lies below the downstream water level, the step between the bottom of the culvert and the bottom of the plunge pool can act as a barrier. The optimum solution is to avoid any drop at all; if this is not possible, the drop from the end of the culvert to the water should be as small as possible. Any drop should end in a deep pool. This serves two purposes, enabling the fish to get up the speed to jump the barrier, and reducing erosion in the scour pool. Building a riffle (rapid) downstream of the plunge pool can eliminate the drop by elevating the water level in the pool.

Inadequate depth within passage

It is important that there is enough water inside the passage for the fish to get through. Different species have different demands during different stages of their life cycle and in different periods of the year, *e.g.* adult salmon require a water depth of at least 30 cm, while trout require a depth of 10-15 cm, dependent on the size of the fish.

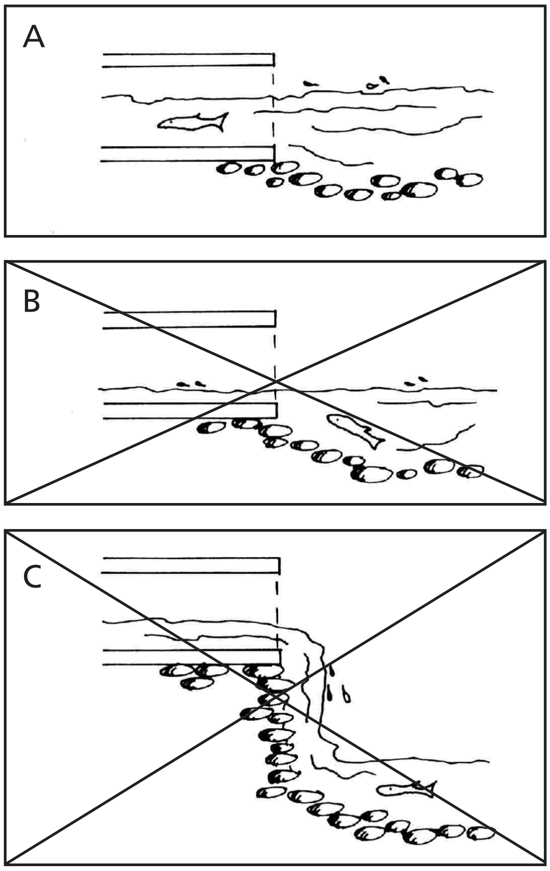

Figure 7.65 - Fish and other aquatic organisms should be able to pass through pipes and culverts. The water level and the design of in- and outlets are crucial elements. A: ideal situation. B: the water level in the pipe is too low. C: the outlet is too high above the downstream part of the watercourse.

Figure 7.66 - This pipe in Norway was placed too high above the stream. The outfall drop creates a barrier to fish moving upstream. (Photo by B. Iuell)

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Too high velocity within the passage

The flow of water running through a fish passage can be a barrier for juvenile and slow moving fish, but it is difficult to reduce velocity enough for many juvenile fish. For this reason, stream simulation (see section on design) is generally preferred. Passages must be analysed at both low and high flow conditions. As well as the depth, the current velocity can easily be modified by riffle construction. In downstream steep culverts the riffle has to be so high that the water table in the entire culvert is at the same level. This solution requires some maintenance as sediments and debris will be deposited in the pool.

Debris accumulation at passage inlet

Debris and bed material should be managed by allowing it to pass unhindered through the passage. Accumulation of debris can create barriers within the fish passage and a backwater can be created upstream that extends the effect of the pipe/culvert.

Turbulence within the passage

Turbulence caused either by the structure itself or by baffles and debris within the culvert, can be an obstacle for juvenile fish and smaller species.

Design: pipes

Small pipes are mainly used for drainage of very small streams. Often circular or elliptical, they can be made of steel, aluminium, plastic or concrete. Pipes should be wide enough to take care of high flow, but still maintain a certain water level in dry periods, by designing the pipe as a 'standing ellipse', or shaping the bottom of the pipe with a narrower channel. Pipes with corrugation will slow the water velocity.

Design: culverts

Culverts modified to create passages for terrestrial animals are described in Section 7.3.5. Here those features are described which are specific to make them suitable for fish to pass through.

In general, culverts that leave the natural bottom substrate intact should be preferred to closed culverts with a concrete bottom. Closed culverts should have a deeper channel in the bottom to keep a minimum water level through the passage even in dry seasons.

Three different design types are currently used:

Horizontal ('no-slope') design

- Fish passage can be expected if the culvert is sufficiently large and installed relatively flat, allowing the natural movement of bed load to form a stable bed inside the culvert.
- Where no flows or velocities are calculated, the fact that velocities are sufficiently low to allow a bed to deposit in the culvert is accepted as evidence that a broad range of fish species and sizes will be able to move through the culvert.
- Even when a culvert is constructed horizontally, the bed within the culvert must still match the natural slope of the channel.

A successful way of ensuring fish passage through a new culvert is to make sure that the culvert is oversized compared to flow conditions. The bottom level of the culvert should be 15-20 cm below the level of the streambed. This will result in natural sedimentation in the culvert and a natural, meandering stream, which will adapt to the actual water flow at any time.

Hydraulic design

- Culvert design must simultaneously consider the hydraulic effects of culvert size, slope, material and elevation to create depths, velocities and a hydraulic profile suitable for fish swimming abilities. It must be understood that there are many assumptions made in the design process, and that there are consequences to every assumption; adequate information allows the design to be optimised.
- The hydraulic design process is based on the maximum water velocity target fish species can cope with depending on the length of the culvert. The longer the culvert, the lower the maximum permissible velocity. Adding headwalls to each end of the culvert, narrowing the road, or steepening the fill embankments can minimise the length. Reducing the slope or making a rough surface can lower the velocity. The target velocity must not exceed the highest

flow expected during the migration of target species.

- Increased velocity from a culvert can erode the downstream banks and thus promulgate the need for bank protection and extend the impacts of the culvert. It is recommended that the culvert exit velocity should not exceed the original channel velocity at the outlet location by more than 25% at the same stream flow (if the original channel velocity is very high, 25% might be too much).
- An undersized culvert creates bed instability upstream. Sites with banks or beds susceptible to erosion may require special consideration.

Stream simulation design

- Stream simulation is a design that mimics a natural stream within a culvert. Sediment transport, fish passage, flood and debris conveyance within the culvert are intended to function as they would in a natural channel. Passage for most species is assured by this option. The premise of stream simulation is that if a fish or other aquatic species can migrate through the channel of the natural stream, they should be able to migrate through the simulated channel in the culvert.
- Stream simulation design culverts are usually the preferred alternative for steep channels and long culverts.
- The primary criterion for stream simulation is the width of the culvert. To achieve stream simulation, the channel bed in the culvert should be greater than the width of the natural channel, so that natural processes can continue through the culvert and bank lines, or channel margins are created to allow passage of weak-swimming fish.
- The primary factors that determine the suitability of a site for stream simulation culverts are the channel bed width and the natural slope of the stream. The channel width should be less than 10 m. For wider channels bridge crossings should be considered (see Section 7.3.1).
- Culvert slope should be minimised to decrease shear stress between the culvert bottom and the bed material. Stream gradients should correspond to the natural situation around the culverts. The culvert itself should be installed either flat or at a grade. This depends on length and bed slope. Longer passages will require some slope to maintain waterway area at the inlet.
- Where the stream simulation design will be placed at the same gradient as the channel, the composition and pattern of the adjacent channel (outside the influence of structures) should be used to determine what the bed in the culvert should look like.
- While stream simulation culverts are probably the best culvert alternative for streams with high debris potential, there is still the risk that wood will form a jam inside the passage and back up flow. Bridges are in general much better than culverts for transporting debris.
- The exact type of culvert used for stream simulation is largely a matter of preference. Bottomless structures have been successful and have the advantage that the channel can be built from above before the culvert is set in place.

Points for special attention

Species and size of fish

The design of fish passages following the principles for hydraulic design should be based on the weakest species or size of fish. What species are potentially present? When are they present? This information should be obtained at an early stage.

Upstream migration of juvenile salmonids (50-120 mm trout and salmon) is also important at many sites. These fish are small and weak and therefore require a very low passage velocity and low level of turbulence. A culvert specifically designed for 200 mm trout will in many cases also provide passage for juvenile salmonids, and hydraulic characteristics suitable for passage of adult trout during peak flows may provide passage of juveniles during lesser flows.

Accompanying measures

Baffles

Baffles are a feature added to a culvert to increase the hydraulic roughness of the culvert and reduce the velocity for culverts designed by the hydraulic system. They can also be used to keep a minimum water level in the passage through the dry seasons. The tendency of baffles to catch woody debris reduces the culvert capacity and can create a fish barrier as well as culvert blockage. For maintenance access, baffles should not be installed in culverts with less than 150 cm of headroom.

Roughened Channel

Roughened channels are a graded mix of rock and sediment built into a culvert to create enough roughness and diversity to achieve fish passage for culverts designed by the hydraulic system. The roughness controls the velocity and the uneven and changing surface provides migration paths and resting areas for a variety of fish sizes.

Figure 7.67 - Baffles in a fish passage in Norway during and after construction. (Photos by B. Iuell)

Debris rack

- The debris rack should be mounted high on the culvert above the ordinary high water level.
- The space below the rack should be left open for flow.
- Openings should be no smaller than 20-25 cm.
- A specific monitoring and maintenance plan should be developed for any debris rack.

Maintenance

- Barriers in fish passages are often the result of a lack of maintenance.
- The outlet drop should be checked after every flood period and at least twice a year.
- Culvert maintenance for the purpose of high flow capacity is often different from that required for fish passage. Debris blocking slots in baffles may not affect the flow capacity of a culvert but may be critical to fish passage.

Frequent inspection and maintenance of baffled culverts is necessary. Passage for many salmonid species is most critical during spates in the autumn months, when there is the greatest risk of floods and quantity of debris. Maintenance is usually impossible during high flow conditions and passage is lost for at least part of a season when passages fail or plug. Baffles and other potential barriers are out of sight and difficult to monitor in high water conditions.

7.3.7 Amphibian tunnels

General description and targets

Most amphibians need water bodies for breeding, whereas during the non-breeding period of their life cycle they may live in the water, at the water's edge or on land. Many species thus migrate seasonally between different habitat types. In spring, adults migrate from their winter habitats to their breeding sites which some of them then leave after breeding to reach their terrestrial habitat. During summer after metamorphosis juveniles leave their birth pond to migrate to terrestrial habitats. In autumn, some species migrate back to their winter habitats. Some amphibians will return to their natal pond year on year, *e.g.* common frog and common toad have been reported to return to their breeding site even several years after its destruction. Other species breed in temporary aquatic ponds.

The concentration of movements towards spawning sites requires specific measures to ensure safe crossing of transport infrastructure. Additional measures aiming at reducing mortality on and around transport infrastructure, such as sloping kerbs and adaptation of drains are dealt with in Section 7.4.6.

Measures have the following aims:

- To block the access onto the road to prevent road kills.
- To enable amphibians to safely cross roads while moving between breeding and non-breeding sites.

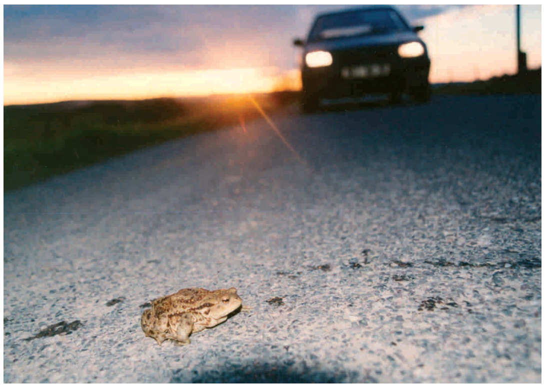

Figure 7.68 - Common toads are often killed in high numbers when they cross roads on their migration to breeding ponds. (Photo by A. Toman)

Amphibians don't necessarily need special types of crossing structures. Culverts designed for a variety of small animals can be suitable for amphibians as well. Some points are however particularly important for amphibians:

- Guiding structures leading the animals to tunnels are particularly important and have to be fitted very carefully (see below for details).
- Amphibians are sensitive to drying out, in particular young animals. Long dry tunnels are therefore unsuitable, while a combination of functions with a drainage channel or stream can provide humid parts at the edge of the stream.

In many countries specific guidelines for amphibians already exist. Not all of these take into account the latest research on the effectiveness of structures. On the other hand, they may take into account local factors. In this section those systems that can be considered a current standard are described. Not all of the details can be described. In any case, an expert familiar with the particular requirements of amphibians should be consulted.

Location

- At road sections with high numbers of road kills of amphibians or low numbers of road kills of endangered species of amphibians.
- On the seasonal migration routes of the amphibians between their terrestrial habitats and spawning grounds.

Temporary installations

General description

A barrier is built temporarily on the migration route to block access to the road and to guide the amphibians to buckets, which are dug into the ground. The animals are collected in the buckets and released on the other side of the road on a regular basis. The system is usually installed where volunteers are available to check the installations.

Figure 7.69 - A bucket to collect amphibians. It is placed close to the fence to prevent animals from passing the bucket without being caught. (Photo by P. Schlup)

Buckets

- The buckets should be at least 30-40 cm high.
- The edge of the buckets should be level with the ground.
- The recommended distance between the buckets is 10 m.
- During the peak migration period, buckets have to be checked frequently. The frequency depends on the number of animals present: at least one to three times per 24 hours, in areas with large numbers of amphibians up to every half hour.
- Water gathering in the buckets should be poured out to prevent other animals from drowning.
- In some situations a bucket with a broad rim is recommended to prevent newts, young frogs and toads or tree-frogs from climbing out.
- At locations where mice and shrews could get trapped in the buckets a thin stick may help them to get out.

Fences

- Wire mesh and nets are not recommended, because animals may climb over them. Nets in particular have only limited guiding ability.
- Fences should be used to guide amphibians to the buckets.
- A bucket should be placed at the ends of the fences. Alternatively, the ends should be U-shaped to minimise the number of animals leaving the fence.
- The minimum height of the fence should be 40 cm; in presence of the agile frog the height should be at least 60 cm.
- The fence must be extended into the ground and prevent animals from climbing over, *e.g.* by bending the upper part.
- Stakes should not be places on the side where amphibians are moving.
- Magnetising material should not be used, because this could disorient the common toad.

Temporary installations can also be suitable for the migration of juveniles from birth sites to their terrestrial habitats. Buckets are not suitable for juveniles. A successful method for juveniles is to block the animals with barriers, which are opened from time to time while the traffic on the road is stopped. In dry weather the road surface should be wetted to facilitate the juveniles' crossing.

Figure 7.70 - A strong opaque plastic foil can be put up without stabilising wire mesh, as in this example from Hungary. However, the posts should not be placed on the side the amphibians approach from to improve the guiding function of the fence. (Photo by M. Puky)

Permanent installations

These installations consist of a guiding structure and a tunnel. The former directs animals to the tunnel in which they can cross under the road. The guiding structures should not bar the way for animals coming from the road. The tunnels should be placed exactly on the migration routes. If the guiding structures are parallel to the road, the distance between the tunnels should be less than 60 m. If the guiding structures are leading in V-shape towards the tunnel, spacing of 100 m can be considered. Small mammals will also benefit from these structures. Where there are streams a culvert with permanently dry parts besides the stream is the best type of passage for amphibians.

Guiding structures

- Joining the vertical part and the movement surface with a 90° angle is important. Rounded angles don't provide adequate guiding.
- The ends of the fences should be U-shaped to stop the animals from leaving the fence.
- The height should be at least 40 cm (60 cm if the agile frog is present).
- The top end of the fence should be bent over to prevent animals from climbing over.
- A movement surface free from vegetation is recommended. Vegetation adjacent to the movement surface is recommended to provide cover.
- The guiding structures should be placed as close to the road as possible to minimise the length of the tunnel. A crash barrier avoids vehicles from getting caught in the guiding structures when veering off the road.
- Where the guiding structure joins the entrance to the tunnel corners and edges should be avoided.

Figure 7.71 - A U-shaped end of the fence forces amphibians to turn back and reduces the number of animals continuing onto the road at the end of the fence. (Photo by S. Zumbach)

7

Figure 7.72 - View of a rectangular tunnel in Germany with neatly fitted guiding structures. (Photo by J. Niederstrasser)

One-pipe tunnel system

One-pipe tunnel systems (also called two-way system) allow animals to move in both directions in the same tunnel. If the diameter of the tunnel is large enough (cf. Table 7.3), free movement is possible. This system has been successfully tested and is also suitable for small mammals.

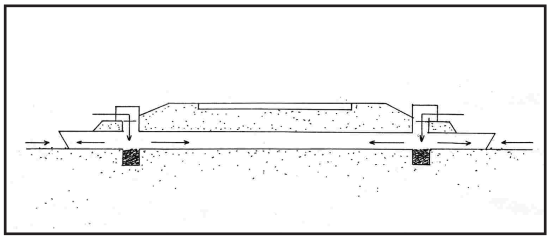

Figure 7.73 - A one-pipe tunnel for amphibians.

Table 7.3 - Minimum size requirements for different construction types depending on the length of the tunnel, *i.e.* the width of the road.

	minimum clear sizes for tunnel lengths from			
construction type	<20 m	20-30 m	30-40 m	40-50 m
rectangular tunnel (clear width; clear height)	1.0 m; 0.75 m	1.5 m; 1.0 m	1.75 m; 1.25 m	2.0 m; 1.5 m
pipe (diameter)	1.0 m	1.4 m	1.6 m	2.0 m
dome-shaped (half circle) (clear width; clear height)	1.0 m; 0.7 m	1.4 m; 0.7 m,	1.6 m; 1.1 m	-

7

Figure 7.74 - Amphibian tunnel with open grid in Spain. (Photo by Giasa, Spain)

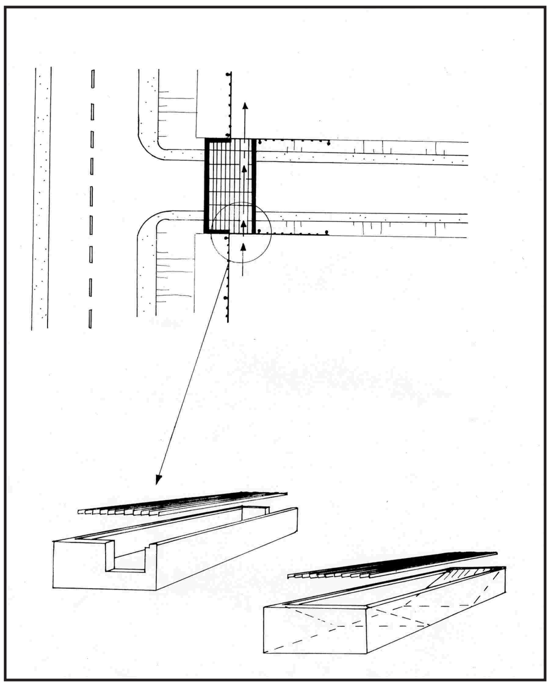

Figure 7.75 - At road junctions, U-shaped tunnels (0.4 m deep and 0.3 m wide) covered with iron bars or a grid (60 x 100 mm) are necessary to join the guiding structures which would otherwise be cut by the side road where it joins the main road.

Figure 7.76 - For amphibians and other small animals, half-pipes can be used as passages under the rails where larger tunnels are not possible. (Photo by U. Bolz)

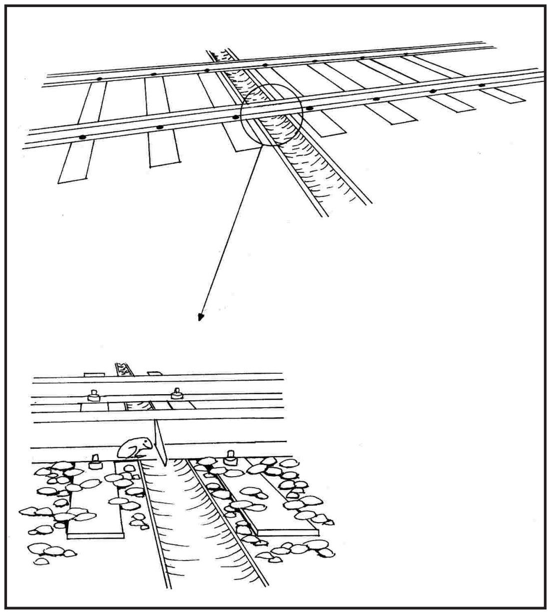

Figure 7.77 - A sheet steel buffer forces amphibians to jump into the half-pipe under the rail. (After Müller & Berthoud 1996)

Points for special attention

- Tunnels with rectangular cross-sections are recommended because of the larger bottom compared to pipes of similar clear heights. It is also easier to fix the guiding structures neatly to the tunnel.
- If round pipes are used, the bottom of the pipes should be filled with concrete to enlarge the surface area suitable for animal movement.
- Concrete is preferable to steel, plastic or other materials.
- If amphibian tunnels are also used for drainage, an embankment that stays permanently dry is necessary.
- Water should drain easily from the tunnels.

Double-pipe tunnel system

One of the first systems developed for amphibians consisted of two different tunnels. Animals fall into a trap at the roadside only getting out after having crossed the road in the tunnel. While the system seems to be effective for certain target species, *e.g.* toads, in some cases a considerable mortality was detected for newts and juvenile frogs and toads. These systems are not suitable for small mammals. The double-pipe or one-way tunnel system is therefore no longer recommended.

Maintenance

- Many passages do not work due to lack of maintenance. Regular maintenance at the critical points is necessary (fences, obstruction of the tunnel by water, soil or litter, faults in guidance structures).
- A maintenance control pit is necessary for tunnel inspection and to enable the removal of any obstacles.

7

7.4 Avoiding and reducing animal mortality

Collisions between large mammals and cars are the effect of traffic on wildlife most obvious to the road user. However, many smaller animals are killed on roads as well. In addition, features connected with the transport infrastructure may cause the death of many animals too: birds of prey collide with overhead wires on railway lines, small mammals get caught in drains, insects die when attracted to the light of street lamps, mammals can't get out of canals with steep banks etc. This chapter presents a variety of measures designed to reduce the number of animals killed on or around transport infrastructure. It is far from complete, but aims also at drawing attention to the detection and avoidance of potential traps that may cause the unnecessary death of animals.

7

7.4.1 Fences

General description and targets

Fences are erected to prevent the access of animals onto roads or railway lines. They are mostly constructed to reduce accidents due to collisions between large mammals and cars, but also to reduce the number of smaller animals killed on the roads. The disadvantage of fences is that they increase the barrier effect. Where fences or other barriers are erected, it has to be ensured that the species concerned have enough opportunities to cross the road or railway line. In most cases, fences must therefore be combined with wildlife passages. In these cases they fulfil an important role in guiding animals to the crossing points. When traffic safety is not an issue fences should only be erected where animal mortality might threaten a population otherwise the barrier effect might have worse effects on the survival of the populations in the long term than the mortality due to traffic.

Location

- In general, wildlife fences should be erected only in places where the number of animals killed is high or where there is a high risk of accidents involving wildlife. This is mostly the case along high-speed roads and railway lines. On ordinary roads with low traffic density fences should only be erected at high-risk spots.

Figure 7.78 - Several types of wildlife fences in Europe: Top: a standard fence in Switzerland (Photo by V. Keller). Centre: A high fence with an extra wire at the top in Norway (Photo by B. Iuell). Bottom: fence with wooden poles in Hungary (Photo by J. Zsidakovits).

- The surrounding landscape has to be checked with respect to other fences or barriers to animal movement: creating new traps between parallel fences has to be avoided, and the number of fence lines should be reduced wherever possible.
- Fences should always be built on both sides of a road or railway line. The ends of the fences are danger points: animals may go round the end of the fence and

get trapped on the road. Fences should therefore end at structures like bridges. Where only a stretch of the road is fenced in they should be extended 500 m or more beyond the danger area.

- On roads with relatively little traffic, openings in fences can be provided at locations where animals can easily cross and where crossing animals are well visible to drivers.
- In areas where natural habitats for animals have been reduced to small patches, any potential habitat should be made available to the animals. From the point of view of the animals, a fence should therefore be placed close to the road to reduce the amount of inaccessible area along the verge, thus allowing animals to use the verge as a habitat or movement corridor. However, the location of the fence in relation to the road has to also take into account aspects of traffic safety and road maintenance.
- Where a road is built on an embankment with a wide slope it is preferable not to put the fences at the foot of the slope but at the top or halfway up, depending on the local situation. The same applies to cuttings.
- Particular attention has to be paid to the placing of fences in relation to fauna passages and other possible crossing points for animals. Fences must not block entrances to passages nor provide traps, but they do have an important function to guide animals towards passages. (See also Sections 7.2.1 and 7.3.2)

Design

Conventional wildlife fences consist of wire mesh fixed with poles. Height and mesh size depend on the target species. In order to be an effective barrier, a fence has to meet the following requirements:

- The height should be such that animals cannot jump over it.
- The wire mesh has to prevent animals from passing through the openings.
- The mesh has to be fixed such that animals cannot pass under the fence.
- Electric fences are expensive to run and need frequent checks and maintenance. They are not an option for long stretches of road, but may be considered locally where a high risk exists for endangered species, and can be used temporarily to train animals to change their habits after a new road is built.

Height

- The height is determined by the occurrence of different ungulate species:

  Red deer, fallow deer, moose: minimum height: 2.2 m (preferably 2.6-2.8 m)

  Roe deer, wild boar: minimum height 1.5m (preferably 1.6-1.8 m).
- The height has to be adjusted to the terrain and is measured on the side of the approach of the animals (see Figure 7.79). Where the approach of the animals is downhill, this adjustment is essential.
- In areas with snow cover, the minimum height has to be guaranteed in winter as well.

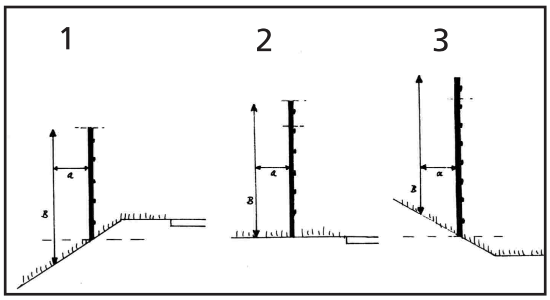

Figure 7.79 - The minimum height of a fence is measured on the approach side of the animals. 1: If the road is on an embankment, the fence can be lower than in a flat situation (2). 3: If the road is in a cutting, the fence has to be higher than in a flat situation (2). (After Müller & Berthoud 1996)

Mesh

- For conventional wildlife fences, a smaller mesh size in the bottom half or third of the fence is recommended. Distance between horizontal wires: bottom: 50-150 mm, top: 150-200 mm. Distance between vertical wires: 150 mm.
- Wires should have a diameter of at least 2.5 mm and should consist of rust-free material.
- In areas with heavy snowfall, the top wire of the netting must be reinforced with a cable capable of bearing the weight of the snow settling on it.
- The bottom wire should lie directly on the ground and be fixed to prevent animals from crawling under the fence. Burying the wire mesh 20-40 cm under ground may be necessary in areas with badgers or wild boar. Where the ground is uneven, it has to be levelled out to avoid gaps *e.g.* due to holes in the ground. Special care should be given to places where fences cross ditches.
- The wire mesh should be fixed on the outside of the poles (*i.e.* away from the road) to prevent mesh from falling away from posts when large animals crash into fence.

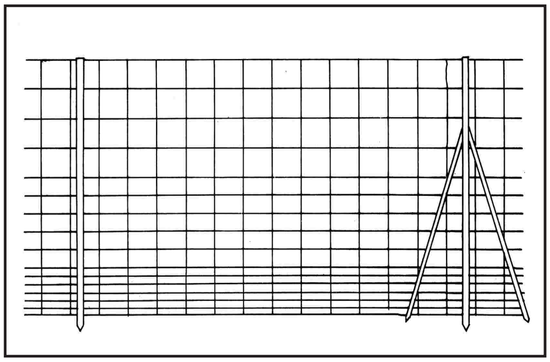

Figure 7.80 - A smaller mesh size at the bottom of a wildlife fence is used to prevent smaller animals from passing through the fence.

Poles

- Metal or wooden posts are both suitable.
- Poles have to be strong enough to withstand the impact of an animal in flight running into the fence. End posts should have a diameter of 2-2.5" (steel) or 10 x 10 cm / 12 cm diameter (wood). Middle posts can be slightly thinner. Poles should be replaced when they are damaged.
- All posts must be firmly embedded in the ground (approximately 70 cm or more depending on the ground).
- For deer, the distance between posts should be 4-6 m (up to 10 m in flat areas), for wild boar 4 m maximum.

Exits

- Where there is a danger that animals might get trapped on the road, *i.e.* particularly when the whole stretch is not fenced, exits should be provided to allow the escape of animals.
- It is better to avoid the Dutch type of exit doors for badgers or any other mechanical doors. Experience has shown that they often stay open or become damaged.

Figure 7.81 - A simple exit made of tree stumps allows Iberian lynx in the south of Spain to cross a fence if they get trapped between fences. (Photo by H. Bekker)

Figure 7.82 - An exit in the same area in the south of Spain designed for different animal species (Photo by H. Bekker)

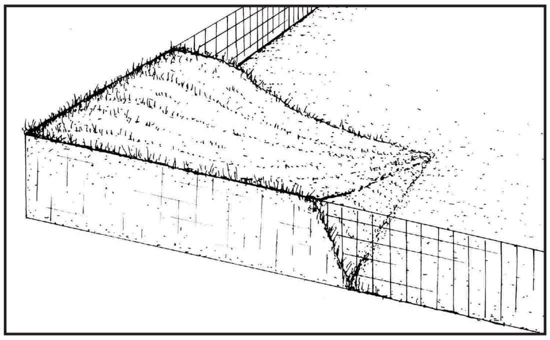

Figure 7.83 - A ramp allows mammals to jump across the fence when they get trapped on the road side of the fence.

Additional considerations for small animals

- Fences to keep out small animals (amphibians, reptiles, small mammals) should only be erected in conjunction with passages. Otherwise, small animals should not be kept away from road verges completely, because these often provide suitable habitat and serve as movement corridors for these species. Only in cases with high road mortality is it justified to keep species like tortoises or lizards away from the road areas.
- To keep out small animals an additional mesh can be fixed to the standard fence. Depending on the species mesh size should not be greater than 2 x 2 to 4 x 4 cm. Height: 40-60 cm. To prevent animals from climbing over the fence, the top part should be turned out- and downwards.
- For amphibians opaque barriers instead of wire fences are recommended. These are discussed in Section 7.3.7.

Maintenance

- Fences have to be checked in detail as part of ordinary road inspection at least once a year and more frequently during the first year.
- Particular attention has to be paid to:
  - holes (which have to be repaired immediately),
  - attachment to the poles,
  - attachment to the ground,
  - trails and hollows which indicate the regular passage of animals under the fence.
- If fences are damaged by cars after accidents or after storms, they have to be repaired immediately.

Points for special attention

- Fences are effective barriers for most, but not all species: wire fences effectively hinder the access of deer, wild boar, hares and other non-burrowing and non-climbing species, but brown bears, lynx, martens and others are able to climb over most fence types. Burrowing animals like badgers and foxes may force under a fence if the fence is not fixed underground.
- Where gates have to be provided to allow access to the road or railway line, their design has to be such that only gaps as small as possible exist between the gate and the ground and between the gate and fence.
- A dense row of bushes planted close to the fence on its outside can prevent mammals from attempting to jump across a fence. No plant species attractive to foraging animals should be used.
- All small bridges, underpasses, culverts and other possibilities for joint-use fauna passages across the highway have to be accessible by animals from the outside of the fence.
- Where narrow access roads require an opening in the fence cattle grids may provide a barrier to larger animals. However, they are a danger for small animals that easily fall in. They should therefore be equipped with escape ramps. A hole in the side of the base of the cattle grid can also help to avoid victims.

Figure 7.84 - Cattle grids are usually used on agricultural tracks as in this example from Denmark. However, they can also be used where a side road enters a main road. (Photo by B. Wandall)

7.4.2 Artificial deterrents

Artificial deterrents aim at keeping mammals away from roads or railway lines in order to reduce the number of collisions. They are mainly targeted at deer. Various systems exist based on optical, acoustic or olfactory devices. Experience shows that the effectiveness of such measures is usually very limited.

Reflectors/mirrors

Wildlife warning reflectors are widespread.They consist of various types of metal strips placed around trees or other structures. The light of approaching vehicles is reflected towards the side of the road, which should warn animals and stop them from entering the road. These features are popular because they are cheap and easy to place. However, a thorough analysis of studies carried out over the last 40 years all over the world found little evidence for the effectiveness of wildlife warning reflectors. Reflectors also require a lot of maintenance.

Figure 7.85 - A wildlife warning reflector in Spain. There is little evidence of the effectiveness of this measure. (Photo by C. Rosell)

Acoustic deterrents

Ultrasound devices emit acoustic signals that should deter mammals. Like other acoustic deterrents there is no evidence for their effectiveness.

Olfactory repellents

Olfactory repellents are a relatively new measure to prevent accidents, mainly involving deer. Natural or artificial substances, usually a mix of scents from humans, wolves and other predators, are injected into a foam as a carrier substance which is then applied to trees or posts in the vicinity of the roads. The first tests of these relatively new systems indicate that the number of collisions with cars is effectively reduced. Observations seemed to show that deer increase their attentiveness and thus may become more aware of approaching cars. When there were no cars around, the animals crossed the roads. Other observations indicated, however, that while deer crossed less in the treated stretches of the road, they shifted to adjacent untreated areas.

To prevent habituation by animals olfactory repellents should only be placed during critical periods, *e.g.* during the migration period of deer.

Further research is needed to show the effectiveness of these measures in the long term. More experience is needed with regard to maintenance needs. The possible impact on non-target species is unknown.

Figure 7.86 - Olfactory repellents are applied to poles along the road. (Photo by C. Rosell)

7.4.3 Warning signs

Warning signs aim at influencing the behaviour of drivers in order to reduce the number and severity of collisions between large mammals and cars. Standard traffic signals are placed in areas where collisions often occur. They also exist for amphibians, waterbirds and other animals. However, research has shown that drivers don't pay much attention to signals on their own and in particular don't reduce their speed. Therefore systems have been developed to increase their effectiveness.

Figure 7.87 - A moose warning sign in Norway. Such warning signs are not very effective, because drivers get used to them. (Photo by S. Persson, Østlandets Blad)

Location

- Wildlife warning signs should be placed only in places where there is a high risk of collisions, because the more widespread they are, the less people pay attention to them.
- Putting up signs only during critical seasons could make people more attentive to them.

Points for special attention

- The combination of a wildlife warning sign with a speed limit is slightly more effective.
- The effectiveness is further enhanced if signs are marked with flashing lights or a flashing speed limit sign, which are lit only during periods of high animal activity.

7.4.4 Wildlife warning systems with sensors

Wildlife warning systems combined with heat sensors have shown to be able to reduce the number of collisions. Heat sensors in the vicinity of the roads detect approaching mammals up to a distance of 250 m. The sensors trigger the fibre optic wildlife warning signs which are combined with speed reduction signs (30-40 km). Normally the signs appear dark and the light points are only visible when activated. The system can be powered by solar energy. Wildlife warning signs without speed reduction are less effective.

Figure 7.88 - A wildlife warning system combined with heat sensors, used in an area in Switzerland where red deer regularly cross the road. (Photo by H. Bekker)

Points for special attention

- People should be informed about the way the combined system works, because only if they know that an illuminated sign does not only indicate a potential danger, but also the actual presence of an animal, will they adapt their behaviour.
- Warning signs should be combined with speed limits.
- Like any other technical equipment, the combined system has to be checked regularly.

7.4.5 Adaptation of the habitat alongside the infrastructure

General description

Different ways of designing and managing habitats alongside roads and railway lines are used with the aim of reducing the number of collisions. Some are designed to prevent animals from moving onto the road surface by attracting animals elsewhere, others by influencing the behaviour of animals or by making animals more visible.

Cutting of vegetation

The cutting of bushes and trees within a 3-10 m strip alongside the road reduces the attractiveness for large mammals such as moose. At the same time the visibility of the animals to drivers is improved. The measure is designed to reduce the number of collisions between large mammals and cars. This measure is suitable for roads with low traffic load and for railway lines.

Verges with short vegetation often have high densities of small mammals (rodents) and are therefore attractive to birds of prey. This may increase the risk of collisions with birds.

Figure 7.89 - Cutting high vegetation alongside the roads makes large mammals, *e.g.* moose like in this example from the E18, Akershus in Norway more visible to drivers, and removal of vegetation which is an attractive food-source will reduce the risk of having animals foraging along the road. (Photo by B. Iuell)

Choice of plant species

The choice of the right plant species to be planted alongside roads can reduce the number of collisions between cars or trains and animals. While it is advised to use native plant species, care should be taken to avoid plants which may attract animals to the road verges for foraging, increasing the risk of collisions with cars:

- Bushes and trees, which are not attractive to browsing deer, etc.
- No bushes with attractive berries, in particular not in the central reservation. Berry bushes attract songbirds, mainly during migration.
- Forest fires often start from roads. Plant species that burn easily should not be planted to reduce the risk of fires spreading to adjacent habitats.

Hedges

- Hedges along fences can lead animals towards fauna passages. A gap between the fence and the hedge facilitates maintenance work along the fences.
- Bushes alongside the fence reduce the danger that large mammals try to jump the fence.
- Tall tree hedges force birds to fly high. Thus they cross the road at a height where they don't collide with cars. On the other hand, hedges may attract birds to the vicinity of the road increasing the risk of collisions.
- The planting of hedges has to consider the above-mentioned points of visibility and choice of food plants.

7.4.6 Adaptation of infrastructure

Noise barriers

Noise barriers are constructed close to human settlements to reduce noise emissions, although in certain situations they are erected to protect, for example, colonies of breeding birds from disturbance. However, even if not constructed for wildlife they have to be treated in this chapter because they can increase habitat fragmentation even more than fences. In densely built-up areas noise barriers do not usually provide any problems in this respect. In more natural surroundings they are complete barriers for all terrestrial animals.

Non-transparent screens

Noise barriers built of concrete, wood or other material are complete barriers for animals. In natural environments they must therefore be combined with fauna passages. This has to be considered also in cases of low noise screens along railway lines, which may hinder the movement of small vertebrates like snakes, which without barriers would not have been greatly affected by the railway line.

In combination with passages noise screens can function as guiding structures.

Noise screens are usually built on a solid concrete base. They thus completely isolate the road verges from the surrounding habitats. For small animals, especially invertebrates, they are therefore a more complete barrier than fences. No experience exists as to the effects on the animal populations or regarding possible solutions to reduce the barrier effects, such as small openings at the base of the structures.

Figure 7.90 - This noise barrier has openings at the bottom to reduce the barrier effect for small animals. (Photo by H. Bekker)

Transparent screens

Transparent screens are erected in areas where planners wish the drivers or passengers to be able to see the surrounding landscape. They entail a high risk of mostly fatal collisions for birds, which don't recognise the wall as an obstacle, in particular where natural vegetation can be seen through the glass or where the glass reflects bushes or trees. It has been shown that with appropriate markings the number of collisions can be reduced substantially.

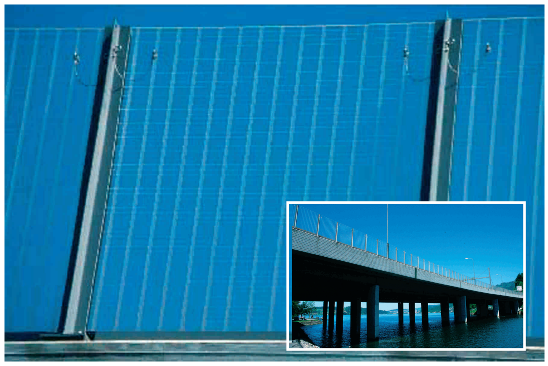

Figure 7.91 - Transparent noise barrier along a motorway in Switzerland with vertical markings. (Photo by H. Schmid)

Design

- Vertical markings are recommended, although other types may also be effective.
- Marking strips should be 2 cm wide with a distance between the strips of a maximum of 10 cm (or 1 cm wide, distance 5 cm).
- Light colours are preferable to dark ones, because they are more visible in the twilight.
- Markings should be applied on the outer side of the wall (*i.e.* away from road) to avoid reflection.
- Silhouettes of birds of prey are not recommended. They are only effective to prevent collisions if put up at a very high density.
- No reflective material or glass should be used.

Figure 7.92 - A few isolated silhouettes of birds of prey are ineffective to prevent collision by birds. (Photo by C. Rosell)

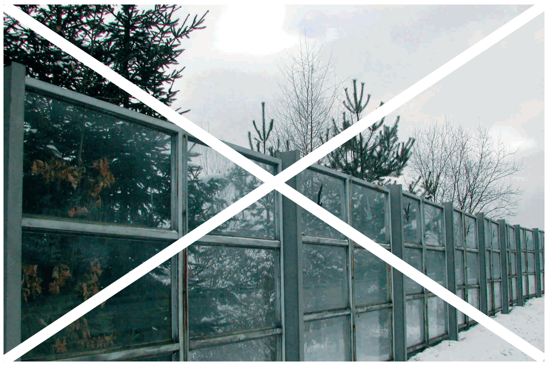

Figure 7.93 - The planting of bushes close to transparent screens should be avoided. (Photo by V. Hlaváč)

Points for special attention

- Wherever possible, transparent screens should not be built. Non-transparent walls can be covered with bushes or climbing plants.
- No trees or bushes should be planted in the vicinity of transparent noise barriers because this increases the risk of collisions. Where trees or bushes are planted as mitigation measures, no transparent noise barriers should be built.

Figure 7.94 - Hedgehog trapped by a kerbstone. (Photo by B. Iuell)

7

Adaptation of the kerb

Vertical kerbstones are often too high for small amphibians, reptiles, mammals or invertebrates. If they don't find an exit, animals get trapped and usually die. Gently sloping kerbs are a cheap alternative. With a height above the road of a few millimetres at the bottom they are still detectable, *e.g.* by blind people using a guiding stick. A gap between vertical kerbstones can provide escape possibilities as well, especially if plants are allowed to grow between the stones.

Escape ramps from drains

The gaps in metal covers of drains are often too big for small vertebrates and for invertebrates, which fall in and drown. Ramps offer the possibility of escape. In areas with spawning runs of amphibians a wire mesh placed under the cover of the drain prevents animals from falling in. Amphibians are the only animals to survive the way from drains to clarification plants and therefore need purpose-built escape ramps at the plant to get out.

Notes:

- The ramps should have a rough surface to provide a good grip.
- The end of a ramp should be about 15 cm higher than the surrounding terrain.
- The end of a ramp should be fitted with wire netting to prevent small predators from climbing onto the ramp. The mesh size should be about the same size as the gap in the metal cover.

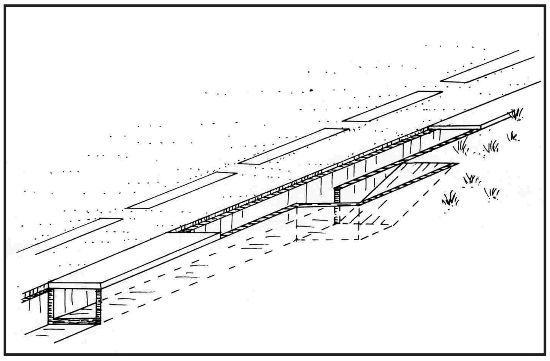

Figure 7.95 - Escape ramps from drains each 25 m help to avoid the deadly trapping of small animals.

Road lighting

Road lights often attract insects and as a consequence bats or nocturnal birds which hunt them. This results in high mortality for the insects as well as for their predators. In sensitive areas the need to establish road lights should therefore be balanced against the consequences for nature. To prevent collisions of insects the use of sodium lights is recommended.

Fauna exits from waterways

General description

Canals and irrigation channels are often protected against erosion by (almost) vertical embankments. The waves by wind or by boats, the current in the river and the lack of space between the water and the adjacent area are often the reasons for bank protection by sheet piling.

Many animals drown when there is no opportunity to climb out of the water. This problem is increased when the sheet piling is 0.2 m or more above the waterline. It is a problem for all kind of mammals and even young waterbirds may be victims.

It is possible to prevent animals from drowning by offering exits. There are two main solutions:

- The best solution is a complete new embankment with a natural slope that gives opportunities for vegetation growth. The embankment can function as a habitat and as a corridor.
- When there is no room for this, the sheet piling can locally be lowered below the water level to allow animals to exit the water.

Location

A concentration of drowned animals can be an indication where fauna exits are necessary. The exact location of the fauna exit is at the place where tracks come close to the water. The identification of the place of drowning is a problem because drowned animals may be displaced by the current or removed by scavengers.

Figure 7.96 - Different possibilities for fauna exits on waterways in the Netherlands. Exits at the water side of the sheet piling is only possible when there is no danger for ships. In use by badgers, roe deer, young ducks and hedgehogs. (Photos by H. Bekker)

7

Design of natural embankments

The number of possibilities is enormous, depending on the situation, material, forces of waves and current, etc. Projects in the Netherlands have shown there can be many benefits for nature. The issue is covered in other handbooks.

Design of fauna exits

- Several designs are possible; depending on the function and characteristics of the waterway: ships, currents, waves, species.
- Exits can be placed behind or before the sheet piling.
- Exits can be made from wood, steel or stone.
- Dimensions: in canals a high number of small exits of 1 m width or fewer of 5-7 m width are recommended in the Netherlands.
- Distances of 50 m between fauna exits are recommended in the Netherlands.
- Vegetation around the fauna exit can help attract the animals so that they swim towards the fauna exit. This vegetation can be part of the whole landscape structure around the fauna exit.
- Exits are required on both sides of the water. The distances different species can reach by swimming needs to be researched.

Accompanying measures

- Around the exit should be vegetation which provides shelter for the animals. The vegetation should be integrated with the surroundings landscape structure.
- Fauna exits can be connected to underpasses when a road parallel to the canal forms an obstacle.
- Fences or hedges can be used as guidance from the land side.

Maintenance

- Sheet piling is often damaged because of big boats with big stern waves. Waves are worse when there are sheet-piling defences at both sides of the water. The defence in a fauna exit gets these same waves, which increases the risk of destruction by stern waves.
- The fauna exits are often places where floating waste gathers.

Extra information: The Dutch Handbook (CUR) contains six volumes on ecological embankments covering both the technical and ecological issues. It is currently being translated into English.

7.5 Reducing the barrier effect and mortality: other measures

7.5.1 Adapting road width and reducing traffic intensity

The barrier effect of roads for small animals is partly an effect of the width of the tarmacked surface. The number of vehicles and their speed, however, also affect the number of animals killed. Different types of measures can be beneficial for wildlife:

Reducing the width of the infrastructure

- Agricultural and forestry roads which are not tarmacked are more easily crossed by small animals, *e.g.* invertebrates.
- On agricultural roads an alternative to a fully tarmacked road is the provision of two concrete tractor-strips. The area between the strips is kept vegetated, thus providing cover for invertebrates.

Reducing the amount of traffic

- Temporary closure of roads is a suitable measure in cases where animals only cross a road during a limited period. It is recommended, for example, to protect amphibians on their migration to spawning grounds (closure during humid nights in spring) or to allow wild reindeer to move to their wintering grounds undisturbed (closure of a road during critical periods in winter).
- Any other common measure to reduce the amount of traffic (one-way streets, restricted access, etc.) can also be used as a measure to reduce collisions with wildlife.

Reducing the speed of the vehicles

- Reducing the width of the road can reduce the speed of the vehicles and thus reduce the risk of collisions with mammals. This measure is suitable for rural roads with relatively light traffic.
- Temporarily or permanently lowered speed limits at high-risk spots can contribute to reducing the risk of collisions with mammals.
- Where collisions happen mainly during the night, speed limits at night might be sufficient.
- Speed ramps are recommended on roads with light traffic.

7.5.2 Decommissioning of infrastructure

The decommissioning of roads or railway lines should be considered in particular where new infrastructure is constructed. If stretches of old infrastructure are completely removed and the ground returned to nature, this may be considered as a compensation measure for the additional habitat fragmentation created by the new infrastructure. However, in most cases, an old infrastructure will not be completely removed but will for example be used as a footpath or cycleway. Thus it may contribute to reduced habitat fragmentation at a small scale.

Decommissioning of infrastructure should be part of the general planning procedure (see Chapter 5).

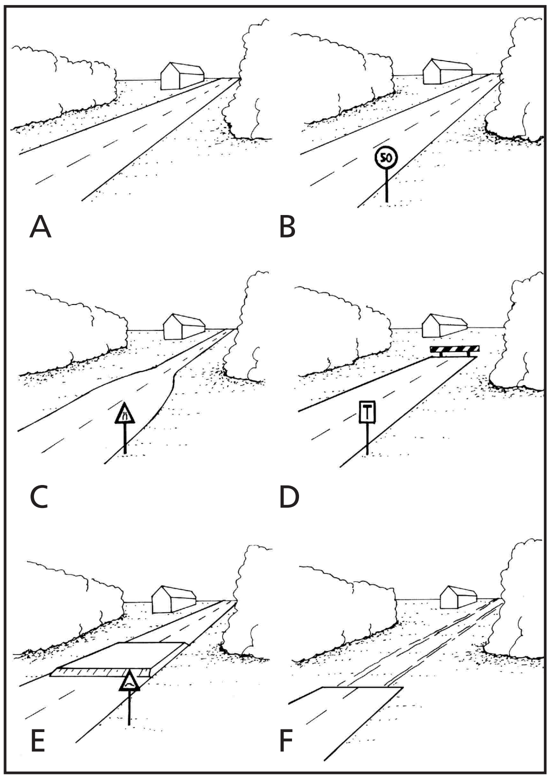

Figure 7.97 - Traffic calming measures reduce the barrier effect and the number of collisions. A: original situation. B: reducing the speed limit. C: reducing speed and traffic capacity by narrowing the road. D: dead-end: reducing traffic by stopping transit traffic. E: reducing speed by speed ramps. F: replacing road with two concrete strips still allows agricultural traffic and reduces the barrier for invertebrates.

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8 Ecological Compensation

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8.1 The concept of ecological compensation

8.1.1 Ecological compensation for habitat loss and degradation

Despite good planning and use of mitigation measures aiming to avoid or reduce adverse impacts on natural habitats, it is impossible to completely avoid the negative effects of infrastructure development. This realisation has led to the principle of ecological compensation in many European countries. Ecological compensation implies that specified natural habitats and their qualities, such as wetlands or old-growth forests, should be developed elsewhere when they are impacted by an approved project. When compensation is implemented, the measures should balance the ecological damage, aiming for a 'no net loss' situation that benefits both habitats and their associated species. Ecological compensation may be defined as creating, restoring or enhancing nature qualities in order to counterbalance ecological damage caused by infrastructure developments.

Ecological compensation aims to enhance the role of nature conservation interests in project planning and decision-making (see Chapter 5), and to pursue a 'no net loss' solution once development is approved. These aims imply that ecological compensation is a 'last resort' solution - it is only considered where planning and mitigation measures are not able to prevent damage. Ecological compensation should not be considered as an enabling activity to allow developers to get planning permission by buying-off environmental objections.

Since legal instruments, such as expropriation tools, that enable developers to acquire suitable land from landowners for compensation purposes are few, compensatory measures are mainly implemented on a voluntary basis, rooted in agreements between project developers, nature conservation trusts, landowners or other stakeholders.

8.1.2 Compensation as part of the nature conservation concept

Compensatory measures are fundamentally different from the protection or enhancement of natural values (nature conservation policy). However, compensatory measures must be in line with local and national nature conservation targets. In contrast with landscaping and mitigation measures, ecological compensation is generally undertaken outside the highway management area. As initiators of projects are held responsible for the implementation of the compensatory measures, highway agencies should put serious effort into acquiring land in the neighbourhood of the infrastructure for compensation objectives. By locating the compensation sites properly, for example spatially linked to nature reserves or networks, ecological functions and relations may be protected or enhanced.

8.1.3 Scope of compensatory measures

The way compensatory measures are applied varies from country to country, and depends on the geographical and cultural context. Compensation may include conversion of land for the development of new new habitats (woods, river beds, etc.). Habitat enhancement may also encompass the adaptation of farming activities towards nature conservation considerations (*e.g.* meadow-birds or plants). Artificial wetlands (not necessarily ponds) may be created in order to attract species such as amphibians and reptiles. Created wetlands may not compensate for the impacted wetlands from a landscape-ecological point of view. Research enabling compensation to be targeted for the benefit of specific species can also be considered as compensation. Ecological compensation can be applied to the complete spectrum of impacts, including habitat degradation (habitat is still present, but impacted), and loss of functions such as nutrient and energy flows.

8.2 Legal obligations

8.2.1 Regulations and international legislation

Compensatory measures may be required in the case of:

I. a. International legislation: the EU Birds Directive (1979) and the EU Habitats Directive (1992).

b. National legislation on compensation.

Underlying principles when compensation is required by international or national legislation:

- Species and habitats protected under (inter)national regulations require stringent constraints within the planning process and it is usually difficult to justify the social necessity for developments in protected areas, or areas with protected species.
- Financial compensation or compensation in terms of other values than the impacted ones (trading-off) should not be permitted.
- Ecological compensation must address physical and functional aspects of the impact.
- According to the Birds and Habitats Directives compensatory measures should be implemented before the start of the infrastructure development.

II. Formal compensation policy: non-legislative regulation, *e.g.* laid down in national policy plans.

Where compensation is linked to formal national policy usually less stringent measures are required:

- Economic or social necessity may, in exceptional cases, justify project development, under the condition that ecological damage is compensated for.
- Compensation in terms of 'comparable' ecological values as well as financial compensation are both permitted, though less preferable.
- Compensatory measures do not necessarily have to be implemented before the project starts.

III. Compensation based on voluntary agreements, implying that it has neither a legislative nor a policy basis.

Non-legislative policy requires less stringent conditions on the implementation of the compensation principle. In the assessment process, socio-economic and nature conservation interests are weighed against each other.

8.3 Achieving ecological compensation in infrastructure projects

8.3.1 When to compensate for ecological impacts

Compensatory measures have to be taken:

- If a development is foreseen to have significant impacts on areas that are protected by the EU Birds and Habitat Directives (this is the case in all EU member states) or by national regulations (this is the case in Germany and Switzerland).
- If a development is foreseen to have impacts on areas of high conservation value on which a non-legislative compensation policy is operative.

See also Chapter 5 which defines criteria where ecological impacts require mitigation measures.

8.3.2 Responsibility for implementing compensatory measures

- The developer is responsible for implementing the ecological compensation principle.
- As a result of this, the developer provides funds to achieve compensatory measures, and to monitor and modify them if results are unsatisfactory.

8.3.3 Habitat creation

Several European countries have experience with habitat creation. It usually involves the conversion of farmland into habitats with increased nature qualities. The process includes:

- Land acquisition (or management agreements).
- Specific design (*e.g.* soil manipulation, adjusting the water table).
- Management planting of selected species *e.g.* hay meadow species or woodland species, fertilizer management, time of cutting etc.
- Monitoring and aftercare.

Figure 8.1 - Mosbulten (NL). Above: to compensate for the loss of marshland habitat due to the construction of Highway A50 Eindhoven-Oss, the first thing to do was transform set-aside farmland by removing the top soil. Below: after removal of the soil of former arable land, marshland habitat may develop and attract breeding birds. Target species are reed warbler and water rail. (Photos by H. Bekker)

8.3.4 Translocation

Sometimes habitat creation may be accompanied by translocation, *i.e.* soil and/or species being removed from the impacted (donor) site to the new (receptor or compensation) site. The receptor site must be suitable, and should contain the same soil properties as the donor site. The advantage of this technique is that the donor and receptor sites show high similarity in soil and/or target species. However, this method is expensive, and timing as well as soil conditions are critical.

8.3.5 Habitat enhancement

Enhancement of habitat implies that the compensatory habitat is present, but not of the right quality. Former impacts may have caused habitat deterioration. Compensation may include measures needed to enhance habitat quality (such as reducing grazing pressure, raising the water table). The advantage of enhancing the quality of existing habitat is that often the soil and hydrological properties are close to those required to meet conservation objectives.

8.3.6 In-kind/out-of-kind and on-site/off-site compensation

Compensation aims at a 'no net loss' situation for protected species and habitats. So compensatory measures should preferably aim at creating similar ecological qualities to the area impacted ('in-kind' compensation). However, it may be legitimate to compensate in terms of comparable qualities ('out-of-kind' compensation). This is the case when in-kind compensation is not feasible and out-of-kind compensation favours the persistence of an important species that is impacted by infrastructure developments.

Location of compensation sites can be considered as on-site or off-site compensation. Compensatory measures are best undertaken outside the impact zone of the highway but within the landscape-ecological context of the area ('on-site' compensation). If the compensation is too close to the highway, the ecological values on the compensation sites will be influenced negatively by the highway. The width of the impact zone may depend on the target species of the compensatory measures. It may be advisable to locate compensation areas away from impacted areas (off-site compensation) if this increases the chances of success or reflects availability of suitable compensatory areas.

In-kind vs. out-of-kind habitat compensation

In-kind compensation involves replacement with the same habitats, species or functions; out-of-kind compensation involves replacement with alternative habitats, species or functions.

In-kind compensation for three type of impacts:

1. Habitat loss: creation of habitat patches of the same size and quality (on-site or off-site); upgrading existing habitat may also be effective as a secondary approach.
2. Habitat degradation: upgrading habitats.
3. Habitat isolation: a combination of enlarging and upgrading habitats or increasing the connectivity of isolated habitat patches.

Examples of compensating for habitat degradation

1. Off-site raising of groundwater levels to compensate for depressed water tables.
2. On-site/off-site raising of the water table or introducing a new management regime to render noise-affected habitat more attractive to meadow birds.

Examples of compensation for habitat isolation

1. Closure of the 'lower-level' road network (*e.g.* trunk roads) to motorised traffic to compensate for highway construction.
2. Developing new patches attached spatially to or located within existing nature areas, thus forming larger units with a potentially greater number of species and individuals.
3. Developing new patches to serve as links between the core habitats of species, thus reinforcing or creating ecological corridor functions.

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Figure 8.2 - Example of habitat enhancement: regeneration of a stretch of the River Inn to compensate for impacts of the new road on protected riparian vegetation. Above: before, below: after. The compensation encompasses re-establishment of floodplain habitat further from the road which was impacted by gravel extraction, Strada Bypass, Switzerland. (Photo by Canton Graubünden Tiefbauamt)

8.3.7 Sustainable compensation

In order to make sure that compensatory measures are successful, the following activities should be considered:

- Monitoring during and after implementation (see Chapter 9).
- Incorporating compensation sites in local conservation and landuse plans, implying that the sites are protected against future developments.
- Transferring the management of acquired compensation sites to well-established conservation organisations.
- Including management of measures in the overall compensatory plan.
- Compensation is more likely to be sustainable on sites requiring minimal management input.
- Attaching contingency measures to compensation plans so that measures will be adjusted if the results are unsatisfactory.

Figure 8.3 – Example of wetland construction in the Glen of the Downs, Ireland. Above: during construction, below: on completion. (Photo by R. Nairn)

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8.4 Mitigation banking

In the USA, 'mitigation banking' was introduced more than ten years ago. This is a scheme whereby large areas of 'reserve land' are accumulated. Developers can buy a compensation site once a project has been approved. Banking of credits in advance favours acceleration of the approval procedure, because the compensation site is available and of suitable quality. This lowers mitigation and compensation costs and increases the ecological value of compensation, as one large compensation site avoids the fragmentation associated with smaller sites. These arguments, and particularly the fact that land acquisition is already difficult in some regions, make it worth considering the application of mitigation banking in parts of Europe.

9 Monitoring and Evaluation

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9.1 General principles of monitoring

9.1.1 The need for monitoring and its objectives

After the construction of roads, railways and waterways the application of monitoring is of crucial importance as it is this mechanism that allows planners to check the effectiveness of measures which have been applied in order to reduce the infrastructure's impact on habitat fragmentation. A well-designed monitoring scheme will help to achieve several goals:

- To detect failures in the installation, construction or maintenance of measures.
- To establish if the mitigation measures fulfil their purpose.
- To evaluate if the measures provide long term mitigation for the species and habitats.

In short, monitoring will contribute to establishing whether or not suitable and sufficient mitigation measures have been provided for during the planning and construction phases of a transport infrastructure, guaranteeing minimum impact on the fragmentation of animal populations and habitats.

The dissemination of the results of the monitoring scheme is also very important for gaining knowledge on the development of more effective and less expensive measures. Therefore, important objectives of monitoring include helping the infrastructure planners to:

- Avoid repeating mistakes.
- Provide new information for improving the design of mitigation measures.
- Identify the measures with an optimum relationship between cost and benefit.
- Save money for future projects.

Monitoring schemes should be an integral part of the routine technical management that leads to the adaptation and improvement of the design of measures which avoid or reduce the effects of transport infrastructure on habitat fragmentation.

9.1.2 Definition and types of monitoring

In general, monitoring should consist of regularly repeated measurements of selected variables. An activity can only be called monitoring if the following requirements are met:

- Measurements are standardised.
- The variables selected indicate ecological processes of interest or properties that need to be detected.
- The scale (both in time and space) of measurement is appropriate for the detection of change.

Without clear objectives for monitoring, these requirements cannot be fulfilled. The establishment of these objectives and the selection of methods, standards, scale and criteria for the evaluation of the effectiveness of measures requires basic ecological knowledge of the systems affected. Therefore, the involvement of ecologists or wildlife biologists in the design of monitoring schemes is fundamental.

It is possible to distinguish between two types of monitoring, described below.

Monitoring of measures: routine monitoring

This type of monitoring focuses on the inspection and control of the effectiveness of measures by measuring local variables such as the number of animals using a passage or the number of animals run over per kilometre of infrastructure. Construction standards (materials, dimensions, location, etc.) and maintenance are verified and variables are measured to evaluate if they fulfil their purpose. When failures appear, corrective measures can be applied to amend the problems.

Monitoring can be focused on an isolated measure but more often than not it is advisable to monitor the measures which show interrelationships or have a combined effect to achieve the same objective.

This type of monitoring can be included in the routine management and maintenance plan of the infrastructure and in some countries is developed as a statutory procedure in all new transport infrastructure developments. It includes activities that do not require high specialisation of the professionals who implement it and can be achieved with reasonable budgets.

Some examples of activities that can be included in this type of monitoring are:

- Identifying if fauna passages are used or not by the target species and the frequency of use. If they are not used, an attempt should be made to identify the causes of failure and to design corrective measures.
- Registering the number of road and railway casualties, locating black spots where a large number of animals per unit length are run over, and identifying which species are affected.
- Identifying other problems such as pits that can act as lethal traps, fences which are not properly installed, etc.
- Verifying the noise reduction effect of barriers installed to reduce this disturbance.
- Checking if a new pond which has been constructed as a compensatory measure is being used by the target species.

Monitoring the effects of measures on species and habitats: ecological monitoring

This focuses on the ecological effects of mitigation and compensation measures. It tries to identify changes in genetic diversity, species distribution, population dynamics, habitats and landscapes. Selected habitat features, landscape patterns and natural processes are registered after the construction of a new transport infrastructure and compared to baseline conditions.

Ecological monitoring requires long-term and large-scale approaches, which take into account the whole number of measures that have been applied and the synergistic effects that occur when new transport infrastructure is added to the existing network. For this reason, this type of monitoring can only be applied as routine in special cases, for example when a wildlife overpass has been constructed

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Figure 9.1 - Monitoring of fauna passages or registering road casualties to locate black spots can be carried out by standard procedures included in the infrastructure maintenance plans. (Photo by C. Rosell)

to link the habitats of endangered species or to connect natural protected areas.

Some of the aspects of ecological monitoring are:

- Incidence of mortality caused by road and railway casualties and its effect on the population dynamics of target species.
- Evaluation of the barrier effect of the whole infrastructure network, taking into account not only the proportion of animals that try to cross and are run over but also the proportion of individuals that attempt the crossing and are dissuaded from doing so by disturbance (noise, light, etc.).
- Changes in the behaviour of indicator species due to disturbances.
- Effects of new habitats associated with the infrastructure such as cuttings and verges. Colonisation by invasive species and consequences of the attraction of predators such as birds of prey to these areas.
- Landscape changes generated by the new infrastructure such as the degree of habitat fragmentation, distance between fragments of the same type of habitat and others.
- Changes in distribution, composition and quality of the habitats adjacent to roads and railways due to pollutants generated by the infrastructure.

Ecological monitoring provides very valuable information for the design of new infrastructure in order to mitigate its effects, and also improves understanding of the problems. The design of these monitoring projects must be carried out by wildlife specialists because methods and temporal and spatial scale of measurements show a high variation between different species and landscapes. As a result, this chapter does not describe this type of monitoring but rather focusses on the monitoring schemes to be applied as part of the management and maintenance of transport infrastructure.

Figure 9.2 - Telemetry data provide information on the behaviour of the animals in relation to transport infrastructure but it requires high specialisation and investment of time and money. Its application to routine monitoring is limited, but it can be very useful in special cases. (Photo by B.Iuell)

9.1.3 Practical considerations

The main lesson to be learnt from existing monitoring schemes is that successful schemes are simple, cheap, co-ordinated and standardised.

All monitoring schemes are limited by the practical considerations of cost and feasibility, which means that monitoring objectives have to be examined very closely for relevance. Priorities must be linked to objectives in order to identify which parameters are important and which can be omitted.

Some of the practical considerations which are important when planning the monitoring of infrastructure developments are:

- Clear monitoring objectives should be defined. This is necessary in terms of what information will be provided.
- Clear achievement targets for mitigation measures should also be defined. Monitoring cannot show which targets to aim for when setting standards: these are value judgements. However, what monitoring can do is indicate whether or not these targets are being achieved.
- Systematic and standard recording schemes and methods should be used. Training and co-ordination are important.
- Information on the baseline conditions should be gathered when possible.
- Species with a recognised value as indicators of habitat fragmentation should be selected. It is not possible to monitor everything.
- A scale of recording appropriate to the process/animal being monitored should be chosen.
- Monitoring work should continue beyond the infrastructure development phase. Monitoring requires repeated records.
- Monitoring records should be stored safely and in such a way that they are accessible to all stakeholders.
- Records should be kept in a standardised way. Change can only be detected if the original work is geo-referenced and sites can be relocated.

Four points are thus particularly important: the selection of target species, the selection of the spatial and temporal scale, the methodology and the development of standards.

Standards for evaluating whether goals are achieved

Monitoring provides results about variables that need to be compared with a standard measurement. The existence of standard measurements allows the degree of effectiveness of measures to be evaluated and aids the decision about when corrective actions must be applied to improve their effectiveness. A standard must be a quantitative variable when possible and should be based on clear criteria. Expressing the objectives of mitigation measures in a standard way provides the best basis for the monitoring and evaluation of the effectiveness of mitigation measures.

Selection of target species

Some measures have been designed for a particular species such as species of high conservation value or native species which are sensitive to habitat fragmentation and require large areas of continuous habitat, or the maintenance of migration routes (for example wolf, bear or ungulates). In this case the choice of target species is clear.

Nevertheless in other cases, the measures have a more general goal such as avoiding the loss of quality of an adjacent habitat or maintaining links between fragmented habitats or populations. In these cases, it is necessary to select target species (see Chapter 5) on which to focus the monitoring activities. The following characteristics are suggested:

- Species for which measures were designed.
- Species which respond to changes in fragmentation and do so rapidly.
- Organisms about which substantial ecological knowledge is available and standard monitoring methods have been clearly established.
- Species that are easy to detect and identify.
- Taxonomic groups recognised as indicators of habitat fragmentation, which give information about the state of whole ecosystems.

Scale

The selection of appropriate spatial and temporal scales for monitoring is of major importance but it is not possible to establish general rules. Essentially, to detect change a sufficiently large area over a long enough period of time needs to be sampled. For example, the duration and periodicity of monitoring will be completely different in an analysis of the effectiveness of a fauna passage and a analysis of a reduction in road casualties caused by a new fence. The selection of spatial scale cannot be generalised.

Standardisation of monitoring techniques

One problem which limits comparisons of the impact of infrastructure developments or mitigation measures is that monitoring methods vary widely. The result of this variation is that few studies can be directly compared and patterns cannot easily be summarised. Standard monitoring protocols are essential if studies are to be compared or results from different monitoring programmes combined. This is essential to enable the analysis of different mitigation measures in different cirumstances. It is therefore important to be open for co-operation.

9.2 Designing a monitoring programme

9.2.1 The monitoring programme from design to application

The application of the monitoring programme begins when the transport infrastructure is opened. However, the purpose of the programme must be established right at the beginning of the development of the project during the design and planning phase. A summary of the whole process is shown in Figure 9.3 and includes three major steps that are described below.

Designing the monitoring programme and establishing the baseline conditions during the planning phase

Knowledge about the baseline conditions of habitats and species allows comparison to be made with the results obtained after the construction of the transport infrastructure. This information is also fundamental to the identification of sensitive areas and target species. Baseline conditions must be clearly defined during the initial stages of infrastructure planning, during the preliminary studies and especially in the Environmental Impact Assessment (EIA). The Environmental Impact Study should contain a detailed description of habitats (type, distribution, degree of fragmentation, conservation value, etc.), species (distribution, sensitivity to habitat fragmentation, population level, conservation interest) and wildlife corridors (see Chapter 5). The ES is also the most suitable report in which to include the design of the monitoring programme, identifying the goals for mitigation measures and the activities that must be carried out in order to evaluate their effectiveness, with a detailed description of methods, periodicity of controls, standards, etc.

Controlling the application of measures during the construction phase

Monitoring the works during the construction period of the infrastructure is an opportunity to ensure the effectiveness of measures. During the construction of the infrastructure, it is important to carry out inspections and quality control activities on site. These activities are routinely carried out in some countries to avoid negative impacts on the surrounding habitats during the construction phase, but they are also needed to ensure the correct installation and construction of the measures that will allow the achievement of their goals. New conditions and unexpected changes can appear during this phase which were not detected in the EIA and these may require the implementation of new measures or adaptation of the measures originally proposed.

Applying monitoring activities during the operational phase

The application of the monitoring programme should start when the infrastructure opens. During this phase controls are applied and an evaluation of the effectiveness of measures is carried out. As described in the next chapter, the dissemination of the results is also part of this process.

Planning phase

Environmental Impact Study

- Establishing the baseline conditions
- Identifying the mitigation measures to be applied and their objectives
- Designing the monitoring programme

Construction phase

Quality control and environmental follow up activities

- Supervising the appropriate construction and installation of mitigation measures
- Re-designing measures when a new problem appears

Operational phase

Implementation of the monitoring programme

- Testing suitability and adequacy of mitigation measures
- Checking proper installation and construction
- Evaluating effectiveness of measures

- Improving ineffective measures (corrective activities)
- Gathering knowledge on species requirements and criteria for designing effective mitigation measures
- Providing information on the cost-benefit ratio of different mitigation measures

Figure 9.3 - Phases in the life of an infrastructure project and the design and planning of the monitoring programme.

9.2.2 Steps for the design of the monitoring programme

The procedure for the design of a monitoring programme is summarised in the following six steps (see Figure 9.4):

I. **Analysing the general characteristics of the infrastructure, baseline conditions (species, habitats and landscape features) and overview of mitigation measures.**

This information should be produced during the planning phase and especially by the EIA procedure. The number of mitigation measures should be identified, describing the technical characteristics, location and goals of each one. The existence of sensitive natural areas or endangered species must be taken into account in order to identify specific monitoring requirements.

II. **Selecting and describing measures to be monitored and evaluated.**

The selection must be carried out on the basis of clear criteria and include all those measures, the effectiveness of which has not yet been clearly established. The description should also include a representative number of the different types of measures taken to avoid, mitigate and compensate habitat fragmentation.

III. **Identifying the need for specific ecological monitoring when endangered species or habitats are affected.**

This type of activity requires more complex methodologies and long-term monitoring to be undertaken by specialists. This can be carried out in parallel to the routine monitoring programme.

IV. **Describing in detail the monitoring activities.**

A detailed description of each mitigation measure (or system of related measures) including:

- The objective to be achieved with the application of the measure, describing the variables on which evaluation will focus and the standards to be used, expressed as quantifiable measurements where possible. The existence of clear and measurable goals enables evaluation of whether or not the objectives are met.

- Target species or habitats.
- The protocols for monitoring methods, including the techniques to obtain information (as standardised as possible) and the duration and periodicity of measurements. The monitoring should cover a minimum period of three years. The evaluation of effectiveness should not be based on the results obtained immediately after the opening of the infrastructure, because the animals need a period to adapt to the changed surroundings.
- The procedure of storing and analysing the information obtained.

  It is also recommended to include in the monitoring programme a section describing the monitoring of activities to be included in the quality control plan that it is carried out during the construction phase (see Section 9.3). This is an important step to guarantee that the measures will not fail due to inappropriate materials or problems of construction.

V. **Defining the contents of the monitoring report.**

These reports must include as a minimum the following sections:

- A description of measures that have been monitored and methods applied.
- Identification of non-effective measures and reasons for their failure.
- The design of new measures to be taken to improve the effectiveness of existing ones.
- Recommendations to improve the design of future measures.

VI. **Establishing a system for the dissemination of the results.**

It is important to establish the dissemination activities and systems to guarantee the accessibility of data from the monitoring programme to all the stakeholders.

The design of the programme should be carried out during the planning phase (see Figure 9.3) but the monitoring activities and the evaluation of measures are developed during the operational phase, usually by professionals who have not been involved in the design of the measures. For this reason it is recommended that all the information needed to carry out the monitoring programme is compiled in a document that will provide the guidelines to implement the programme.

The organisations which manage the transport infrastructure in each country or region should provide detailed instructions based on these general procedures to ensure that the results of the monitoring of different projects are comparable.

Step I. Analysing the general characteristics of the infrastructure, baseline conditions (species, habitats and landscape features) and overview of mitigation measures

↓

Step II. Selecting and describing measures to be monitored and evaluated.

↓

Step III. Identifying the need for specific ecological monitoring when endangered species or habitats are affected.

↓

Step IV. Describing in detail the monitoring activities:
- Objectives to be achieved by each measure.
- Target species.
- Methods to be applied. Periodicity and duration.
- Procedures for storing and analysing information.

↓

Step V. Defining the contents of the monitoring report.

↓

Step VI. Establishing a system for the dissemination of results.

Figure 9.4 - Steps to design a monitoring programme for mitigation measures.

9.3 Quality control during the construction phase

Usually during the construction phase a quality control plan is applied which aims to ensure the appropriate installation and construction of all of the infrastructure project's elements. These plans should also include environmental follow up activities which aim to ensure that the construction activities are having minimum impact on the habitat and also that the measures are installed in the correct place, with the correct materials and dimensions and finalised according to the technical prescriptions established by the environmental impact studies.

This chapter does not aim to describe in detail this type of monitoring activity. However, a short check list is provided to draw attention to the main activities that can be included in the quality control plans to avoid the most common causes of failure of measures.

Aspects to be checked during the environmental follow up and quality control activities during the construction phase:

- **Calendar of works**. All works should be planned in such a way that disturbances are avoided to ponds and rivers during the amphibian breeding period and during the fish spawning season and also in the vicinity of birds' nests during breeding periods (especially birds of prey). Disturbances which affect amphibians and fish breeding sites include pollution or alteration of physical or chemical properties of the water and movement of soil. Disturbances affecting birds of prey include the movement of machinery and people and noise, especially the noise caused by blasting.
- **Location of measures**. Measures should be correctly located according to the guidelines established in the EIA.
- **Fences**. The dimensions and type of mesh should be checked. After installation it should be checked that the fence is well fixed to the soil with no opportunities for animals to pass underneath it.
- **Fauna passages**. It should be checked that the materials and dimensions are applied following the guidelines provided by the EIA. Other crucial points to check are that the surface is well formed with the correct planting and installation of other structures (stumps, stones, etc.). Access to the passage is also fundamental, including slope of ramps (when they exist), continuity of vegetation from the surrounding natural habitats to the passage and drainage of the surrounding areas. Often the drainage of cuttings or embankments near passages leads to flooding during periods of rain.
- **Restoration activities**. Disturbed areas which need to be restored or areas where compensatory measures are applied must be exhaustively monitored during the construction phase. It is important that species and ecotypes of plants have been correctly chosen and that irrigation and all the other systems that require maintenance have been installed. Restoration activities can also include the translocation of animals which requires specific control activities, such as the control of the origin population and sanitary aspects.
- **Avoiding disturbances and pollution of adjacent habitats**. The whole number of activities carried out during the construction of a road or railway can cause pollution to the adjacent soil or waters, and other disturbances originated by the movements of machines and workers. There are a large number of mitigation measures that can be carried out to ensure that all these impacts are minimised.

A definition of follow up activities during the construction phase can be undertaken within the framework of standard norms, such as ISO 14001 (to minimise the environmental impacts) and ISO 9000 (to ensure the quality of works).

9.4 Methods for monitoring fauna casualties and the use of fauna passages

A large number of methods can be used to monitor mitigation measures. This chapter describes the most common methods for recording fauna casualties and checking the use of fauna passages, giving information about the procedures and variables to be recorded and standards to be achieved. Standards of reference cannot be generalised because they depend on many factors such as the population level of target species, the landscape conditions or the objective of the measure. For this reason, instructions are only provided on standards which can be used for the evaluation.

9.4.1. Recording of road and railway casualties

Objectives

To identify the stretches of the transport infrastructure where most animals are run over or where traffic security must be improved.

Description

Checking how many casualties of different species occur on the road or railway per unit length once the transport infrastructure is operational.

Procedure

Follow the road under study in a slow-moving vehicle (15 km/h) or walk along the railway line. This should be done very early in the morning before scavengers such as magpies can remove the remains of animals that have been killed. For each animal that has been run over the species should be identified and the variables listed below recorded. The periodicity of sampling varies depending on the target species but in general monitoring of various taxonomic groups should be repeated at least every 10 to 15 days during main periods of animal movement, which include periods of dispersal of young individuals, migration periods and the hunting season.

Variables to be recorded

Date and the time the survey starts and ends. For each casualty it is necessary to identify the species or taxonomic group, kilometric point of the road or railway where it was found, its exact location on the carriageway/railway, state of decay and any other observation (sex, age, etc.). Registering other variables such as road section, landscape characteristics or presence/absence and state of fences can help to analyse the factors which contribute to increases in road casualties.

Standards

It is very difficult to achieve the goal of zero casualties. For this reason the recommended standard variable is the maximum number of animals of each species (or taxonomic group) per kilometre that is permissible for a certain population size. If casualties are above this number then corrective measures should be applied.

Observations and possible variations

Monitoring can also focus on identifying black spots where target species are run over. This method can be applied for example to determine black spots for amphibian, lynx, wolf, otter or badger casualties and to identify the places where their migratory routes cross transport infrastructure. Extensive monitoring of a large length of transport infrastructure is often necessary and it is recommended to involve volunteers and/or people responsible for maintenance to provide data about the location of dead animals or crossing points. A co-ordination centre should compile the information and check all the blacks spots to determine the corrective measures that can be applied in each case.

Examining dead animals on a stretch of road with heavy traffic is a dangerous activity. For these reasons the security of workers who carry out these activities must be taken into account.

Figure 9.5 - Recording road casualties is a good method to identify locations where corrective measures should be applied. Both volunteers and people responsible for infrastructure maintenance can be involved in this task. (Photo by V. Hlaváč)

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9.4.2 Registering the proportion of animals that succeed in crossing the transport infrastructure

Objectives

To identify the ratio of animals that live in the vicinity of the infrastructure and successfully cross it. This can also be used both to determine the proportion of animals which cross using fauna passages, culverts or other structures and the proportion crossing directly over the road or railway.

Description

Counting the number of animal tracks registered near the infrastructure and determining the number of animals that cross it and the number of animals that refuse to cross.

Procedure

This method is particularly recommended in regions where there is often snow cover. In the winter when snow covers the ground, the length of the infrastructure should be walked at a distance of approximately 20 m from the road or railway and the length of the transect line should be measured. The tracks of different species, the number of animals walking alongside the infrastructure, the number of animals that refuse to cross it and return to their original habitats and the number of animals that succeed in crossing the infrastructure should be determined. Both sides of the road should be inspected. The distance of the transect line from the road should be adapted to the home range of the target species.

The operation should be repeated at least every 10 to 15 days during periods of maximum animal movement when there is snow cover present. Main periods of animal movement include periods of dispersal of young individuals, migration periods and the hunting season.

Variables to be recorded

The date and time the survey starts and ends. For each track it is necessary to identify the species and the behaviour of the animal in relation to the infrastructure.

Standards

The ratio of individuals successfully crossing or failing to cross the infrastructure to the total population of each species.

Observations and possible variations

Determining the age class of the individuals by means of the length of the footprint can provide information about differences in the behaviour of resident adults and young animals in the dispersal phase. In countries where it is not possible to record tracks in the snow this method can be adapted by constructing strips of a suitable surface such as sand. This is more intensive as it is necessary to remove the existing vegetation and build a strip at least 50-100 cm wide alongside the infrastructure (depending on the target species).

Figure 9.6 - Tracks in the snow allow the number of animals that cross or refuse to cross the infrastructure to be analysed. The method can also be applied to monitor the use of fauna passages. (Photo by V. Hlaváč)

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9.4.3 Monitoring the use of fauna passages by recording animal tracks on beds of sand or powdered marble

Objectives

To evaluate the use of culverts, fauna passages and other structures as crossing points by different species of vertebrates.

Description

This method consists of detecting the crossing of animals by recording the footprints they leave in suitable natural surfaces (sand or loose clay), or strips of artificial surfaces, such as marble dust, which are located on the structure to be studied.

Procedure

The middle section of the fauna passage should be covered across its entire width with a thin layer of sand or marble dust (ideally dust with a particle diameter of 800 µm). The strip should be wide enough to stop animals jumping over it easily. For culverts a strip of 1 m is wide enough but on larger overpasses a width of at least 2 m it is recommended. As an alternative method, two strips can be installed, one near each entrance, which allows the comparison of footprints registered at each entrance to see if animals successfully use the passage. The strip of sand or marble dust should be checked every day and the tracks recorded. After recording the tracks, the sand should be smoothed with a brush and more sand added if necessary. Monitoring should be repeated for 10 to 15 days during the main periods of animal movement, which include dispersal periods of young individuals, migration periods and the hunting season.

Variables to be recorded

Date and the time the survey starts and ends, weather, structure identification number, location, species identified, direction of tracks. Registering details of the infrastructure (dimensions, materials, surface, vegetation at the entrances, existence of pits, steeped canals, etc.) helps to determine the reasons for failure and the requirements of different species.

Standards

The evaluation often focuses on determining if footprints of target species are present or absent inside the fauna passage, indicating if the structure is used or not used by each target species.

The frequency of use (the number of days with a positive result as a proportion of the number of survey days) can also be used as a standard measurement.

Observations and possible variations

Marble dust absorbs water very easily which limits the application of the method to dry conditions. When the surface of the structure is damp, the floor of the structure should be covered with a film of plastic before sprinkling with marble dust. The measurement of footprint length can provide additional information on the number of different individuals using the fauna passages. When marble dust is used all the material must be removed after the monitoring period because of the problems it can pose to the movements of small animals, such as snails, which need to avoid desiccation.

Figure 9.7 - Powdered marble is a good material for recording animal tracks. Nevertheless its use is limited to dry conditions because the dust becomes hard when it is wetted. (Photo by Centro de Estudios y Experimentación de Obras Públicas, Ministerio de Fomento / Universidad Autónoma de Madrid, Spain)

9.4.4 Monitoring the use of fauna passages by recording footprints with ink beds

Objectives

To evaluate different species' use of walkways (catwalks) located in fauna passages, modified culverts or other passages.

Description

The detection of animals by recording the footprints they leave on a sheet of paper after passing over an ink bed.

Procedure

In the middle section of the passage (no longer than 100 cm) a mix of liquid paraffin with carbon powder is spread on a sheet of plasticised paper with a small folded vertical edge. On either side of the ink container sheets of paper are fixed. The recommended length of the ink container is 50 cm and the length of each paper sheet is 100 cm. The ink container and papers must cover the whole width of the passageway. Footprints are imprinted on the paper sheets after the animals have passed over the ink container. The paper should be replaced periodically (for example every week) and the tracks can be analysed back in the office.

Variables to be recorded

The date and the time the survey starts and ends, weather, structure identification number, location, species identified, direction of the tracks. Recording details of the infrastructure (dimensions, materials, surface, vegetation at the entrances, existence of pits, stepped channels, etc.) helps to determine the reasons for failure and the requirements of different species.

Standards

The presence of footprints of target species inside the fauna passage allows the use by each target species to be determined. The frequency of use (the number of days with a positive result as a proportion of the number of survey days) can also be used as a standard measurement.

Observations and possible variations

This method facilitates the measurement of footprint length and allows information on the use by different individuals of the same species to be obtained.

Figure 9.8 - Ink beds are installed on the walkway to allow the passage of small animals such as rodents, shrews or small carnivores to be recorded. (Photo by H. Bekker)

9.4.5 Monitoring the use of fauna passages using photographs and videos

Objectives

To detect the use of culverts, fauna passages and other measures by different species of vertebrates and to identify the behaviour of the animals using the structures.

Description

This method consists of filming with infra-red light at night time using photographic systems activated by a light or pressure sensor to provide images of the species which cross the structure. The equipment is set up at the entrance of the structure. Some devices are provided with long life batteries and may be left for long periods. This has the advantage of reducing the effects of human presence on crossing rates where sensitive species are concerned.

Procedure

The video camera and infra-red light should be installed where it will not block the entrance. Alternatively a photoelectric cell can be installed so that the beam crosses the width of the structure and a camera can be placed at the middle or entrance of the structure. The camera is activated when the animal breaks the beam. The beam should be at the correct height so that any animal which crosses the structure will break it. Cameras should be hidden by plants or other elements found in the surrounding area (stones, piles of logs) or with elements which help to mask the scent of humans, which mammals would probably be aware of even if cameras are hidden. Equipment may also need to be protected by boxes against bad weather. Systems should be operational at least for 10 to 15 days during the main periods of animal movement, which include dispersal periods of young individuals, migration periods and the hunting season.

Variables to be recorded

Date and time the cameras were set up and dismantled, weather, structure identification number, location, species identified, its time of using the structure. This information is obtained when the video has been watched or the photographs developed.

Standards

The main standard measurement should be whether or not the animal has used the measure. The frequency of use (the number of days with a positive result as a proportion of the number of survey days) can also be used as a standard measurement.

Observations and possible variations

One of the main advantages of using video cameras is that the behaviour of animals can be analysed. The theft of equipment is a major problem when fauna passages are also used by humans.

Figure 9.9 - Photographs are a good method of determining which species use the fauna passage. In some cases individuals can be identified by their coats (*e.g.* genet). (Photo by Minuartia, Spain)

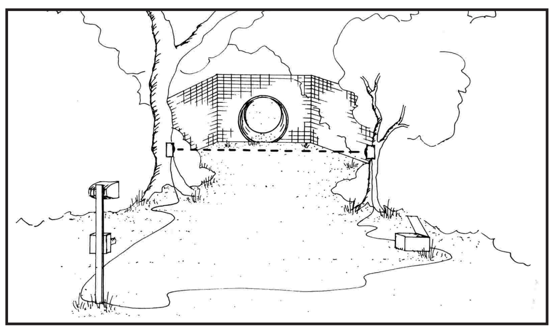

Figure 9.10 - Animals crossing the beam of infra-red light activate photo or video cameras located at the entrances or inside the fauna passages. Digital cameras can store a large number of photos and at present battery life is the main factor which limits the length of the monitoring period.

9.4.6 Other methods of monitoring the use of fauna passages

Infra-red detectors

Standard infra-red detectors, also called trail traffic counters, can be used to determine the number of animals using the passage. The movement of an animal activates the counter and records the total number of animals that have used the structure during a set period. The detectors are fixed to the walls of fauna passages or culverts and some of them can be modified to record the movement of small animals and to register the date and time of movements. The disadvantage of this method is that the species is not recorded so that the information provided is of limited value.

Hair registering

Pieces of wood are smeared with gum and fixed to each side or to the roof of the culvert. The hair of the animals using the structure sticks to the gum and can be analysed by specialists to determine which species are using the passage. This method is limited to small culverts and only provides information about mammals. Nevertheless it can for example be useful when the target species is a badger or otter.

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Examining the recordings of security or traffic control video cameras

Some overpasses, tunnels or waterways have CCTV cameras to monitor traffic and security. Recordings often contain images of animals that cross the causeway or are in the vicinity of the transport infrastructure. This information can be used to detect inappropriate use of fauna passages, the failure of fences or other information related to animal behaviour with respect to transport infrastructure.

Tracking movements with the aid of fluorescent ink

Fluorescent ink can be placed in a small container at the entrance or in the vicinity of a fauna passage. Animals that pass through the container leave fluorescent footprints that are visible at night with a special lamp. This method is especially useful for following the movements of small mammals and has the advantages of low cost and simplicity. Nevertheless this method has not been used very much and it has never been used with big mammals so the scope of its application is not well known.

Capture-recapture data

This method has been used with animals with high population densities which are easy to capture such as small mammals. Traps (Shermann traps or similar) are located on embankments and cuttings on either side of the transport infrastructure. The captured animals are marked and released and successive re-capture of these animals allows analysis of whether their movements are restricted to one side of the road or railway or if their home range includes both sides of the infrastructure. Long trapping periods are needed to obtain enough information and this method does not allow the identification of the location of crossing point.

Telemetry data

Marking animals with transmitters can provide much more information than capture-recapture data about the behaviour of the animals in relation to the transport infrastructure. Transmitters can be fixed to collars, adhered to hair, inserted under the skin or fixed to the peritoneum of the animals. The receiver provides information about the movement of the animals, their home range and the location of infrastructure crossing points. This method is only recommended when endangered species are involved because it requires a large investment of time and money both to capture the animals and to monitor their movements.

Example: Evaluation of the effectiveness of fauna passages on the road C65, Transversal Axis of Catalonia, north-eastern Spain.

This new motorway with three lanes and segregated junctions, was opened to traffic in 1995. It is one of the first roads in Spain to include culverts and underpasses adapted as fauna passages.

The monitoring programme was designed in 1992 and was carried out by a team of experts from the University of Barcelona with the support of the Autonomous Government (Generalitat de Catalunya) and a private foundation (Fundació La Caixa). It was a unique programme that went far beyond the routine monitoring of most of the new roads and railways at present constructed in the region. Monitoring focused on a stretch of 20 km which crosses two areas of mountainous forest, Montseny and Guilleries, which are proposed to be included in the Natura 2000 network. Baseline conditions identified that species of amphibians, reptiles and mammals were present in the area and characterised those stretches where a high density of species was identified.

29 structures (including culverts, underpasses and overpasses) were monitored at three stages after the opening of the road: six months, one year and two years. Monitoring methods were applied to check if animals were using the structures. Three methods were used: (i) powdered marble on permanently dry passages, (ii) photo cameras on passages which contain water courses or were humid and (iii) a video camera in one underpass. Each structure was described (length, width, height, material of construction, slope of the cuttings or embankments at the entrances, distance to the natural vegetation of the surroundings, presence of water inside and at the entrances, etc.). Adjacent habitats were also surveyed for vegetation type, profile of the road, etc.

The standard measurement was whether each target species used the passage at least once during each monitoring period. The monitoring period was for approximately 10 days in the autumn. This period was chosen because it is one of the main periods of mobility of mammals due to the dispersal of young individuals and hunting.

The results allowed the analysis of which kind of structures were more intensively used and which variables helped to explain the observed differences. During the first monitoring period (six month after the road was opened) many structures were not used by the target species, but some months later, most of them were intensively used. The results were compiled in annual reports which formed the basis, together with reports from several other schemes, for a handbook on the design of fauna passages. This was the main method of disseminating the results.

Figure 9.11 - A view of the road where one of the monitoring programmes was undertaken. The road crosses a forested area which is proposed to be included in the Natura 2000 network. (Photo by C. Rosell) (Source: Rosell and Velasco 1999)

10 Annexes

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Annex 1: Glossary

Words, expressions and terms used in the handbook.

Term	Meaning
Agricultural underpass	Underground passageway or tunnel under transport infrastructure for agricultural use, which may also be used by wildlife.
Amphibian fencing	A continuous structure erected alongside infrastructure, designed to prevent amphibians from crossing or directing them to a specific crossing point.
Amphibian tunnel	An enclosed passage or channel constructed for the purpose of conveying amphibians from one side of an infrastructure 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 to avoid environmental impacts. See also 'Mitigation'.
Balancing pond	Artificial water body 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 drainage system.
Barrier effect	The combined effect of traffic mortality, physical barriers 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 richness among living organisms including terrestrial, marine and freshwater 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 to describe distinct land units and vegetation patches identified from an anthropocentric perspective. 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 transport infrastructure or other landuse, has become a limiting factor to animal migration or dispersal.
Brash	Cuttings of woody vegetation (often left in a pile, or randomly scattered across infrastructure verges).

Term	Meaning
Buffer zone	Vegetated strip of land intended to protect sensitive habitats, *e.g.* protected sites, from impacts such as pollution or disturbance from infrastructure.
By-pass	Highway 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). In this handbook this may also refer to the area from which animals come to use a particular fauna passage.
Cattle creep	See 'Agricultural underpass'.
Central reservation	The strip running down the centre of a dual carriageway or motorway (sometimes vegetated), which separates traffic flowing in opposite directions.
Clippings	Cuttings from herbaceous vegetation.
Community (biotic)	Assemblage of interacting species living in a given location at a given time.
Compensatory measure	Measure or action taken to compensate for 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. The physical connections between landscape elements.
Consequence	See 'Impact'.
Corridor	Tract of land or water connecting two or more areas of habitats that aid animal movement across the landscape. See also 'Wildlife corridor'.
Crossing	Designated or recognised place for people or fauna to cross from one side of an infrastructure to the other.
Crossroads	The intersection of two or more roads.
Culvert	Buried pipe or channel structure, that allows a watercourse and/or road drainage to pass under infrastructure.
Curb	See 'Kerb'.
Cutting	V-shaped excavation of the land enabling transport infrastructure to be placed 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. See 'Wildlife fence'.
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.

Term	Meaning
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 of cattle or sheep.
Dual carriageway	Road with two lanes of traffic moving in opposite directions on either side of a central reservation (see above).
Dyke	See 'Dike'.
Ecoduct	See 'Wildlife overpass' or 'Landscape bridge'.
Ecological corridor	Landscape structures of various size, shape and vegetative cover that maintain, establish or enhance 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 and increasing the overall extent of habitat available to individuals.
Ecological infrastructure	The interconnected pattern of ecological corridors (see above) serving as a conduit for species moving across the landscape.
Ecological network	System of ecological corridors (see above), habitat core areas and their buffer zones which provide the network of habitats needed for the successful protection of biological diversity at the landscape level.
Ecosystem	Dynamic complex of plant, animal and micro-organism communities and their non-living environment, interacting as a functional unit.
Ecotone	Transitional zone between two habitats.
Ecotope	Distinct area with a recognisable set of characteristics relating to the soil, vegetation or water conditions. The ecotope represents the smallest land unit that makes up the landscape mosaic.
Edge (effect)	The portion of an ecosystem near its perimeter, where influences of the surroundings prevent the development of interior environmental conditions.
Effect	See 'Impact'.
Embankment	Artificial bank (made of packed earth or gravel) such as a mound or dike, constructed above the natural ground surface in a linear form and designed to carry a roadway or railway across a lower lying area.
Endemic species	A species confined to a particular region and thought to have originated there.

Term	Meaning
Environmental Impact Assessment (EIA)	A method and a process by which information about potential environmental effects is collected, assessed and used to inform decision-making. See also 'Strategic Environmental Assessment'. Also referred to as Environmental Assessment (EA)
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 amphibian ramps.
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 and 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.
Habitat	The type of site (vegetation, soils, etc.) where an organism or population naturally occurs - including a mosaic of components required for the survival of a species.
Habitat attrition	Habitat destruction due to progressive damage, loss or decline in quality.
Habitat fragmentation	Dissection and reduction of the habitat area available to a given species - caused directly by habitat loss (*e.g.* land-take) or indirectly by habitat isolation (*e.g.* by barriers preventing movement between neighbouring habitat patches).
Habitat translocation	The relocation of a habitat from one place to another usually to avoid destruction of the habitat by infrastructure development.
Halophyte	Terrestrial plant living in a salty environment.
Hard shoulder	See 'Shoulder'.

Term	Meaning
Hedgerow	A close row of woody species (bushes or trees) serving as a boundary feature between open areas (often used in combination with or as an alternative to a fence).
Herbicide	A chemical application which kills weeds.
Highway	See ‘Road’.
Impact	The immediate response of an organism, species or community to an external factor. This response may have an effect on the species that may result in wider consequences at the population, species or community level.
Indicator	Measures of simple environmental variables used to indicate some aspect of the state of the environment, *e.g.* the degree of habitat fragmentation.
Indicator species	Species indicative of (a) some current or historical 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 transport services within an area.
Invertebrate	Animals lacking a vertebral column, or backbone
Junction	See 'Crossroads'.
Kerb	Edging (usually concrete) built along highways infrastructure to form part of the gutter (see above).
Keystone species	A species that plays a pivotal role in an ecosystem and upon which a large part of the community depends for survival.
Land cover	Combination of landuse and vegetation cover.
Landform	Natural feature on the surface of the earth.
Landscape	The total spatial and visual entity of human living space integrating the geological, biological and human-made environment. A heterogeneous land area composed of a cluster of interacting ecosystems that create a specific, recognisable pattern.
Landscape bridge	Large wildlife overpass or ecoduct used to connect habitats over an infrastructure barrier.
Landscape diversity	The variation and richness of landscapes in a region.

Term	Meaning
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 topography and/or plant cover - this may include building earthworks to form new landscape structures.
Landtake	Land used for highway schemes (in the context of this report).
Land unit	The smallest functional element of the landscape.
Landuse planning	Activity aimed at predetermining the future spatial usage of land and water by society.
Linear transport infrastructure	Road, railway or navigable inland waterway.
Major road	Road which is assigned permanent traffic priority over other roads.
Matrix	In landscape ecology, the background habitat or landuse type in a mosaic, characterised by extensive cover and high connectivity.
Metapopulation	A set of local populations within an area, where typically migration from one local population to at least some others is necessary 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 and corridors embedded in a matrix (in this case, within a landscape). See ‘Matrix’.
Motorway	Major arterial highway that features: two or more traffic lanes of traffic moving in each direction, separated by a 'central reservation' (see above); controlled entries and exits; and alignment eliminating steep grades, sharp curves, and other hazards (*e.g.* grade crossings) and inconveniences to driving.
Multimodal	Pertaining to more than one 'mode' of transport (see above).

Term	Meaning
Natura 2000	Natura 2000 sites are those identified as sites of Community importance under the Habitats Directive 92/43/EEC or classified as special protection areas (SPAs) under the Birds Directive 79/409/EEC. Together, the SPAs designated by the Member States make up the European network of protected sites, Natura 2000.
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 used 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).
Red list	The IUCN Red List of Threatened Species provides taxonomic, conservation status and distribution information on taxa that have been evaluated using a system designed to determine the relative risk of extinction. The main purpose of the IUCN Red List is to catalogue and highlight those taxa that are facing a higher risk of global extinction (*i.e.* those listed as Critically Endangered, Endangered and Vulnerable). Red lists of species also exist at the national level.
Region	A geographical area (usually larger than 100 km^2) embracing several landscapes or ecosystems that share some features, *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 state. 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 verges (usually vegetated). 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.
Salmonids	Group of fish species; salmon, trout, sea trout, char.
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 patterns 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.
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.

Term	Meaning
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 above) to policies, plans and programmes at a regional, national and international level.
Surface-water drainage	System devised to remove water from the surface of the ground (or infrastructure) (see also 'drainage').
Target species	A species that is the subject of a conservation action or the focus of a study.
Taxon (pl. taxa)	Category in the Linnean classification of living organisms, *e.g.* species.
Terrestrial	Pertaining to land or earth.
Top soil	The top layer of soil that supports vegetation.
Underpass	Structure, including its approaches, which allows one route to pass under another route or obstacle.
Verge	The strip of land (often vegetated) beyond the infrastructure surface itself, but within the infrastructure corridor.
Vertebrate	Any animal characterised by a vertebral column, or backbone.
Viaduct	Long elevated bridge, supported on pillars, which carries infrastructure over a valley or other similar low-level landscape area.
Waterway	A navigable body of water.
Weir	Construction in a river or canal designed to hold the water upstream at a certain level.
Wetland	Land or area containing high levels of soil moisture or completely submerged in water for either part or the whole of the year.
Wildlife	All wild animals, plants, fungi 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, or to lead animals to safe crossing points.

Term	Meaning
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.
Wildlife underpass	Construction built under infrastructure in order to connect the habitats on either side. The surface is, at least partly, covered with soil or other natural material that allows the establishment of vegetation.
Willingness-to-pay (WTP)	A term used in economics to quantify the maximum amount of consumption possibilities that an individual is prepared to sacrifice in order to consume a particular good. In many research projects, such as valuation of various environmental assets, the purpose is to estimate WTP in terms of money.

Annex 2: Abbreviations

A	Austria
B	Belgium
CCTV	Closed-circuit television
CH	Switzerland
COST	European Co-operation in the Field of Scientific and Technical Research
CY	Cyprus
CZ	Czech Republic
dBA	Decibels
DK	Denmark
E	Spain
EC	European Commission
ECNC	European Centre for Nature Conservation
EEA	European Environment Agency
EEC	European Economic Commission
EIA	Environmental Impact Assessment
EU	European Union
F	France
GIS	Geographical Information System
H	Hungary
I	Italy
IENE	Infra Eco Network Europe
ICOET	International Conference on Ecology and Transportation
IRL	Republic of Ireland
IUCN	The World Conservation Union
N	Norway
NGOs	Non-Governmental Organisations
NL	The Netherlands
P	Portugal
PAH	Polycyclic aromatic hydrocarbons
RO	Romania
S	Sweden
SEA	Strategic Environmental Assessment
SETRA	Service d'Etudes Techniques des Routes et Autoroutes (F)
SLO	The Republic of Slovenia
USDA	United States Department of Agriculture
UK	United Kingdom
WWF	World Wide Fund for Nature

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Annex 4: Related websites

Centre for Transportation and the Environment (North Carolina, US)
www.itre.ncsu.edu/cte/cte

European Centre for Nature Conservation (ECNC)
www.ecnc.nl

European Environment Agency (EEA)
www.eea.eu.int

Forum of European National Highway Research Laboratories (FEHRL)
www.fehrl.org

Infra Eco Network Europe (IENE)
www.iene.info

International Conference on Ecology and Transportation (ICOET)
www.itre.ncsu.edu/cte/icoet

The World Conservation Union (IUCN)
www.iucn.org

Wildlife Crossings Toolkit (USDA Forest Service, US)
www.crossingstructures.org

Annex 5: Handbooks and guidelines

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COST 341 products

COST 341: Habitat Fragmentation due to Transportation Infrastructure

COST 341: *Habitat Fragmentation due to Transportation Infrastructure* started in 1998 after an initiative taken by Infra Eco Network Europe (IENE). IENE had underlined the need for co-operation and exchange of information in the field of habitat fragmentation caused by transport infrastructure at a European level.

Over the 5 years of the COST 341 Action, the following countries and organisations have officially participated in the project: Austria, Belgium, Cyprus, Czech Republic, Denmark, France, Hungary, The Republic of Ireland, The Netherlands, Norway, Portugal, Romania, Spain, Sweden, Switzerland, United Kingdom and the European Centre for Nature Conservation (ECNC).

Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions is a solution-orientated handbook, based upon the accumulated knowledge of a broad range of experts from participating countries and from numerous international contacts. It gives practical guidance for those involved in the different phases of the planning, construction and maintenance of transportation infrastructure. The main aim of the handbook is to assist planners and engineers to minimise ecological barriers and fragmentation effects of transportation infrastructure such as roads, railways and waterways.

The handbook takes the reader chapter-by-chapter through all the different phases, from the first steps of strategic planning, through the integration of roads in the landscape, the use of mitigation measures such as over- and underpasses for different animals, the lesser known field of compensatory measures, and finally to consider the monitoring and evaluation of the chosen solutions.

In addition to this handbook the COST 341 Action has delivered four other products:

- **National State-of-the-Art Reports** from 13 European countries: Belgium, Cyprus, Czech Republic, Denmark, Estonia, France, Hungary, The Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. Each national report describes existing practice regarding methods, indicators, technical design and procedures for avoidance, mitigation and compensation of adverse effects on nature in that country. These reports created the basis for the European Review. Most of the National Reports are also published separately in the respective countries.

- **COST 341 - Habitat Fragmentation due to Transportation Infrastructure: The European Review.** 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.

- **An online database**, which contains information on existing international and national literature and projects related to habitat fragmentation. The database gives references to reports that are difficult to trace via other referencing systems. Access to the database is through the IENE website: www.iene.info.

- **The Final Report**, which describes the problem, provides a summary of the results of the project, and possible solutions and ways forward.

All the COST 341 products outlined above are available on a CD-ROM, and can be downloaded from the COST 341 website (http://cost341.instnat.be/). CD-ROMs and documents can also be ordered from: