Wildlife and traffic

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Abstract. Habitat fragmentation, the splitting of natural habitats and ecosystems into smaller and more isolated patches, is recognised as one of the most important global threats to the conservation of biological diversity. Habitat fragmentation is mainly a result of changes in land use, but a major impact also results from the barrier effect caused by the construction and use of linear infrastructure of transportation systems.

The project COST 341 *Habitat fragmentation due to transportation infrastructure* started in 1998, and 16 countries were officially involved in the initiative. The project produced a *European review* on habitat fragmentation on a European level, built upon national reports from the participating countries. The project found a strong awareness of the problem throughout Europe and that a diversity of solutions to the problem had been tried out. However, there was still a need for yet a systematically approach, retrofitting existing infrastructure where necessary, and integrating concerns on fragmentation in the planning of new ones.

The most important outcome of the COST 341 Action was the handbook *Wildlife and traffic – A European handbook for identifying conflicts and designing solutions*. It's a solution-orientated handbook, based upon the accumulated knowledge of a broad range of experts from the participating countries and from numerous international contacts. It gives practical guidance to the various actors involved in the planning, construction or maintenance of transportation infrastructures, on how to avoid, minimise, mitigate or compensate habitat fragmentation.

This paper presents the major findings of the European review and an overview of the contents of the handbook.

Key words: Handbook, infrastructure, wildlife, barrier, fragmentation, habitat

1. Introduction

1.1. The Problem

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

Habitat fragmentation, the splitting of natural habitats and ecosystems into smaller and more isolated patches, is recognised as one of the most severe threats to the conservation of biological diversity globally. Fragmentation of habitats is mainly the result of different forms of land use change. The construction and use of transport infrastructure is one of the major agents causing this change as well as creating barriers between habitat patches (Fig. 1).

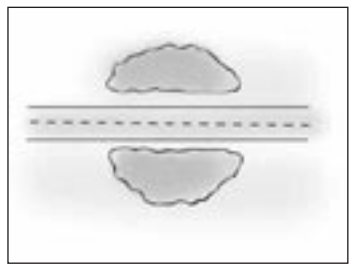

Fig. 1. A road fragmenting natural habitats

As transport systems have grown denser, their impact on fragmentation has increased (Fig. 2). The steadily growing number of animal casualties on roads and railways is a well-documented indicator of this problem. Barriers causing habitat fragmentation have on the other side, a long-term effect that are not that easy to detect.

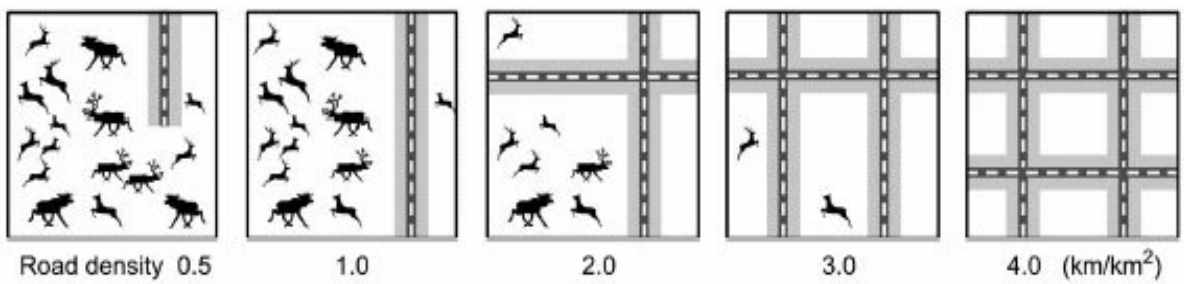

Fig. 2. Loss and degradation of habitat by infrastructure

Infrastructure causes a loss and degradation of habitat due to disturbance effects (grey corridors) and isolation. With increasing infrastructure density, areas of undisturbed habitat (white) are reduced in size and become inaccessible. Remnant fragments of suitable habitat may eventually become too small and isolated to prevent local populations from going extinct. The critical threshold in road density is species-specific, but will also depend on landscape and infrastructure characteristics. From Trocme *et al.* (2003).

Mitigation of these adverse effects on wildlife to obtain an ecologically sustainable transport infrastructure needs a holistic approach that integrates both the social and ecological factors operating across the landscape. Hence, one of the challenges for ecologists, road-planners and engineers is to develop adequate tools for the assessment, prevention and mitigation of the impacts of infrastructure. The task of the COST 341 Action was to address the issues associated with *Habitat fragmentation due to transportation infrastructure*. (COST is an intergovernmental framework for European Co-operation in the field of Scientific and Technical Research, allowing the co-ordination of nationally funded research on a European level. COST Actions cover basic and pre-competitive research as well as activities of public utility).

1.2. COST 341 Habitat fragmentation due to transportation infrastructure

In 1996 representatives from nearly 20 European countries in the **I**nfra **E**co **N**etwork **E**urope (IENE) 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 of support at a European governmental level. This led to the development of COST 341 *Habitat fragmentation due to transportation infrastructure*, starting up in 1998.

16 countries (Austria, Belgium, Cyprus, The Czech Republic, Denmark, France, Hungary, Norway, Portugal, Romania, Spain, Sweden, Switzerland, The Netherlands, The Republic of Ireland, United Kingdom), and one NGO (The European Centre for Nature Conservation, ECNC) signed the *Memorandum of Understanding* and participated in the action.

The COST 341 Action had two major goals. *First*, to produce a State-of-the-Art report, describing the European situation and the main future challenges. *Second*, to develop a handbook presenting all known measures for how to avoid, minimise or mitigate the barrier effects caused by transportation infrastructure.

As a tool for distributing existing knowledge about habitat fragmentation, an on-line database was established. The *COST 341 Database* offers information about ongoing projects and project results, data on existing literature, and description of different measures. It is accessible through the IENE web-site (www.iene.info).

2. The European review

The European Review (Trocmé *et al.* 2003) describes the State-of-the-Art for Europe, and underlines the importance of taking habitat fragmentation into consideration in all stages of the development of transportation networks (planning, designing, constructing and maintaining the network). The review was built upon national reports from the participating countries, and most of these national reports were published separately in the countries themselves.

Throughout Europe the process of addressing the impact of habitat fragmentation due to transportation infrastructure is still in its infancy. Nevertheless, it is also clear that positive progress has been made in tackling the negative effects. Valuable experiences can be learned from densely populated and intensively developed countries like The Netherlands, where the problems of habitat fragmentation have long been recognised. Many other European countries have also developed national programmes of research into the effects of infrastructure on biodiversity, the findings from which must be used to inform the planning and design procedures for new infrastructure. But there is still a long way to go before ecological tools are fully developed and implemented in transportation planning.

Major findings

Habitat fragmentation was recognised as one of the most significant factors which contributes towards the decline of biodiversity in Europe, and should thus be a major concern for society. Transportation infrastructure is often considered to be a principal cause of fragmentation.

In general, species with large area requirements or strong dependence on a specific type of habitat will be most vulnerable to habitat fragmentation. Unfortunately, these are quite often the species that are of greatest conservation concern *e.g.* wild reindeer in Norway, badgers in the Netherlands, or the Iberian lynx in Spain.

In summarising the experiences of the COST 341 countries, the following principles and recommendations should act as guidelines for dealing with the issue of fragmentation of natural habitats by transportation infrastructure in the future:

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

- European and national nature protection legislation needs to be integrated in the planning process at the earliest possible stage. Only an interdisciplinary approach involving planners, economists, engineers, ecologists, landscape architects etc., can provide all the necessary tools for addressing fragmentation successfully. The approaches need to be integrated at all levels of the transportation network.
- Because of the complexity and widespread nature of the problem, an ongoing exchange of knowledge between countries is vital. A systematic and uniform approach to collecting information on mitigation techniques and measures is necessary if statistics are to be compared between countries.

- The disturbance effect created by infrastructure needs to be more widely studied and mitigated for so as to minimise habitat degradation adjacent to infrastructure.
- Mitigation measures such as fauna underpasses and overpasses have a proven record of success. However, mitigation should not only focus on the more prestigious passages for large animals. Much can also be done, at relatively low cost, to increase the permeability of the existing and future transportation infrastructure by adapting the design of engineering structures to wildlife.
- Monitoring programmes to establish the effectiveness of mitigation measures are essential and need to be standardised. The cost of monitoring programmes should be included in the overall budget for new infrastructure schemes.
- The fragmentation of natural habitats by transportation infrastructure is a problem which cannot be solved without an acceptance of the issue at a policy level, or without interdisciplinary co-ordination and co-operation at scientific and technical levels. Public involvement is also essential, to ensure the success of the chosen solutions.

3. The handbook

The main topic of the handbook *Wildlife and Traffic – a European handbook for identifying conflicts and designing solutions* (Iuell *et al*. 2003), is to minimize ecological barriers and fragmentation effects of transportation infrastructure. The primary target groups for the handbook are those involved in the planning, design, construction and maintenance of infrastructure, as well as decision makers at the national, regional and local levels.

The barrier- and fragmentation effects of infrastructure can be minimised during several phases of development and use, and even avoided if considered in the early phases of planning. 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 more unknown field of compensatory measures, and to the use of different methods of monitoring and evaluation of the chosen solutions.

3.1. Roads, railways and waterways

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

3.2. New and existing networks

While habitat fragmentation is increasingly taken into account when new infrastructure is planned, there remain many existing stretches of roads and railway lines where mitigation measures are badly needed. This need often increases when new infrastructure is built, which may result in changing the ecological impact of existing infrastructure. When designing measures to counteract habitat fragmentation, the focus should, therefore, be on the impact of the infrastructure network as a whole. In several European countries de-fragmentation programmes have been established with the aim to restore the ecological infrastructure on the national or regional levels.

3.3. The European approach

The handbook is produced to cover the many different circumstances found across Europe. There are important differences between the countries regarding 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 less suitable in another. Therefore, one of the big challenges in the production of the handbook was to deal with all these differences.

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

The design of fauna passages and other mitigation measures used differs between countries, partly due to different traditions, and partly due to different physical and ecological contexts. As a result, there are few general formal standards for the design, construction and maintenance of mitigation measures in Europe. To date, only a small number of evaluations of mitigation measures have been carried out and further work that includes studies of effects of measures at the population level is needed. 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.

With this as a background, it is important to underline that there are no 100% correct solutions. The advice provided in the handbook is based upon the accumulated experiences of the participating experts and the results of projects worldwide. 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.

4. Integrated solutions

The barrier- and fragmentation effects of infrastructure can be eliminated or minimised in different ways and during several phases of its development and use. If the ‘right decisions’ are taken in the early phases of planning, fragmentation problems can be completely avoided. The barrier effect can be reduced by integrating the infrastructure into the surrounding landscape, or by building secure and sufficient crossing points for wildlife. Also during use and maintenance of existing infrastructure, consideration should focus on how to reduce the barrier effect of infrastructure and how to de-fragment landscapes.

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

1. avoidance > 2. minimisation > 3. mitigation > 4. compensation

The basic philosophy is that prevention is better than cure in avoiding the negative effects of habitat fragmentation. Where avoidance is impossible or impractical, mitigation measures should be designed as an integral part of the scheme. Where mitigation is insufficient or significant residual impacts remain, the compensatory measures should be considered, but only as a last resort.

Within this system, two of the key questions to address are *when* measures are needed, and *what* are the criteria for success. This approach forces infrastructure planning to look outside the normal bounds of the transport corridor, and to examine the development of the whole infrastructure

network and wider land use issues including national and international spatial planning strategies. Measures within the infrastructure corridor must include a consideration of the adjacent land use, and also planned development as this may severely reduce the efficacy of any mitigation or compensatory measures.

Finding integrated solutions to road planning requires information on how to plan the routes of transportation infrastructure to minimise impacts within the constraints of cost and engineering. Assessment of new infrastructure will increasingly focus on integrated solutions attempting to find the route and design producing the least impact and greatest benefit to the greatest number of interests. The integration process is especially difficult in geographic areas where the competition for space is very high such as narrow valleys, coastal strips etc. Such 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.

5. Planning tools

Minimising habitat fragmentation should be done when planning new infrastructure or when planning upgrading of existing infrastructure. By carrying out a Strategic Environmental Assessments (SEA) on programmes and Environmental Impact Assessments (EIA) on projects it is ensured that environmental considerations are included already at an early stage. 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.

Fragmentation issues in relation to existing infrastructure are somewhat different. For a great part of the existing infrastructure, mitigation measures may not have been taken into consideration at the time they were planned and designed. In these situations, the fragmentation brought about by the existing infrastructure may most likely already have affected the area, and other sources of fragmentation, unforeseen at the time of the study, could have appeared. Any environmental studies that may originally have been made may also be outdated, why new evaluation is necessary.

As pointed out in the handbook, the definition of the study area is crucial for a meaningful study of fragmentation issues, and in many cases it is necessary to evaluate the potential impact in a regional context. The handbook also describes different data and methods that can be used in the planning process, and how to define conflict points between ecological infrastructure and man made infrastructure for transportation.

6. Adapting to surrounding landscape

When the decision is taken to build new highways, railways or waterways, it is still possible to minimise the barrier effect and thus fragmentation by adaptation of the infrastructure to the adjacent landscape and ecology.

The construction of new infrastructure can have an impact on the biological diversity in a number of ways:

- Habitat loss and fragmentation of natural habitats.
- Changes to the water table and drainage patterns and systems.
- Physical barrier and visual intrusion due to: the infrastructure itself, large earthworks, embankments crossing valleys and low-lying land, cuttings which fragment habitats, junctions that form ‘wildlife traps’.

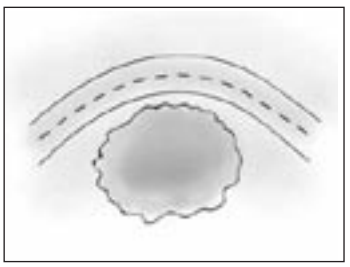

Fig. 3. Avoiding fragmentation by changing alignment

Good alignment and sensitive design can be employed to minimise the magnitude of these effects. Detailed advice is given in the handbook on how to:

- Choose a route which:
    - minimises the extent of habitat loss
    - avoids sites of nature conservation interest and, where possible, protects non-renewable resources (e.g. ancient woodland)
    - seeks to maintain habitat connectivity through the use of structures that 'carry the landscape over the infrastructure' or permit the landscape to 'flow under the infrastructure'(Fig.3).
- Design profiles which reflect the local topography.
- Aim to achieve the most sustainable use of excavated material i.e. create a balance of cut and fill material and minimize 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 – natural revegetation.
- Restore as much of the pre-existing pattern of field boundaries, woodland, heathland etc. as possible.

7. Mitigation measures

The most comprehensive chapter of the handbook describes individual technical measures designed to mitigate the negative effects of transportation infrastructure (Fig. 4). It includes landscape bridges, wildlife over- and underpasses, culverts and pipes for aquatic species, and several measures for reducing wildlife mortality. For each measure a general description is given, and important information on design and special attention points for that specific measure is added. Technical specifications such as the material to be used and technical design details are presented if they are of particular importance to ensure the functioning of the measure.

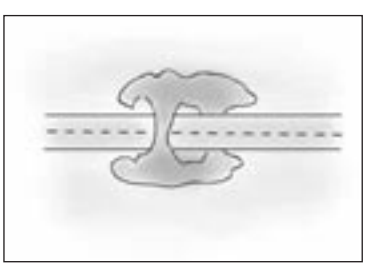

Fig. 4. Mitigating fragmentation effects

Some measures have been well tested and considerable experience has accumulated. Others are new and 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 the ones presented here because they take into account regional issues such as a specific climate or habitat.

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

7.1. Fauna passages as part of a general landscape permeability concept

Fauna passages and other structures adapted to increase the crossing of transportation infrastructure by animals should never be considered in isolation. They are part of a general 'permeability concept' to maintain the necessary contact within and between populations of animals. This concept emphasises the connectivity between habitats on at least a regional scale and considers not only the transportation infrastructure but 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 a transportation 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 in such a concept. Again, the primary objective must be to maintain the permeability of the transportation infrastructure for wildlife, to ensure the connectivity of the habitats at a larger scale.

Mitigation measures, and in particular fauna passages, are necessary if:

- A transportation infrastructure bisects important patches of habitat or creates barriers to migration.
- 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.
- The road or railway line is fenced along its length.

The type of measure to be used, the location, the numbers, and how to make it effective, are all maters that will have to be dealt with in each specific project.

7.2. The 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 (Fig. 5). 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 in a local, regional, national and international perspective as part of an EIA. In general, the more important habitat connectivity is to the species of concern, the more elaborate the mitigation measures have to be. Thus, where an internationally important corridor for 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 may help to 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.

It's essential that the purpose of the measures is clearly stated from the start. 'To maintain habitat connectivity' can be too general, it means different thing in different settings, and it is difficult to quantify. This is crucial both for the choice of measures, the numbers of measures and their location, and for the evaluation of the effectiveness of the measures afterwards.

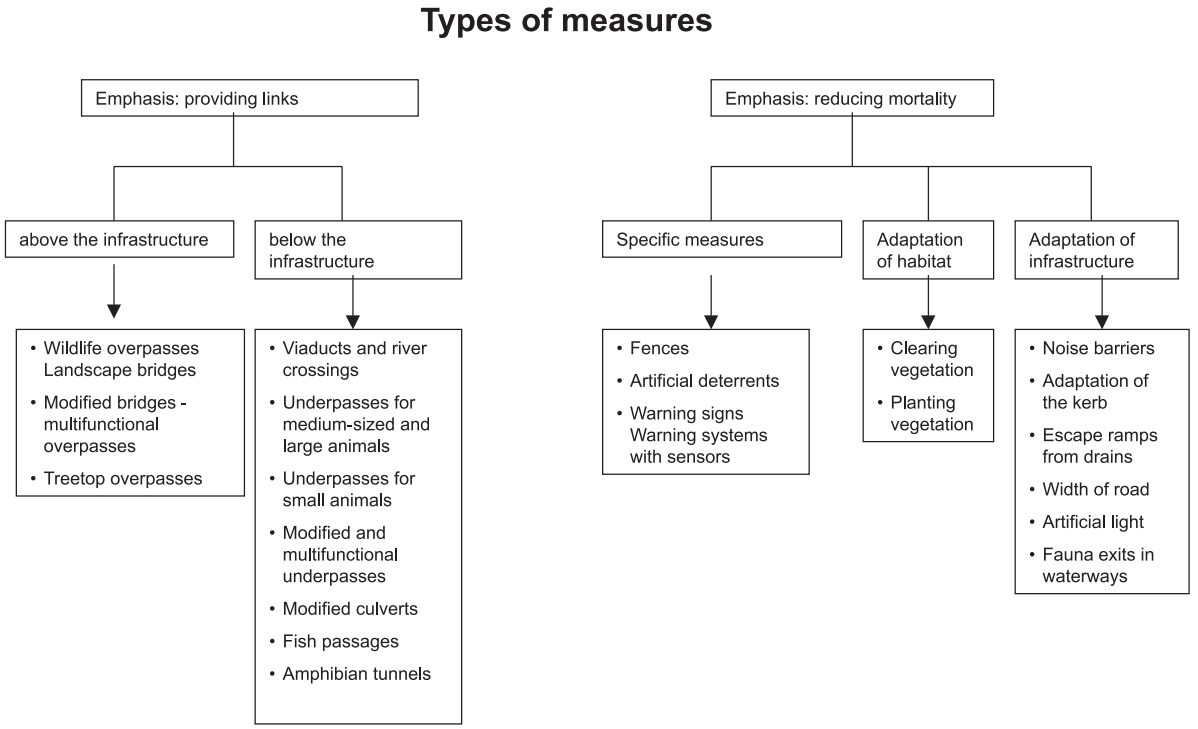

Fig. 5. Different types of measures to mitigate habitat fragmentation

7.3. Density of passages

The density of fauna passages required to effectively maintain habitat connectivity is a major decision in planning mitigation measures (Fig. 6). Deciding on the required number and the type of measures will depend on the target species and the distribution of the habitat types in the area. In some cases one or several 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.

When determining the number 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 many artificial barriers due to transportation infrastructure or built-up areas exist, fauna passages can be essential for maintaining the general permeability of the landscape. In such cases, they could be integrated with all remaining open corridors.

7.4. Location of passages

The location of the 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 habitats, the passage has to ensure the connectivity to suitable habitat on either side of the planned infrastructure. Other barriers existing in the surrounding landscape have to be considered, too, when locating passages and access to the passage must be guaranteed in the future.

Fig. 6. Examples to reduce fragmentation effects

The type of measure to be used, the location, the numbers, and how to make them effective, are all maters that will have to be dealt with in each specific project. (Photos from the COST 341 Handbook)

Ensuring that passages are built at all known 'conflict points' must be the first step in defining the location of passages. If this result in a density of passages considered too low to create the necessary level of permeability of the infrastructure in the particular region, additional locations have to be found.

7.5. Integration into surroundings

Fauna passages should be well connected to the surroundings, either by way of habitat corridors leading towards passages for small animals or by way of guiding lines for larger ones. As a result of the channelling effect of guiding structures, the probability of an animal encountering a fauna passage can be improved considerably. 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 de-fragmentation, including all infrastructures is required.

7.6. Adapting engineering works for use by animals

Engineering works are designed and constructed for crossings between two different flows. These can be two flows of traffic (e.g. one road crossing the other with an overpass), traffic and water (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, such traditional structures can often be adapted to

serve as fauna passages. Such passages, combining the flows of fauna and traffic or fauna and water, are called joint-use passages.

7.7. Solving problems on existing roads and railway lines

In Europe, thousands of kilometres of motorways and other roads as well as railway lines have been built before people became aware of the potential problems they caused for wildlife. An obvious need for adapting existing structures arises when a high number of collisions between animals and vehicles are registered. 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 the 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. Most measures described in the handbook are also suitable for existing infrastructure or may be adapted accordingly.

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) are often not an optimal solution, but in general less expensive. A large number of adapted passages may, in some cases, give better results for the same price as constructing one new specific passage.
- Modification of maintenance procedures (e.g. treatment of vegetation) may improve the situation.

7.8. Maintenance and monitoring of mitigation measures

All mitigation measures have to be routinely inspected and maintained to ensure their functioning in the long term. Maintenance aspects, including the costs of maintenance, 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 maintenance in terms of responsibility. Specific maintenance aspects are dealt with in the sections on the different measures.

Maintenance of measures is closely linked to monitoring aspects. 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.

8. Compensatory measures

Despite good planning and use of mitigation measures aiming to avoid or reduce adverse impacts on natural values, it is occasionally impossible to completely avoid negative effects of infrastructure development. This realisation has led to the principle of ecological compensation. 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.

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 to landscaping and mitigation measures, ecological compensation is generally undertaken outside the construction area. As initiators of projects are held responsible for the implementation of the compensatory measures, developers should put serious effort in 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 even enhanced.

Compensation may include conversion of land for the development of new nature qualities (woods, river beds, etc.). Habitat enhancement may encompass the adaptation of farming activities towards the development of nature qualities (e.g. meadow-birds or plants). Artificial wetlands (not necessarily ponds) may be created in order to attract species such as amphibians and reptiles. 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 spectre of impacts, including habitat degradation (habitat is still present, but impacted), and loss of functions such as nutrient and energy flows.

9. Monitoring and evaluation

To identify examples of good practice and to provide the basis for codes of good practice, we need to monitor the success of the various methods for mitigating the effects of habitat fragmentation. The handbook provides detailed guidelines on how to monitor the success of mitigation measures and gives advice on maintenance issues.

Monitoring requires clear definition of the objectives of the measures, and programmes should be planned in parallel with the design of the measures themselves.

After the construction of roads, railways and waterways the application of monitoring is of crucial importance as it is this mechanism that allows us to check the effectiveness of measures which have been applied in order to reduce the 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 the 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 monitoring scheme results is also very important for gaining knowledge for the development of more effective and less expensive measures. Therefore, an important objective of monitoring is also to help planners and road- and railway designers to:

- avoid repeating the mistakes
- provide new information for improving the design of mitigation measures
- identify the measures with an optimum relation 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 the fragmentation of habitats.

A wide number of methods can be applied for the monitoring of mitigation measures. In the handbook the description of most commonly used methods to record fauna casualties and to check the use of fauna passages is provided, giving information about the procedures, 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. By this reason, only some orientations about which standards can be used for the evaluation are provided.

10. Closing remarks

A significant challenge to ecologists, road-planners and civil engineers alike is the establishment of an ecologically adapted, safe and sustainable transportation infrastructure system. The key to success is the adoption of a holistic approach that allows the entire range of ecological factors operating across the landscape to be integrated within the planning process from the start. The challenge of fragmentation and its solutions are universal, therefore joint research and combined international efforts are required. To develop adequate tools for assessing, preventing and mitigating the ecological impact of infrastructure, interdisciplinary work is required.

For countries with high density of transportation infrastructure de-fragmentation programmes can be necessary to mitigate fragmentation. In countries that are still developing their infrastructure networks the precautionary principle should be emphasized to prevent increased fragmentation.

The COST 341 Handbook *Wildlife and Traffic* gives practical guidance to the various actors involved in the planning, construction or maintenance of transportation infrastructures. A Spanish version was produced in 2005, and a French version will be presented in 2006. Several countries, not only in Europe, have produced national adapted handbooks based more or less on the COST 341 Handbook, and an increasing number of reports, papers, guidelines, books and conferences are slowly filling up the gaps in our knowledge. How this will affect the development of transport infrastructure and the fragmentation of natural habitats remains to be seen.

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