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MAINSTREAMING BIODIVERSITY WITHIN ROAD INFRASTRUCTURE PROJECTS

A PIARC TECHNICAL REPORT

TECHNICAL COMMITTEE 3.4 *ENVIRONMENTAL SUSTAINABILITY IN ROAD INFRASTRUCTURE AND TRANSPORT*

STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2020–2023 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.

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EXECUTIVE SUMMARY

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MAINSTREAMING BIODIVERSITY WITHIN ROAD INFRASTRUCTURE PROJECTS

A PIARC TECHNICAL REPORT

The development of transport infrastructure is one of the basic elements of the development of countries and their economies. Economic development is often accompanied by environmental protection problems, including biodiversity impacts, because they have not been taken enough into account. Preventing land fragmentation, preserving biodiversity and continuity of ecological corridors is one of the most important challenges for transport infrastructure stakeholders.

The report is a global guide for specialists and decision makers planning, implementing, and managing transport infrastructure. Improperly prepared road network development plans and projects may lead to deep changes in their surroundings. In addition to adverse impacts on humans, impacts on defragmentation and biodiversity are often final. Road and traffic impacts can often lead to irreversible changes. Repair attempts can often fail or involve long-term repair programs with significant economic impact.

Regardless of location in the world, several biodiversity-related activities are universal. These activities and measures were included in the report as recommendations for both newly developed transport solutions and those that have already been created, are exploited and have a significant impact on biodiversity. The report, prepared by members of TC 3.4.3 "Road and road transport impact on wildlife habitats and their interconnections", is based mainly on their experiences from many countries. In accordance with the already known principles that are used in transport solutions, it promotes the basic principle "avoid impact and if it is impossible, apply mitigation measures and, if necessary, also apply compensatory measures". Necessary action in the management of biodiversity also includes monitoring and evaluation of the effectiveness of the measures used.

The full report is a set of recommendations to maintain biodiversity and has been prepared in such a way that it can be used by specialists who make decisions in different countries, regardless of the species and climate. The basis is the interaction of road and traffic, which in practice has the same effect regardless of the country. Differences may occur only in the case of elements of the environment creating the biodiversity of the road surroundings. These cases are illustrated by examples from different countries on all continents. These are primarily the collected and described experiences of countries that are advanced as well as those that have recently started activities in the protection of biodiversity. This full report and case studies prepared in separate documents, are based on the experience of TC 3.4.3 members and their contacts with organisations dealing with biodiversity. The report is supplemented by the Case Studies Appendix, which supplements individual issues in the form of examples in a separate document, so that the theory can be read alongside the case studies. These are mainly experiences from European Union countries, Canada, and Japan. The lack of case studies from LMICs is a limitation of this report, but we have taken care to include these countries in our recommendations.

CONTENTS

PREFACE

The global demand for linear infrastructure such as roads, railways, pipelines, and transmission lines, has increased rapidly in the last two decades. With an existing 65-million-kilometre footprint, linear infrastructure dominates landscapes worldwide. Because linear infrastructure, particularly transport infrastructure, plays a pivotal role in economic and social development, it is likely to continue expanding. However, these developments are not without impact, and sustainably developing linear infrastructure networks is one of the great challenges for the global community. There is an urgent need to consider the impact on biodiversity when sustainably developing this infrastructure, particularly the transport sector. This study, Mainstreaming Biodiversity within Road Infrastructure Projects, provides a guide for specialists and decision-makers for planning, implementing and managing road infrastructure.

The study consists of two parts: a report and case studies (see Appendix). The report provides findings that can be used to inform the design of new roads as well as the upgrading and rehabilitation of existing roads. Although the geometry of linear infrastructure suits human needs for efficiency and cost-saving, it often bisects and fragments natural networks, resulting in disjointed zones and points of conflict where infrastructure and nature intersect.

The authors of this report highlight the need for the transport industry to consider biodiversity and the numerous, diverse, and predominantly negative consequences of misplaced infrastructure for biodiversity and ecosystem functioning. These impacts include the destruction and degradation of habitat, fragmentation of habitat important for wildlife populations, direct impacts through collisions, and secondary impacts through increased access by people to previously inaccessible natural resources. Subsequent chapters in the report address environmental protection, mitigation, legislation, and sustainability. The case studies provide insight that supports the report, primarily from the global north. They describe trends in several road developments and touch upon regulatory procedures for obtaining environmental clearance for infrastructure development.

The environment cannot be neglected by any segment of society; the world needs global leaders pioneering new development processes and techniques to ensure a balance between development and environmental preservation and conservation. It is therefore key that any road or linear infrastructure development project consider biodiversity as early as possible in the planning process. There should be no hesitation by project planners to invest in innovative programmes that focus on sustainable development and green infrastructure, particularly in light of the societal transformations needed to mitigate and adapt to climate change.

We are, every one of us, responsible for the world we live in.

Acknowledging the importance of this study, I must compliment the PIARC and their competent TC3.4 team: WG3 “Road Infrastructure & Transport impacts on Biodiversity”, for preparing this insightful study. I see this as a significant contribution and an important step in linking transportation and conservation as well as the Memorandum of Understanding signed between IENE and PIARC.

Wendy Collinson-Jonker

The Endangered Wildlife Trust, South Africa, IENE SEC member

1. INTRODUCTION

The report is related to transport infrastructure and its impact on biodiversity. The study consists of two parts: a report and an Appendix with case studies. Case studies included in the Appendix refer to individual chapters and their content. The task of the Appendix is to indicate examples from various countries, primarily good practices.

The opening chapter 2 describes in general the impact of humans through various forms of human activity, the main biodiversity stakes in general and specific road impacts like habitat fragmentation and landscape changes. The authors ask here the question whether roads cause only negative impacts and indicate possibilities to enhance positive effects.. In the Appendix to this chapter, materials from the oldest Cost Action 341 project promoted by the Infrastructure and Ecology Network Europe (IENE) to the update of the handbook in alliance with the HORIZON 2020 project BISON "Biodiversity and Infrastructure Synergies and Opportunities" are indicated as very helpful for Transport Networks.

Chapter 3 discusses the impact of roads and traffic on wildlife habitats and the effects of these impacts. The chapter presents the main threats to biodiversity associated with the road network. Direct, indirect and cumulative effects, which have been described, have a significant impact on biodiversity. Among the direct impacts, the focus was mainly on: habitat loss and fragmentation, barrier effect, wildlife traffic mortality, avoidance by animals, attraction for animals, interactions between organisms, impact of noise and light, changes in the aquatic environment, and margin effect. In the case of indirect effects, it was pointed out that they are much more difficult to identify and therefore often neglected. Over time, they can cause problems for the entire ecosystem, and it is necessary to consider them together with the direct effects. The description of cumulative effects provides basic information on: growth-inducing effects, cascade effects and managing cumulative effects. Attention was paid to the parameters that are used to assess the effects of cumulative effects.

This chapter also describes permanent and temporary effects related to the operation and construction of roads. Positive effects are also presented, which are mainly related to the maintenance of the road surroundings (e.g., systematic mowing) and the presence of ecological refuge habitats and longitudinal ecological corridors on the edges of roads.

Chapter 4 contains mainly regulations. The chapter begins with a description of the 1979 Bonn Conventions role in protecting migratory wildlife species. Further descriptions refer to other important regulations, such as the Convention on Biological Diversity of 1992 or the UN Sustainable Development Goals of 2015, describing the necessity for sustainable transport systems and resilient infrastructure. The Appendix focuses mainly on the current regulations in the European Union, Canada and Japan.

Chapter 5 describes study management during the lifecycle of infrastructure. The description of the life cycle of infrastructure includes four basic phases: strategy planning, design, construction and operation and maintenance. Another fifth phase - upgrading - has been separated from these four phases because it starts the whole cycle all over again from the design phase. For each phase of this cycle, the environmental processes and the biological and natural indicators assigned to them are described. In the Appendix, these descriptions are supplemented in the study management during the lifecycle of infrastructure in Europe, Canada, and Japan.

Chapter 6 lists actions mitigating and limiting environmental effects on fauna, flora and habitats. Four categories of actions are described: avoidance, reduction, restoration/rehabilitations and offsetting/compensation. This is one of the most important chapters of the report as it identifies possible ways to maintain or restore biodiversity. What is important in this description is the mitigation hierarchy of actions taken with the preference to avoid then mitigate the effects of road investments, and finally compensate. This chapter also specifies and defines two types of measures to mitigate impacts on wildlife. These include reducing mortality and providing corridors. These measure types have been thoroughly and extensively described with examples and diagrams. A detailed description and breakdown is given for overpasses and underpasses in this chapter. Complementary to the content that concerns wildlife mitigation on roads in Canada and the Czech Republic, which, apart from biodiversity issues, also indicate traffic safety problems. This issue was also presented on the basis of the LIFE SAFE-CROSSING project implemented by Italy, Spain, Greece and Romania. In all countries, the focus was on highly threatened carnivores brown bear, Apennine brown bear, wolf and Iberian lynx. The descriptions also include defragmentation programs of several European countries.

Chapter 7 contains a very important description of performance monitoring and evaluation. Three stages are described in this chapter: before, during and after construction. Each of these stages has its own special meaning and is a very important tool in the analysis of biodiversity conservation. The chapter also describes the methods and techniques of monitoring. A very important element of this part of the report is information on the European initiative EuropaBON (https://europabon.org/?page_id=2513:) concerning monitoring activities in Europe. The database that is being developed under this initiative aims to create basic biodiversity variables, basic ecosystem function variables and other indicators relevant to biodiversity management. This is complemented by practical information in the Appendix on monitoring methods used in France and experience from Canada. Examples of impact studies on the use of overpasses are also given from the Czech Republic. Research confirms the impact of road noise, lighting, and visual distribution.

Virtually every chapter has a very rich bibliography that allows you to deepen your knowledge of the topics covered. Each chapter is also accompanied by examples of measures and solutions used in different countries.

2. METHODOLOGY

The methodology used to prepare the report included a literature and regulatory analysis, collected case studies and a description of our own experience and expertise. All chapters were selected by the WG members who are experts in the topics to be covered.

The limitation of this report is the lack of case studies from Low- or Middle-Income Countries (LMIC). Collecting case studies from LMICs may be a task for the next cycle. However, each time it was possible, we made recommendations to these countries in the *NOTA FOR LMIC* (in chapters 7 and 8).

3. BIODIVERSITY STAKES

Since the end of the prehistoric periods, human activities started to generate impacts on ecosystems* and species* with agricultural development. Biodiversity then was relatively preserved or modified in a reversible way until the first industrial revolution in the XIXth Century, when the heavy industries and the development of railways, that mostly appeared in Europe, in the North-American continent and in Japan. This degradation process of ecosystems and species living within, deeply accelerated since the second world war, with a huge increase of population demography and activities, correlated with urban areas expansion, industrialisation of agriculture and densification of transport infrastructure network (mostly roads infrastructures).

The IPBES (the intergovernmental science-policy platform for biodiversity and ecosystem services) summary for policymakers (*https://ipbes.net/global-assessment*), describes the main direct drivers for biodiversity loss as changes in land and sea use, direct exploitation of organisms, climate change, pollution and invasion of alien species. The main roads and traffic related drivers are described below:

3.1. Habitats destruction, fragmentation and landscape changes

New roads contribute to change land-use, directly destroy small habitats and fragment larger habitats and reduce biodiversity [1]. Moreover, new roads indirectly ease the conquest of virgin areas for local human communities and fragment more and more these areas into smaller and less viable territories, especially for large animal species.

Habitat loss and fragmentation are among the most severe negative impacts on biodiversity. Without the possibility to migrate along their natural migration routes populations are - in the long term - affected by inbreeding and genetic isolation, which leads to declining populations.

But in addition to the impacts of the development of the transport infrastructure network, biodiversity is also affected by urban extension and industrial agriculture, making it more difficult to reduce these impacts efficiently. This implies that road infrastructure managers have to discuss and collaborate with the main actors of local communities to facilitate mitigation measure implementation and to avoid any action degrading their efficiency.

Roads and other infrastructure often have particularly deleterious effects, potentially opening a host of environmental problems. The impacts of infrastructure on wildlife and ecosystems are often exacerbated where laws or enforcement are limited. Therefore, the proliferation of unplanned illegal roads and other infrastructure in remote and intact ecosystems is arguably the most serious conservation problem in tropical countries today.

3.2. Alien invasive species

During road construction, soil displacement and bare soil that has not been sown rapidly, contribute to the facilitation of the installation of alien invasive species dissemination which sometimes disrupt entire ecosystems if no adapted control planning is applied.

3.3. References

[1] Scanes, C.G., 2018. Human activity and habitat loss: destruction, fragmentation, and degradation. In *Animals and human society* (pp. 451-482). Academic Press.

4. ROAD AND TRAFFIC IMPACTS ON WILDLIFE HABITATS

4.1. Context

The use of transport infrastructure is an integral part of the daily life of people all over the planet. For the coming decades a "global infrastructure tsunami" is predicted [1] : currently there are 64 million km of paved roads on the planet (enough for 83 round-trips to the moon), with an additional 25 million km planned for construction by 2050 [2]. Infrastructure development is identified as one of the key factors in the global decline of biodiversity, which has reached an unprecedented rate. Nevertheless, infrastructure construction can help in developing regions economically, which explains the planned huge increase in the coming years. Making social and economic development compatible with the conservation of the environment needs to be a cornerstone of advanced society's policies. The construction of a dense transport infrastructure network impacts the environment substantially, especially due to significant interventions in the landscape, which are reflected in the fragmentation of habitats and agricultural land or the occupation of food and breeding habitats used by animals, etc. Due to the fact that transport infrastructure consists of long linear construction, these constructions often have a cross-border character and influence. These effects can be observed from the construction phase and last for the whole operation and maintenance phase.

The most effective way to minimize habitat fragmentation is to avoid it from the start. When planning new infrastructure, it is important to avoid sensitive and large contiguous natural areas, especially if they are still roadless. Alternative solutions such as upgrading existing roads or rerouting traffic may prove to be sufficient or even more cost-effective. Where new infrastructure is to be built, the primary remedy for fragmentation is to maintain connectivity between separated habitats and ensure the ecological permeability of infrastructure barriers. Standards for design of ecologically sustainable infrastructure are being developed and should be implemented particularly in emerging economies experiencing a surge in new infrastructure investments.

The construction of expressways and motorways, if they channel traffic away from lower category roads, can reduce the barrier effect of those roads for animals and sometimes increase transport safety. When building a road network, it is also common that the territory of several linear structures pass through the valley at the same time. Therefore, if safe crossings are not left in the affected area, together with the construction of roads and new passages (bridges, underpasses, ecoducts), such a road becomes very difficult for animals to overcome. It is for this reason that emphasis should be placed on measures to maintain the migratory permeability of roads, which reduce animal mortality and thus also contribute to road safety by preventing collisions with wild animals.

The development of the road network is important for the transport of people and goods and is often a backbone of economic activities. The transport infrastructure needs to be mitigated in such a way as to maintain conditions for healthy wildlife populations and biodiversity. Conserving ecological connectivity is an opportunity to reduce threats to biodiversity and increase opportunities for climate change adaptation.

4.2. Road effects

The construction and operation of roads have a suite of effects on natural areas across both intact and human-dominated landscapes. There are many direct and indirect impacts on ecological connectivity, including direct severance of habitats (reducing structural connectivity), physical habitat deterioration and alteration (reducing structural and functional connectivity), and influence on species.

The variety of impacts that transportation infrastructure has on biodiversity and ecosystems are well-described to include habitat loss and alteration, fragmentation and barrier effects, wildlife-vehicle collisions, noise and light disturbance, the spread of pollution and invasive alien species, and changes in hydrology and microclimate. It could be difficult to distinguish the boundaries between direct, indirect and even cumulative impacts.

In the United States, the National Environmental Policy Act[1] (NEPA) changed the definitions in 2020, merging direct and indirect and eliminating cumulative. The new regulations state that: *"Effects means changes to the human environment from the proposed action or alternatives that are reasonably foreseeable and have a reasonably close causal relationship to the proposed action or alternatives, including those effects that occur at the same time and place as the proposed action or alternatives and may include effects that are later in time or farther removed in distance from the proposed action or alternatives*." (new CEQ 2020 – 40 CFR 1508.1).

As they are used today in our common language when describing environmental effects, we'll continue to use the terms direct, indirect or cumulative effects. We have to keep in mind that the most important thing is to consider the totality of the effects of one or more projects rather than defining the boundaries between a direct, indirect or cumulative effect.

To address and understand the challenges of securing ecological connectivity the following concepts (Tab. 4.1) is used in the "Global Strategy for Ecologically Sustainable Transport and other Linear Infrastructure [3]:

1. Problem: Genetic isolation and wildlife mortality;
2. Cause: Habitat fragmentation and land degradation;
3. Aim: Ecological and landscape connectivity;
4. Objective: Sustainability;
5. Conflict: Green and grey infrastructure; and,
6. Solution: Avoidance and mitigation as the main solutions.

These concepts are the crucial key topics to be addressed when developing Linear Transportation Infrastructure (LTI) projects, to minimise their impact on ecosystem and landscape cohesion.

[1] Aim of NEPA is to establish a national policy for the environment, provide for the establishment of the Council on Environmental Quality (CEQ)

Table 4.1: Basic concept for ecological connectivity [3]

	Ecological connectivity concepts	Logical framework concepts	Description
1	***Genetic isolation and wildlife mortality***	***Problem***	The main environmental challenges related to LTI development are: genetic isolation, wildlife mortality and the loss of ecosystem functions which can cause significant changes in habitats, thus making it impossible for the original community of species can persist.
2	***Habitat fragmentation***	***Cause of the problems***	The lack of genetic exchange is caused by the habitat fragmentation on both terrestrial and aquatic ecosystems.
3	***Securing the ecological connectivity***	***Aim***	The main aim is to secure the ecological connectivity in important natural areas, as species' basic habitats or ecological corridors when they are intersected by TLI.
4	***Sustainability***	***Objective***	Sustainability and quality, must be achieved for three different perspectives: Social, Environmental and Economic.
5	***Green and Grey infrastructure***	***Crossing point and conflict areas***	Adopting the concepts of Green Infrastructure, the Natural Capital and the Ecosystem Services and identifying the conflicts in the main "crossing points" that Grey - Infrastructure such as TLI pass through Green Infrastructure/ natural areas.
6	***The hierarchy of priorities: Avoidance - Mitigation – Compensation***	***Solution***	The achievement of sustainable coexistence of Green and Grey Infrastructure must focus on resolving conflict through specific measures following the hierarchy of priorities of Avoidance - Mitigation – Compensation.

4.2.1. Direct effects:

A direct effect (or impact) is caused by the proposed action and occurs at the same time and place. Direct effects may occur during construction or operation of the project. Effects from a project may be ecological, aesthetic, historic, cultural, economic, social, or health related [4]. The main direct impact of a road on biodiversity is probably the fragmentation of territories. This is due to the road itself but also to road traffic, noise, pollutants and artificial lighting at night.

Described below are various types of direct impacts:

4.2.1.1. Habitat loss and alteration

Corresponds to physical change due to direct disappearance of habitats.

The construction of linear transportation infrastructures (LTI) can result in the loss of wildlife habitat by transforming the natural environment into pavement, dirt tracks, railway lines, canals and subsequent cleared rights-of-way. In addition to the direct loss of habitat, the alteration of habitat quality and living conditions in the surrounding area of the infrastructure like increased noise and light levels, changes in the hydrological conditions and others have to be considered. The effects of "modification of the habitat base" on animals include changes in the amount of food and food species due to the modification of foraging grounds, food shortage, decrease in the number of mates available for breeding and decrease in the breeding rate due to the modification of breeding grounds, decrease in the number of individuals available for habitat due to the modification of roosts, and results of these. There are concerns that the number of inhabiting individuals in the area (the project area of influence) may decrease or become extinct as a result of these factors (Fig. 4.1).

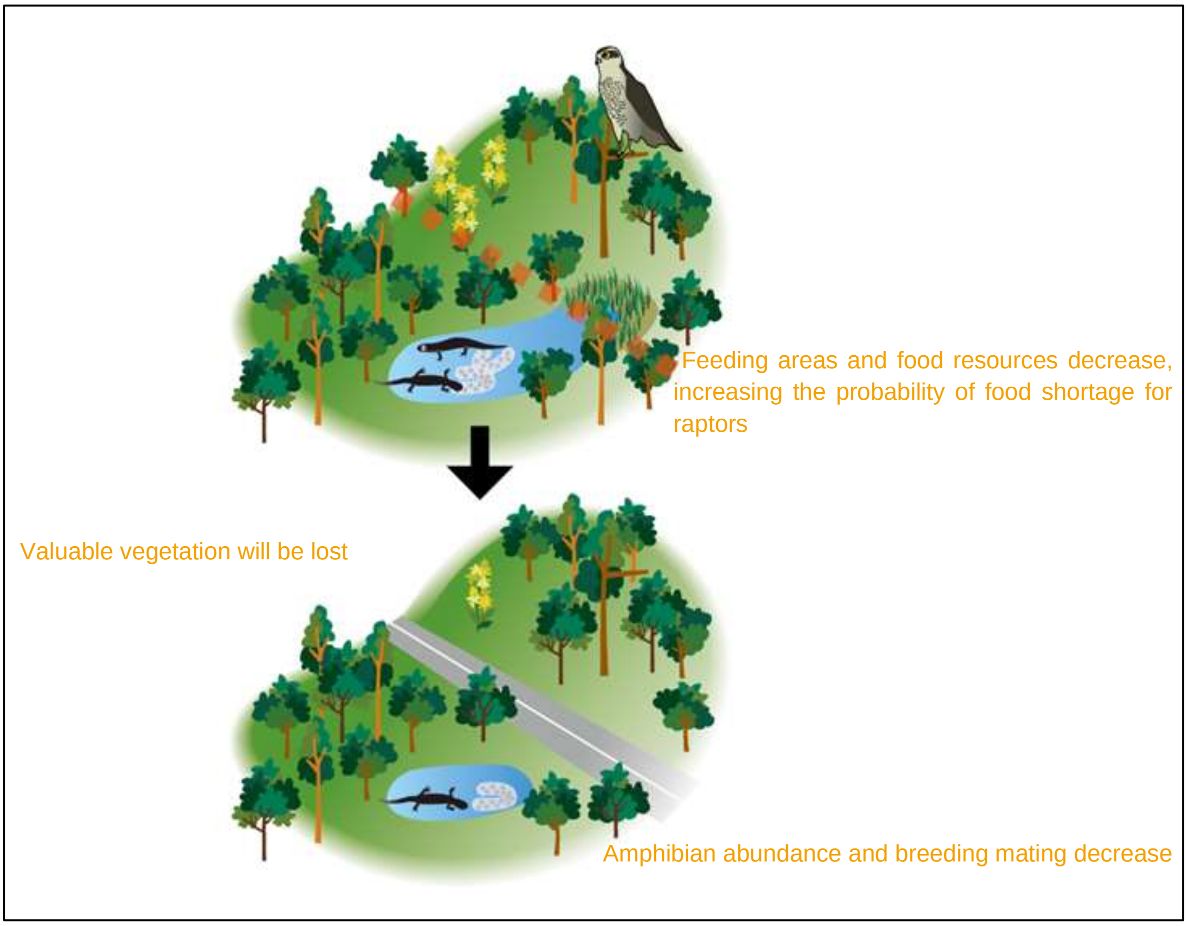


Figure 4.1: Examples of loss or reduction of habitat and habitat growth, etc. Top: Before construction of the road, and Bottom: After construction of the road (Source: [5])

Wide-ranging wildlife, those found in relatively low densities, or others with low reproductive rates, tend to be the most sensitive to habitat loss. Wide- ranging carnivores are particularly vulnerable to road impacts for such reasons, and thresholds of linear transport infrastructure are known to limit some of these species distributions. The principal part of the road, where traffic runs, affects a strip 50m wide approximately, that produces a loss of 5ha habitat/km.

4.2.1.2. Fragmentation and Barrier effect

These effects induce the most important negative ecological impacts. Roads are linearly constructed projects, which may divide the habitats and growing areas of animals and plants, and the spheres of activity and movement routes of animals. Therefore, in road projects, it is necessary to give consideration to the movement routes of animals and to pay sufficient attention to the fragmentation of their living and behavioural areas.

Animals use a variety of places for different purposes, such as feeding, watering, roosting and breeding grounds. An animal species can live only if all of these places exist within a single sphere of activity. In particular, large and medium-sized mammals, which have a wide range of behaviours, may have a very wide range of behaviours, and if their habitat is divided by the construction of a road, there is a high possibility that the species will not be able to survive in that area (Fig. 4.2).

According to species behaviour, the barrier effect may not only be physical. High traffic volume can modify animal behaviour, which tends to avoid noise or other annoyances by moving away from the infrastructure. Other times, they avoid the open areas that the road and its margins constitute. A subdivision of the population is generated, because they distribute between one side and the other of the infrastructure, or there is a big difficulty for animals to reach the resources they need if they are located on the opposite side of the road.

Because of this barrier effect, the gene flow can be disrupted which leads to genetic isolation, inbreeding and population extinction in the long term.

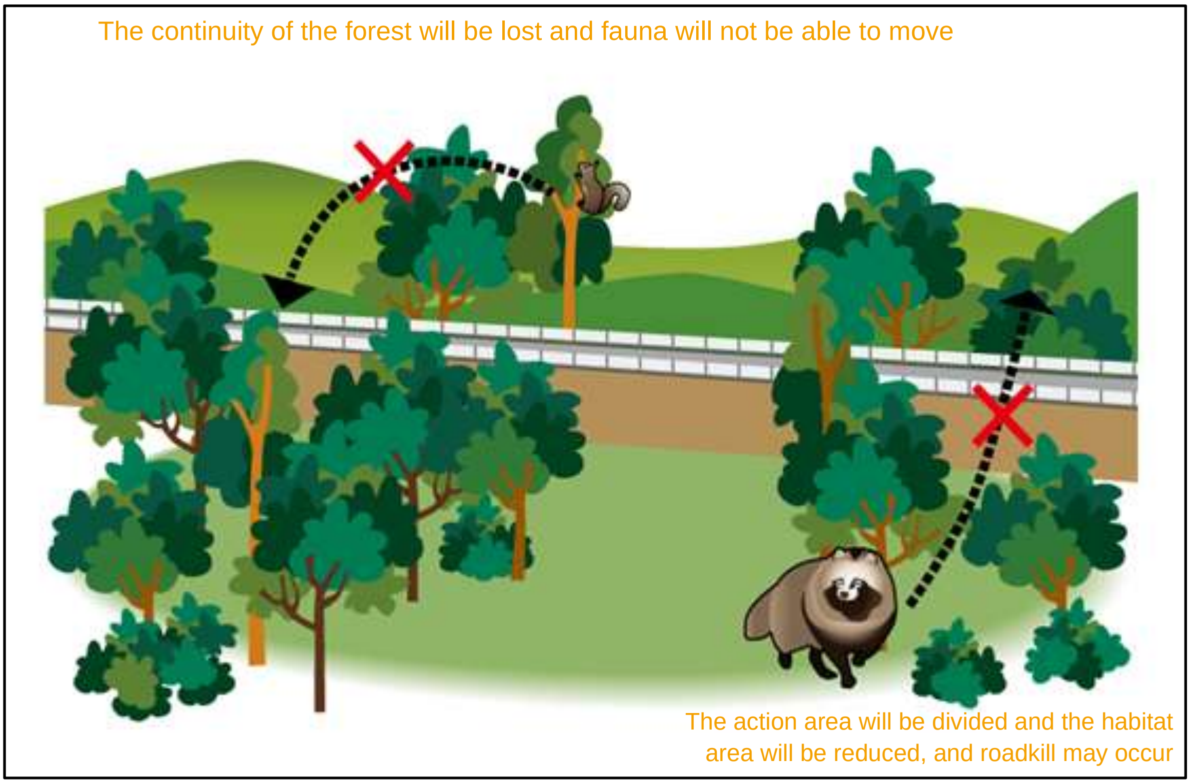


Figure 4.2: Example of the barrier effect (Source: [5])

4.2.1.3. Wildlife Traffic Mortality

Wildlife-vehicles collisions constitute one of the major sources of animal mortality directly linked to human activities. It is especially important in the case of insects, amphibians and reptiles, but also remarkable in birds and medium and large mammals (Fig. 4.3). This is part of the barrier effect that infrastructures imply by making difficult or impeding the movement of different species, reducing the genetic exchange between them.

Figure 4.3: Direct impact example: wildlife mortality due to road traffic, not always easy to determine (Source: cc-by-sa Olivier Pichard (left: European Squirrel), Eric Guinard (right: Pheasant))

Animals can access the roads because they cross their camping areas or dispersal routes, so they can easily end up in them when they move to look for food or to their wintering or reproduction areas.

The main impact of the run over of animals is reflected in the affectation of the populations of the species involved, especially in those species that are threatened or vulnerable and, to a lesser extent, the most common and abundant species. The degree of damage depends on the size of the population and the reproductive capacity of the species. Road accidents are also a road safety issue as they affect people who are involved in large wildlife accidents to the extent that they can die in them and generate large economic costs. Run over mortality can represent a significant loss for the most sensitive species. The intensity of traffic influences this effect. When the collision affects medium or large animals, they can impose a road safety problem.

4.2.1.4. Avoidance and attraction, interactions between animals

Roads, railways, and other linear transportation infrastructure can limit movement of wildlife due to changes in habitat structure and changes caused by operations. As an example of the former, new habitats created alongside road edges have been shown to reduce the species richness of savannah-dwelling and understory birds. At the same time, traffic and associated disturbances can lead to road-avoidance zones.

Roads and railways can also attract animals. Carcasses from road collisions, grain spillage on railway tracks, and pavement surfaces that are warmer than the adjacent habitat and freshwater sources can attract a variety of wildlife. Often, attraction is a result of conditions related to adjacent habitat (nesting, living space) or food found in the cleared areas adjacent to linear infrastructure, often called verges. In some cases, verges support abundant populations of small mammals, insects and birds, as well as native plant species. Verges of roads and railways can be important habitats and possibly the only remaining functional habitat for some species in highly developed and fragmented landscapes. The verge habitat can serve as travel corridors between patches of important habitat, facilitating dispersal and range extensions of some species. Aboundant prey in verges may attract predators and increase hunting activity. For example, when predators hunt in the verges close to traffic, collisions with vehicles tend to occur, thus making carrion available and attracting aerial and terrestrial scavengers. Some species such as squirrels, ravens, raptors, and snakes are able to benefit from the resources produced directly or indirectly in road and rail corridors.

When the environment changes as a result of a project, species that were able to live and grow in the past may no longer be able to exist, or certain species such as invasive alien species may breed and flourish, which may affect the interaction between living organisms and make it difficult for native plant and animal species to live and grow. For example, many plant species depend on insects and birds for the movement of pollen and seeds, so even if there is no direct impact on individual plants, the extinction of these insects and birds will make it difficult for plants to reproduce.

Thus, when considering environmental conservation measures in the project, it is important to consider not only the species to be conserved, but also all interactions with the living world (food web, ecological corridor…). This strengthens the conservation of target species and improves the resilience of ecosystems.

4.2.1.5. Noise

In general, linear transportation infrastructure entails an increase in the level of environmental noise. In fact, it is estimated that the noise produced by traffic is the main cause of acoustic pollution, being considered an environmental health problem for people. The noise generated by vehicular traffic is one of the factors that causes the greatest ecological impacts to fauna, because it produces several effects such as displacement, reduction of areas of activity and low reproductive success, which is associated with hearing loss, altering behaviours and communication interferences during the reproductive season, among others.

Noise is a variable, which is relatively easy to measure, but it turns out that it is difficult to separate its particular effects on fauna from those that are generated by the whole infrastructure. The best known effects affect birds, because they use sound as a way of communication. Songbirds appear to be sensitive even to very low noise levels.

4.2.1.6. Light

Artificial lighting reflects through the night sky, constituting what is called light pollution, which can be produced in three ways: glare, intrusion and radiance. All main effects are well known, such as those of light that can have on birds, insects, bats… (i.e.: margin effect that is assumed to affect nocturnal animals, modifying their feeding patterns, mating, and communication). This is similar for plants, where there are effects related to growth, composition and phenology.

However, the most visible effect is the one that is produced on insects, where light pollution causes a hyperstimulus behaviour that is known as ”fly into the light”.

4.2.1.7. Changes in the water environment

The emergence of road facilities may cause changes in the water environment, such as the fragmentation of water veins, lowering of groundwater levels, and changes in water quality due to the inflow of surface drainage and turbid water generated from construction sites. Since all living things depend on water for their livelihood, the effects of such changes are wide-ranging. In places where the water environment is severely altered, native species may become extinct, and animals with high mobility may be forced to move to other areas. Such changes in the water environment require attention, especially when earthworks such as large-scale embankments and cuttings are involved, or when construction work is carried out in the vicinity of small wetlands in mountainous areas.

4.2.1.8. Margin effect

Margin effect (or edge effect) occurs when an ecosystem is fragmented and the biotic and abiotic conditions of the fragments and the surrounding matrix change. In the case of highways, this effect will occur in the vicinity or edge of the road, where conditions with higher temperatures, lower humidity, higher radiation and greater susceptibility to wind will be created. This margin effect can penetrate differently among species and habitats. As a consequence of this effect, the distribution and abundance of the species is modified, changing the structure of the vegetation and, therefore, the supply of food for the fauna. These changes affect above all the species inside the ecosystem that has been fragmented, because they can be displaced by species from open spaces, which find in the new habitat more favourable conditions for their survival and reproduction.

The effect that is produced is the introduction of border or generalist species in forest habitats; species that have good dispersal capabilities, capable of invading and colonising disturbed habitats, are attracted to the edges and can penetrate inland. Edge species are attracted to these new habitats and many are egg or chick predators or nest parasites, reducing the reproductive success of species frequenting adjacent habitats.

Several studies have been carried out in which it is effectively verified that the population densities of 60% of the forest and grassland species that live near the roadsides are lower than the densities located far from them [6]. Similarly, a research study [7] reported that the population of horneros (a species of bird sensitive to fragmentation) was lower in forest fragments close to roads than in distant ones, due to the edge effect.

4.2.2. Permanent/Temporary effects

Within the direct/ primary effects, schematically, the permanent impacts are those that will last throughout the operation of the road and the temporary impacts are those that last during the construction phase of the infrastructure or even its deconstruction.

However, this must be qualified. During the operation phase of the road, there are of course permanent impacts such as the fragmentation effect of the road. However, there are also temporary impacts. There are many impacts during the construction phase: earth movements, land clearing, risks of pollution by construction equipment, etc. But there are also temporary impacts during the operation phase of the infrastructure, such as road salting or maintenance work, which can sometimes have significant effects on biodiversity. The choice of lighting fixtures when replacing them can also have important consequences on nocturnal fauna. It is also necessary to take into account the variations in intensity of the so-called "permanent" effects. Noise pollution and pollutant emissions, for example, will vary according to the intensity of the traffic. The effect of these nuisances on biodiversity will also vary according to the life cycle of a given species.

4.2.3. Indirect effects

Indirect effects (also called secondary effects) on animals, plants, and ecosystems include changes in the surrounding atmosphere, weather, light, water, soil, and other environmental conditions due to land alteration, which deteriorate or change the growth and habitat of plants and animals (Fig. 4.4). In addition, changes in the use of land, such as the abandonment of surrounding farmland due to road construction, and changes in management patterns are also factors in qualitative changes in the environment. These qualitative changes in the environment also include impacts due to changes in the relationship with other organisms, such as facilitating the invasion of invasive alien species or preventing the flight of insects that carry plant pollen.

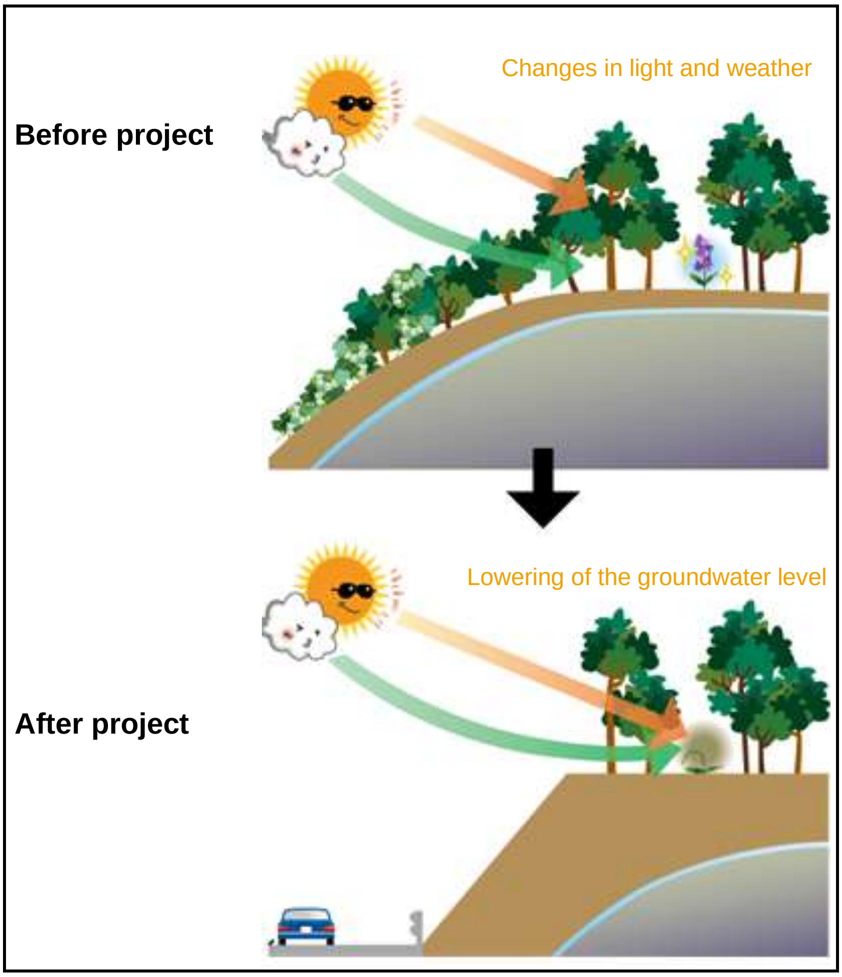


Figure 4.4: Examples of Indirect Impacts (Source: [5])

Understanding these indirect impacts is not as easy as understanding the direct impacts, and is often neglected. However, with the passage of time, the impacts can spread to the entire ecosystem of the region and eventually cause significant deterioration of the ecosystem. For this reason, it is necessary to fully consider the indirect impact together with the direct impact.

This is especially important when new roads are planned through so far "untouched" areas, which are most likely of high natural value, the further development of settlements, industry and more roads has to be taken into account. As an example, the area of Rondonia in Brazil is shown (Fig. 4.5):

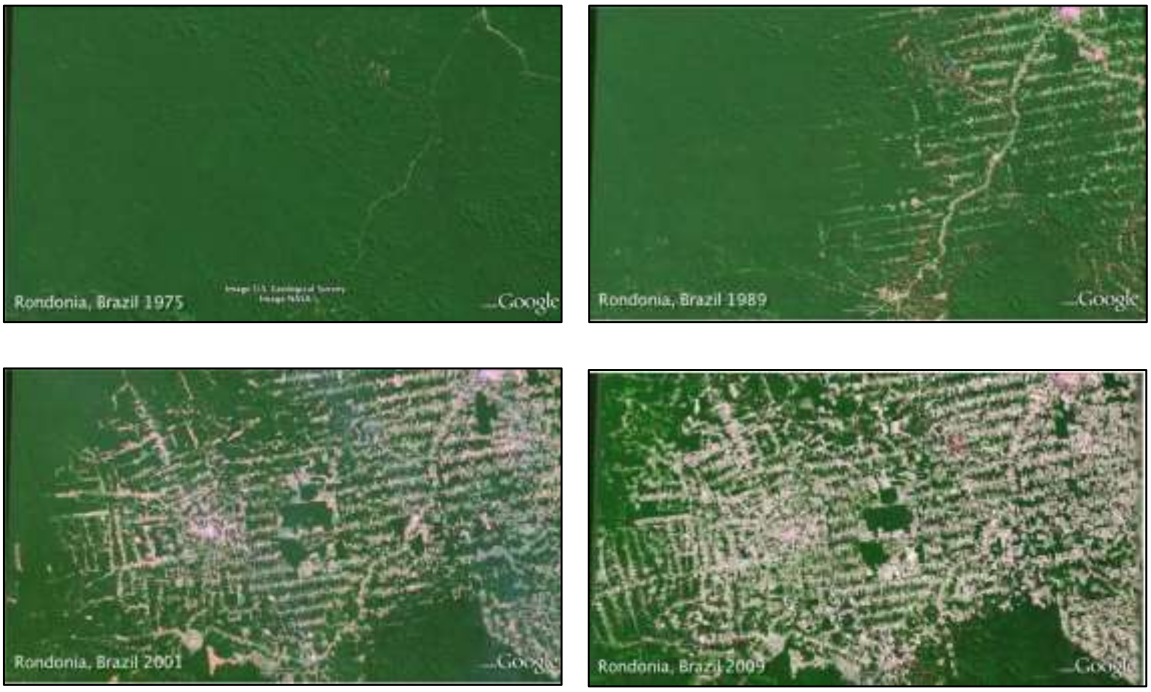


Figure 4.5: Secondary development and deforestation after road construction in the area of Rodonia, Brazil (Source: Google maps).

4.2.4. Positive effects

Habitats related to the infrastructure (HTI) are green areas associated with transport infrastructures and usually managed by transport authorities and stakeholders. These areas include verges, resting sites, water retention ponds and other drainage elements, as well as wildlife crossings (such as ecoducts). Such areas are inhabited by many animals, plants and other organisms which find refuge, food or other resources (IENE, 2016).

In areas with an intensively used landscape, although less visible and highlighted, HTI can yet have some positive effects for biodiversity. Regular mowing of verges maintains grassland habitats favourable to many plant and animal species (Fig. 4.6 and Fig. 4.8 (green arrow) below). It is increasingly documented that these verges can constitute ecological refuge habitats and thus contribute to a longitudinal continuity of the linear infrastructure of transport [8].

If the construction of an infrastructure in itself is unfavourable to biodiversity from a global point of view, the twinning of LTIs can limit the fragmentation, concentrate the barrier effect, contribute to longitudinal ecological corridors (particularly in peri-urban areas or of intensive agriculture), and even act as a reduction measure. The interstitial area between the two infrastructures can constitute interesting environments for many species (as semi-natural habitats), and act more as a filter than a barrier. Some species also have conditions without predators or human disturbance.

Figure 4.6: example of possible positive effects of road verges : regular mowing maintains a grassland habitat, sometimes relict. (Photo: cc by sa Olivier Pichard)

4.2.5. Cumulative effects:

4.2.5.1. Definition

[9] Cardinale and Greig give the following definition of cumulative effects (CE): they "*result from the successive, incremental, and/or combined effects of an action, project, or activity […] when added to other existing, planned, and/or reasonably anticipated future ones*". In the case of roads, it can be for instance the reduction of a wildlife population due to cumulative loss of habitat or their fragmentation, or the accumulation of disturbance of wildlife, including their migratory routes.

Cumulative effects (CE) can include: different effects from a same project; effects from other projects (past, current or future); effects from other changes or actions; accumulation of insignificant effects that become significant together.

There are numerous kinds of cumulative effects. [10] Blakley & Franks presented no less than 40 types of cumulative effects that have been discussed in EIA literature (additive, combined, growth-inducing, cascade effects**,** cross-boundary, induced, secondary…).

It is not possible here to detail all of these types, but we can mention growth-inducing effects and cascade effects.

4.2.5.2. Growth-inducing effects

Growth-inducing infrastructure often induces the growth of spin-off developments, including secondary access through roads, areas of settled or agricultural lands. Moreover, deforestation occurs mostly in the first few km along roads [11]. Infrastructure plays a key role in opening otherwise intact-forested regions to legal and illegal hunting, mining and settlement.

Such infrastructure investments are seen by stakeholders as opportunities to exploit previously unexploitable resources or develop the economy across inaccessible regions [12]. Although the economic benefits of the secondary development serve as grounds for approving growth-inducing infrastructure, the future environmental and social costs of the resulting indirect activities often are marginalised by project proponents and rarely considered by decision makers [12].

4.2.5.3. Cascade effects

Cascade effects refer to "*a sequence of events in which each produces the circumstances necessary for the initiation of the next*" [13].

Transportation infrastructures have an impact on their surrounding environment from their construction to their eventual disruption or end of use. For example, cascade effects of highways are the building of highway intersections or light pollution in living areas adjacent to the road.

4.2.5.4. Managing cumulative effects

Given the scale and scope of a Cumulative Effects Assessment (CEA), it is often beyond the technical and financial responsibility of a single project developer, hence the need for collaboration [9] . One of the main difficulties in CEA is indeed the definition of the scale (time and distance), which is too often minimised, especially the landscape-scale impacts [11] . To obtain a good CEA, it's better to advance it from the project level to regional scale [14] and even to national scale. It is very important to not only assess cumulative effects but to monitor them throughout the operation phase of the project. This requires the definition of qualitative and quantitative indicators of these cumulative effects. It is also useful to have an "ex-post approach" by examining several years later the cumulative effects of a project by comparing it to what was predicted. This helps to increase knowledge of the parameters to be taken into account during the cumulative effects assessment phase.

4.3. THE GLOBAL WARMING EFFECT

The direct consequences of all human activities is the increase of carbon dioxide (CO2) concentration in the atmosphere, heavily contributing to global warming. Transport activities produced in the United States of America, the most important part of CO2 emitted by all human activities, grew from 23% in 2010 [15] to 27% in 2019 [16], being mainly produced on roads (72%) [15]. Global warming disturbs ecosystem regulation and impacts many local species that cannot adapt themselves to such fast changes of environmental parameters like climate change, water salinity increase, desertification and more. An indirect feedback loop effect starting with road constructions, which cause the destruction of natural habitats, feeds and accelerates the phenomenon of global warming, which in turn amplifies the destruction of natural habitats and so on (Fig. 4.7; i.e.: the construction of roads in Amazonia provides access to the pristine tropical forest habitat and increases in the frequency of forest fires, which adds CO2 to the atmosphere, and so on…), illustrating the complexity of all this interrelated network of effects.

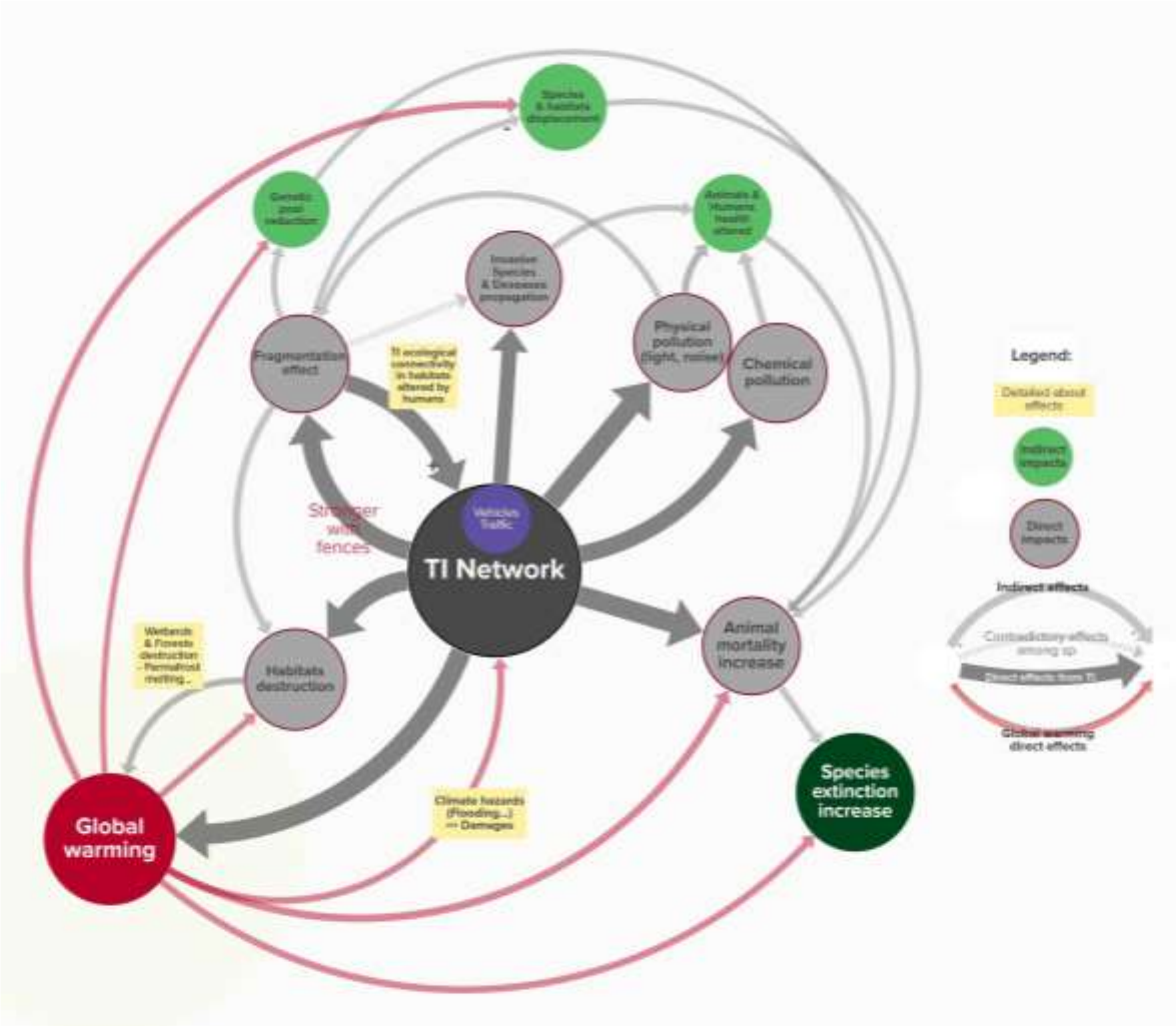


Figure 4.7: The network of Interrelated effects of global warming, transport Infrastructure and traffic, and biodiversity degradation (E. Guinard – Cerema (unpublished study))

These effects are not only caused by roads, and they have an indirect impact on biodiversity and could be considered of little relevance to the subject of this report. However, they cannot be minimised: transport activities and infrastructure, as well as other activities are closely linked and have various significant and sometimes global impacts on all biodiversity and its ultimate component: human populations.

4.4. Are road networks and their landscape fragmentation consequences only negative?

Many research studies detail the mechanism of fragmentation and its negative direct effects: barrier effect and the filter effect of the mortality of wildlife with traffic (Fig. 4.8). Road fragmentation also induces indirect impacts, facilitating deforestation, soil artificialization with increasing urban expansion areas as described above.

In rare cases, positive effects of roads on biodiversity have also been observed (Fig. 4.8): in certain situations, such as where roads or motorways cross intensively farmed plain landscapes, the road verges provide habitat refugia for many species. Invertebrate pollinators, micromammals and some rare plant species are known to benefit from these complementary roadside habitats.

Figure 4.8: Main negative (red arrows) and positive effects (green arrow) of road (and railway in such case) fragmentation (source: Cerema)

But these verges can also induce a negative “sink effect” in certain situations, exposing many sensitive animal species to a higher risk of being killed by the traffic. Specific studies must be conducted to avoid this type of effect and a fine scale verges management, fences and fauna passages and other devices are crucial to decrease wildlife mortality with road traffic. Then road infrastructures can be a great opportunity for regional planning strategy ecological continuities upgrading, Grey Network potentially connecting, with its verges and right-of-ways, Green Infrastructure.

In areas heavily impacted by human activities, the upgrading of existing roads as well as new road infrastructure projects, should be used as opportunities to restore biodiversity. By mitigating negative impacts and enhancing the positive aspects such projects can contribute to Green infrastructure management.

4.5. References

[1] Laurence W.F., 2018. Conservation and the Global Infrastructure Tsunami: Disclose, Debate, Delay! Trends in Ecology and Evolution. TREE 2401. p4.

[2] Dulac J., 2013. Global land transport infrastructure requirements: estimating road and railway infrastructure capacity and cost to 2050. International Energy Agency, Paris.

[3] Georgiadis L. (Coord.), 2020. A Global Strategy for Ecologically Sustainable Transport and other Linear Infrastructure. IENE, ICOET, ANET, ACLIE, WWF, IUCN, Paris, France. P. 24

[4] WASHINGTON STATE DEPARTMENT OF TRANSPORTATION, 2019. *Environmental Manual M 31-11.21* [online]. June 2019. Washington State Department of Transportation, Engineering and Regional Operations. Development Division, Environmental Services Office. Available on: https://wsdot.wa.gov/publications/manuals/fulltext/M31-11/M31-11.21complete.pdf

[5] Shinri, S., et al. Technical Guideline for Environmental Impact Assessment of road project. National Institute of Land and Infrastructure Management (NILIM) report. Japan.

[6] Reijnen, R., Foppen, R. and Meeuwsen, H., 1996. The effects of traffic on the density of breeding birds in Dutch agricultural grasslands. *Biological Conservation*. January 1st, 1996. Vol. 75, n° 3, pp. 255-260. DOI 10.1016/0006-3207(95)00074-7.

[7] Ortega, Y. K. and Capen, D.E., 1999. Effects of forest roads on habitat quality for ovenbirds in a forested landscape. *The Auk*. 1999. Vol. 116, n° 4, pp. 937-946.

[8] Ruiz-Cappilas, P., Mata, C. and Malo, J.E., 2013. Road verges are refuges for small mammal populations in extensively managed Mediterranean landscapes. *Biological Conservation*. February 1st 2013. Vol. 158, pp. 223-229. DOI 10.1016/j.biocon.2012.09.025.

[9] Cardinale, P. and Greig, L., 2013. Cumulative impact assessment and management: Guidance for the private sector in emerging markets.

[10] Blakley, J.A.E. and Franks, D.M., 2021. *Handbook of Cumulative Impact Assessment*. 2021. Edward Elgar Publishing Limited.

[11] Johnson, C.J., Venter, O., Ray, J.C. et Watson, J.E.M., 2020. Growth-inducing infrastructure represents transformative yet ignored keystone environmental decisions. *Conservation Letters*. 2020. Vol. 13, n° 2, pp. e12696. DOI https://doi.org/10.1111/conl.12696.

[12] Alamgir, M., Campbell, M.J., Sloan, S., Goosem, M., Clements, G.R., Mahmoud, M.I. and Laurance, W.F., 2017. Economic, Socio-Political and Environmental Risks of Road Development in the Tropics. *Current Biology*. oktober 2017. Vol. 27, n° 20, pp. R1130-R1140. DOI 10.1016/j.cub.2017.08.067.

[13] Allaby, M., 2010. *A dictionary of ecology*. Oxford University Press.

[14] Seitz, N.E., Westbrook, C.J. and Noble, B.F., 2011. Bringing science into river systems cumulative effects assessment practice. *Environmental Impact Assessment Review*. 2011. Vol. 31, n° 3, pp. 172-179.

[15] IPCC, 2014. *Climate Change 2014: Mitigation of Climate Change (PDF)* (1454 pp, 50MB). Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[16] U.S. Environmental Protection Agency, 2022. Sources of Greenhouse Gas Emissions. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

5. REGULATIONS / LAWS

The Earth's biological resources are vital to humanity's economic and social development. As a result, there is a growing recognition that biological diversity is a global asset of tremendous value to present and future generations. At the same time, the threat to species and ecosystems has never been so great as it is today. Species extinction caused by human activities continues at an alarming rate. Therefore, several international conventions, directives and strategies, but also national laws aim to reduce the threats to biodiversity caused by human activities.

The **Convention on the Conservation of Migratory Species of Wild Animals** (CMS) [1] was signed 1979 in Bonn, which is why it is often referred to as the Bonn Convention. As of 1st January 2021, the Convention on Migratory Species has 132 Parties. As an environmental treaty of the United Nations, CMS provides a global platform for the conservation and sustainable use of migratory animals and their habitats. The Bonn Convention is focusing on the free movement of species; therefore, it is a "Species" oriented convention based on the "Conservation Status of a migratory species" with three categories of Conservation Status: "Favourable", "Unfavourable" and "Endangered" (article I) and focus on Range States of the target species (article IV). Migratory species threatened with extinction are listed in Appendix I [2]. Parties of the Convention aim to strictly protect animals of endangered species, conserving or restoring the places where they live, mitigating obstacles to migration and controlling other factors that might endanger them. Besides establishing obligations for each State joining the Convention, CMS promotes concerted action among the Range States of many of these species.

The Bonn Convention is the first international convention referring indirectly to "fragmentation" in Article III. In this article, in paragraph (§) 4.b, parties that are Range States of a migratory species listed in Appendix I, shall endeavour to prevent, remove, compensate for or minimise, as appropriate, the adverse effects of activities or obstacles that seriously impede or prevent the migration of the species. [2]

The **Convention on Biological Diversity** (CBD) [3] was established at the United Nations Conference on Environment and Development (the Rio "Earth Summit") in 1992. It was inspired by the world community's growing commitment to sustainable development. It represents a dramatic step forward in the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising from the use of genetic resources. The convention on Biological Diversity consists of 196 parties.

The Rio Declaration on Environment and Development - adopted at the Rio Conference - proclames 27 Principles [4]. Especially worth mentioning for infrastructure development are the "**Precautionary Principle**" as well as the "**Polluter Pays Principle**". The Precautionary Principle - adopted as Principle 15 of the Rio Declaration - notes: *In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.* The "Polluter Pays Principle" - adopted as Principle 16 of the Rio Declaration - states: ".... *the polluter should, in principle, bear the cost of pollution, ….*"

The convention is not directly naming threats to biodiversity by linear transportation infrastructure, but it states that "*biological diversity is being significantly reduced by certain human activities*". Fragmentation and degradation of habitat caused by the construction and use of transportation infrastructure is known to be one of the major threats to biodiversity [2].

The Convention also describes that "*the fundamental requirement for the conservation of biological diversity is the in-situ conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings*". This can be transferred to and has to be applied concerning the construction and operation of linear transportation infrastructure, meaning that mitigation and compensation measures have to be implemented.

In 2010 in Japan with the **Aichi Biodiversity Targets** [5]**,** a concrete framework of goals and targets were established by the United Nations setting halting biodiversity loss as a major challenge for the 21st century. Connectivity and reduced fragmentation are part of the strategic goals.

Strategic goal B: *Reduce the direct pressures on biodiversity and promote sustainable use:*

Target 5: By 2020, the rate of loss of all-natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.

Strategic goal C: *Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity:*

Target 11: By 2020, at least 17% of terrestrial and inland water areas, and 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes. [2]

Also, the **UN Sustainable Development Goals** [6], 2015, describe the necessity for sustainable transport systems (Target 11.2) and resilient infrastructure (Target 9a). Goal 15 provides the general necessity to halt biodiversity loss: "*Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*." [2]

While cross-sectoral issues were not previously perceived as a priority issue by stakeholders, the recommendations of the fourteenth meeting of the Conference of the Parties to the Convention on Biological Diversity (COP 14) have changed this. In 2018, COP 14 put into perspective the need - at all levels of society - to integrate biodiversity values in all sectors and to align financial flows to preserve biodiversity instead of destroying it [7].

In the Conference of Parties (COP 15) in Kunming-Montreal 2022 [8], very ambitious targets were agreed on. The "Kunming-Montreal Global Biodiversity Framework" (GBF), includes four goals and 23 targets to be achieved by 2030. Especially worth mentioning are the TARGET 2 *"Ensure that by 2030 at least 30 percent of areas of degraded terrestrial, inland water, and coastal and marine ecosystems are under effective restoration …*", and TARGET 3 "*Ensure and enable that by 2030 at least 30 percent of terrestrial, inland water, and of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem functions and services, are effectively conserved and managed….*". These targets emphasise that biodiversity values have to be taken into account when planning, constructing and operating transportation infrastructure, and that it is obligatory to mitigate possible negative impacts.

5.1. References

[1] CMS | Convention on the Conservation of Migratory Species of Wild Animals www.cms.int/en

[2] Georgiadis, L., Adelsköld, T., Autret, Y., Böttcher, M., Hahn, E., Rosell, C., Sangwine, T., Wagner, P., Seiler, A., Newman, K., van der Ree, R., Sjölund A. and Bekker, H., 2018. Towards developing sustainable Linear Transportation Infrastructure globally. Recommendations for priorities of international action. Final report of the IGELI project: International Guidelines for Ecologically-adapted Linear Infrastructure. IENE. Linköping, Sweden. P 40

[3] Home | Convention on Biological Diversity (cbd.int) www.cbd.int

[4] REPORT OF THE UNITED NATIONS CONFERENCE ON ENVIRONMENT AND DEVELOPMENT* (Rio de Janeiro, 3-14 June 1992) Annex I RIO DECLARATION ON ENVIRONMENT AND DEVELOPMENT

[5] Aichi Targets Aichi Biodiversity Targets (cbd.int) www.cbd.int/sp/targets/

[6] UN Sustainable Development goals Sustainable Development Goals | United Nations Development Programme (undp.org) www.undp.org/sustainable-development-goals

[7] CBD, REPORT OF THE CONFERENCE OF THE PARTIES TO THE CONVENTION ON BIOLOGICAL DIVERSITY ON ITS FOURTEENTH MEETING; document CBD/COP/14/14; Report of the Conference of the Parties to the Convention on Biological Diversity on its fourteenth meeting (cbd.int)

[8] CBD, Final text of Kunming-Montreal Global Biodiversity Framework; document CBD/COP/15/L25 https://www.cbd.int/conferences/2021-2022/cop-15/documents;

Case studies appendix

Regulations in European Union

Regulations in Canada

Regulations in Japan

6. STUDY MANAGEMENT DURING THE LIFECYCLE OF ROAD INFRASTRUCTURE

A correct management of the studies during all phases in a road project lifecycle is crucial to avoid or at least reduce all main impacts generated during the road lifecycle. This chapter details all phases of a road project lifecycle and the study management during these phases.

6.1. WHAT ARE LIFE CYCLE PHASES OF TRANSPORT INFRASTRUCTURE PROJECTS?

From the decision to build a road to its exploitation and eventually to its decommissioning, in many countries, generally five phases follow each other (Fig. 6.1). Upgrading phase is apart from this cycle (Fig. 6.1) because it restarts another cycle from the design phase.

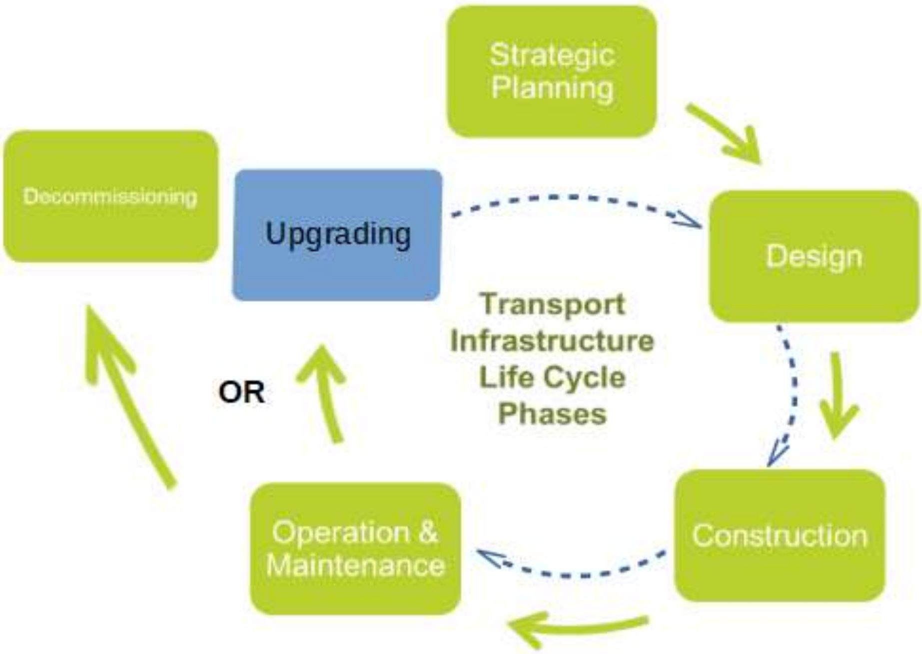


Figure 6.1: life cycle phases of infrastructure of transport project (adapted from BISON project)

Between the end of each phase, public consultancy procedures take place to obtain a “Go / No Go“, from administration and inform the local population before starting the following phase. During these procedures, a balance about the major technical, economic and other environment related issues (water, air, humans, etc) including biodiversity stakes (fauna, flora and natural habitats) with maps of their geographical positions, and the localised effects of the project and the measures of mitigation to be applied are proposed. A compromise must be found between all these different interests. The details in information provided increase at each phase, being the most concise just before the construction phase.

The starting point of all further planning should also be serious and clear strategic planning, not only for infrastructure development but also concerning the valuable natural areas and the ecological corridors connecting them. To combat fragmentation of ecological corridors they need to be defined, publicly visible and legally protected. Real safeguarding of the corridors is only possible if they are legally protected by suitable spatial planning tools, as all stakeholders are obliged to implement all necessary measures to keep the functionality of the ecological corridors.

Unfortunately, that is rarely done in the different countries at this time.

6.2. ENVIRONMENTAL PROCESSES IN LIFE CYCLE PHASES OF ROAD PROJECTS

Each of these phases (Fig. 6.1) includes several successive specific processes to design, build and manage a road project and also corresponding environmental processes such as Strategic Environmental Assessment (SEA)[2] and its version adapted to project scale, Environmental Impact Assessment (EIA)[3], that are detailed in the Table 6.1 below:

Table 6.1: Resume of main transport infrastructure life cycle phases and subphases (source: adapted from BISON project)

Phase	Includes	Environmental process
1. Strategic Planning	**1.1. Transport policy** **1.2. Strategic transport plan** **1.3. Transport area or corridor delimitation** (also called 'Project planning')	SEA
2. Design	**2.1. Site or route selection** (also called 'Concept design' and 'Informative study') **2.2. Procurement** **2.3. Detailed design** (also called 'Constructive project')	EIA -> *Indicators & descriptors, initial state of knowledge*
3. Construction	**3.1. Construction**	Environmental Monitoring Programs
4. Operation & Maintenance	**4.1. Operation and maintenance**	Ecological asset maintenance Monitoring/Evaluation
5. Decommissioning	**5.1. Decommissioning** **5.2. Repurposing**	Monitoring/Evaluation Restoration

Note (Tab. 6.1): Upgrading goes back to design and following phases

6.2.1. Strategic Planning phase:

At this phase, from the national and regional Transport Programmes and Plans, opportunities to develop infrastructure of the transport corridor are studied. The decision being made by the end of this phase after the evaluation of feasibility, the needs, the transport mode, the priority and protected areas to be avoided and corridors, and compilation of all knowledge about biodiversity available at national and regional scales, are part of the SEA dedicated to such a phase

[2] Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) are some of the various procedures that ensure that the environmental implications of decisions are taken into account before the decisions are made (https://www.oecd.org/env/outreach/eapgreen-sea-and-eia.htm). Evaluation is a pillar of regulation, in Europe and in many other countries, on the conduct of plans, programs and projects. These are key processes in the Strategic Environmental Assessment (SEA) which applies to public plans and programs.

[3] Environmental Impact Assessment (EIA) is very similar to SEA except that it applies more specifically to the scale of private and public projects (https://www.era-comm.eu/EU_Legislation_on_Environmental_Assessments)

6.2.2. Design phase:

Following the decision ending the Strategic Planning phase to start the road project, the Design phase will study and design the specificities of the future road infrastructure. Three successive steps, deeply linked with the EIA are engaged to:

1. *Site or route selection sub-phase 1:* the route(s) and the general characteristics of the road project are proposed (where and how). The maximum of data available on biodiversity must be compiled and a planning ranking ecological surveys on not well described and potentially impacted areas. It is in that period that should be selected the main biological and ecological indices and the corresponding descriptor that will be used in compensation and mitigation measures pre-determined.
2. *Site or route selection sub-phase 2:* several road project routes are studied and compared using several items. Then the weighted impacts of strength on biodiversity (without and with mitigation measures technically and economically feasible) as well as impacts on agriculture, landscape, water industrial and meteorological and other risks, human (noise/light and chemical pollution) and the global costs of road project construction of different options are compared. The need for compensation sites must be evaluated for these options. This is also the sub-phase when it is decided the amount of research needed to answer specific questions (about evaluation methods, or on species with poor scientific knowledge).
3. *Detailed Design sub-phase:* after the final route is selected in the previous sub-phase, the concept is then designed in detail. Information taken into account includes the last data collected during accurate surveys that are conducted in the narrow area including the road project aiming to obtain a robust initial state of data, including if possible a control site to be surveyed. These surveys must provide at least the density of species (fauna and flora) and the surface of the diverse natural habitats on site. Mitigation measures and compensation sites must be designed also in detail.

6.2.3. Construction phase:

At this phase the real impacts must be measured by the successive steps of road construction. Mitigation measures, especially reduction (for temporary construction effects as well as for permanent effects) and compensation measures are to be installed on this phase.

6.2.4. Operation and maintenance phase

The mitigation measures* (see Chapter 6) must be regularly surveyed as control of efficiency. They must also be periodically checked and fixed if necessary to maintain their integrity (i.e. motorway fences must be regularly controlled by patrol officers). The control frequency must be adapted to the type of measures, the species or habitat concerned and the biodiversity stake of the impacted site.

Recommendations :

By the end of the design phase to the very beginning of the construction phase, it is absolutely necessary for the stakeholder in charge of a road infrastructure to build their contract documents with both external ecological supervision and internal ecologist management. These contract documents must request to civil-engineering contractors companies and their subcontractors:

- *- to include in their team an ecologist that will regularly do reports to the stakeholder, control in the company and prevent accidental destruction of vulnerable botanic areas by informative panels with visible tape delimiting it*
- *- to include financial penalties in case of damage to species and natural habitats*

7. OVERVIEW OF MITIGATION MEASURES FOR FAUNA, FLORA AND NATURAL HABITATS

7.1. THE MITIGATION HIERARCHY

Given that global road expansion continues at an unprecedented rate and will be mostly concentrated in low income countries where many of the planet's most biologically rich and environmentally important ecosystems are situated, it is critical that best practices integrate biodiversity and environmental considerations at each stage of the project cycle as described in the previous section.

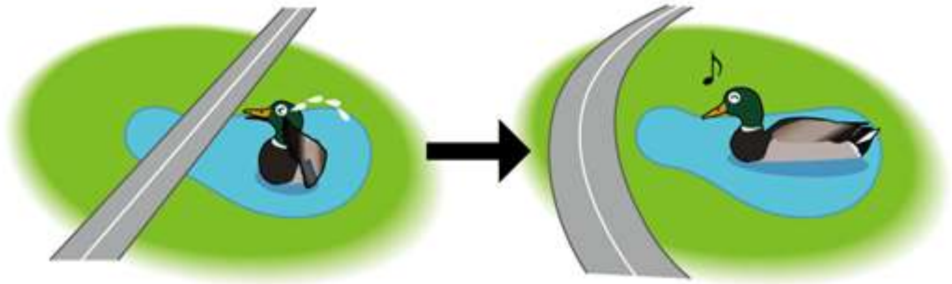
All stages of the project cycle require an assessment of the impacts of decisions made on biodiversity and the environment, which is normally through some sort of Environmental Impact Assessment. It is important that environmental agencies and experts work in coordination with road planners and designers at every stage, starting right from the beginning. The success of environmental impact assessments and the implementation of mitigation measures depends on the awareness of the environmental issues at all stages of the transportation infrastructure project [1]. These assessments will evaluate which combination of mitigation measures will likely be the most effective given that they may not all be equally effective and may have differential effects on different species. The assessments should recommend mitigation measures with the least negative environmental impacts.

The Mitigation Hierarchy is a systematic approach that fully integrates environmental considerations into road development. It is widely regarded as a best practice approach to manage biodiversity risk. This approach seeks to first avoid, then reduce, then restore or rehabilitate, and finally—when the previous options are exhausted—offset or compensate for road impacts to achieve "no net loss" in biodiversity ([1], [2], [3]; Fig. 7.1). In other words, it is necessary to note that "compensatory" environmental conservation measures are the last resort when "avoidance" or "reduction" is not possible. The result of all these types of measures for a road project must at minimum constitute a complete remediation of all impacts (i.e. no-net-loss) but should permit a supplemental benefit of biodiversity (i.e., net gain; Fig. 7.2) [1], [3].

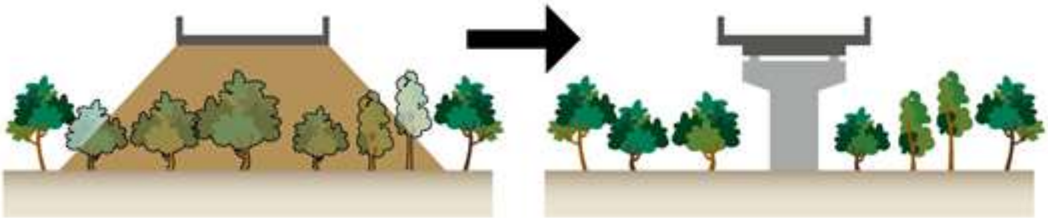
- **Avoidance** is to prevent environmental impacts by excluding them from project site consideration. It is preferable to avoid creating impacts from the outset especially in sensitive areas. Impacts in sensitive areas, such as in wetlands or mangroves for instance, can be more detrimental than elsewhere because they may cause severe *irreversible* damage to the environment. An example of avoidance is full-site protection through project relocation or redesign.

- **Reduction** is to minimise environmental impacts as far as it is practically feasible by reducing the duration, intensity or extent of activities that cannot be completely avoided. Examples of mitigation include the creation of highly protected areas (also known as strategic habitat conservation), restricted conversion or alteration, and measures to minimise ecological damage.

Example of avoidance measure: Select routes that avoid habitats of animals and plants.



Example of reduction measure: Minimising the altered area by devising the road structure



Example of compensation measure: New environment equivalent to the environment that will be lost due to the project creation.

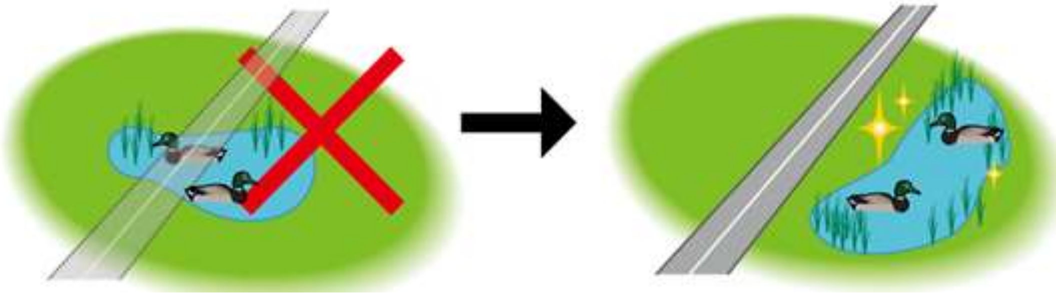


Figure 7.1: Examples of avoidance, reduction and compensation measures (Source: [4])

- **Offsetting/compensation** consists of compensatory measures taken to offset any significantly adverse residual impacts that could not be avoided, reduced, or restored/rehabilitated so that there is no net biodiversity loss or there is a net biodiversity gain. Examples of offsetting/compensation are post-development restoration works, ex-situ measures (captive breeding and plant seed banking), and translocation and/or reintroduction of species.

Recommendation: Prioritise degraded natural habitat for restoration over healthy habitat for mitigation to ensure a real net gain for compensation.

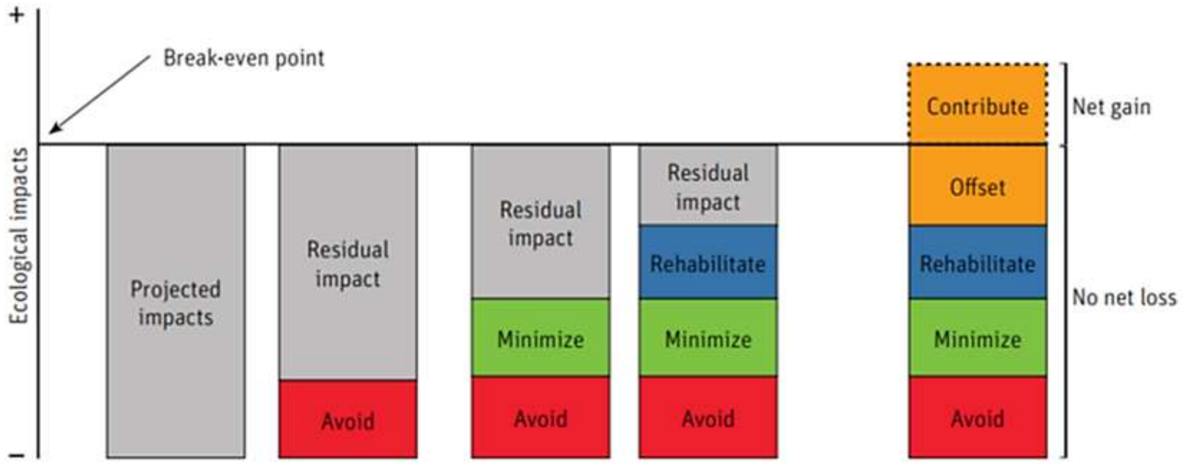


Figure 7.2: Mitigation Hierarchy (Source: [1] adapted from [2] and [3]).

Restoration/rehabilitation[4] is to leave affected areas, in which impacts could not be avoided or reduced, in comparable or better conditions than prior to the project's activities. Examples of restoration/rehabilitation are recovery of degraded habitats, redesign and upgrade culverts, and establishment and maintenance of ecologically similar protected areas of suitable size and integrity. Note that restoration/rehabilitation are considered in Europe for example only as techniques used for Reduction or Compensatory measures among the situation.

The effects of environmental conservation measures for animals, plants, and ecosystems may vary even if the same measures are implemented due to factors such as the characteristics of the target species and individual differences. Therefore, when considering environmental conservation measures for animals, plants, and ecosystems, it is desirable to have an awareness of the need to improve the quality of the measures compared to the previous state and to plan measures with a margin of safety, rather than taking last-minute measures to mitigate impacts.

The formal application of the Mitigation Hierarchy may be required by law in some jurisdictions, where there is enforcement of an effective environmental protection regime. Developers would generally be required to produce an Environmental Impact Assessment or an Environmental and Social Impact Assessment, which considers social and environmental aspects together.

Generally, greater emphasis is placed on the earlier steps of the Mitigation Hierarchy particularly when there are high value biodiversity components at play in order to reduce the risk of losing them [1] (Fig. 7.3). There is an observed emphasis on reduction suggesting that mitigation measures are seemingly considered in the design or construction phase despite the fact that the most effective

[4] "Restoration" refers to physical restoration, such as the creation of an artificial pond. In contrast, 'rehabilitation' refers to the return of organisms, such as amphibians spawning in the artificial pond after 'restoration'. In reality, the two are continuous and difficult to distinguish, so they are used together.

strategy at mitigating impacts is avoidance, which would have been considered in the planning phase [5].

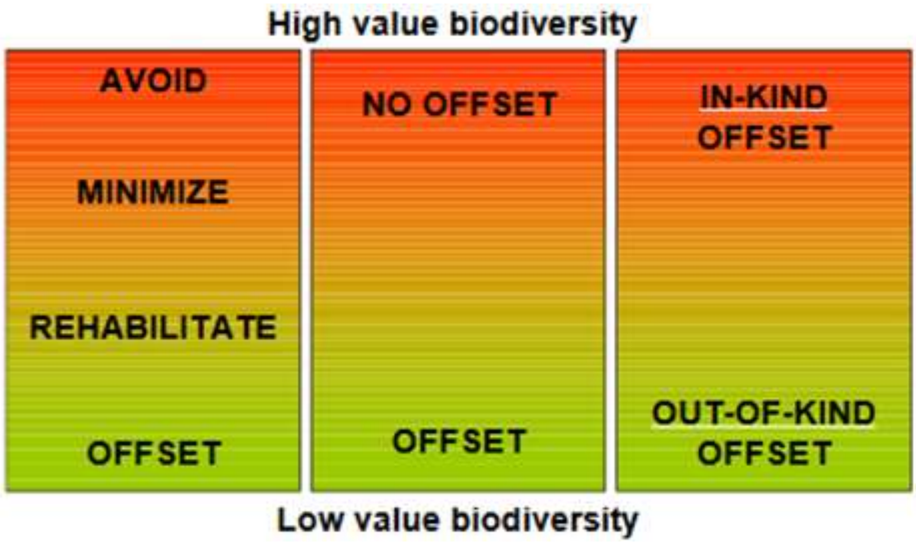


Figure 7.3: Identifying impacts and determining when these can and should be offset/compensated (Source: [2]).

In the application of the Mitigation Hierarchy, there is no universally accepted consensus at the moment as to how or when to advance through this approach. The key is to have open discussions with stakeholders to establish consensus on when it would be appropriate to move to the next level of the hierarchy. The following would be important considerations for such discussions [2]:

- The importance or value of the biodiversity in question.
- The extent to which the biodiversity in question can be substituted or replaced using known techniques.
- The level of investment or effort associated with the different steps and whether this is proportional and appropriate to the benefits that would be gained for biodiversity.
- The benefits that would be gained for biodiversity in relation to the costs incurred in applying different steps of the Mitigation Hierarchy.

When impact residual cannot be avoided, reduced or restored/rehabilitated, the road project can attempt to offset these through compensation measures. The goal is that there is no net biodiversity loss within the area due to the construction of the road. Compensation measures fall under two categories [1]:

- Replacement at the <u>same</u> location where loss or damage occurred, for example, planting trees as replacement for those cut down during construction or increasing existing wetlands if other wetlands are negatively affected.
- Replacement at a <u>different</u> location, for example, planting trees elsewhere if trees were felled during construction or financial compensation.

Recommendation:

It is preferable to replace biodiversity loss or damage at the same location where it was lost or damaged, and only if that is not possible to replace the loss or damage at another site. Any compensatory measure should always reflect the negative impacts identified and benefit the affected party.

7.2. THE MITIGATION MEASURES FOR HABITAT IMPACTS ON WILDLIFE

Habitat modification, including habitat fragmentation, is one of the major causes of biodiversity loss and environmental degradation. Transport systems severely modify and fragment habitats as described in section 2 such that they unintentionally kill millions of animals every year and increase the risk of genetic isolation.

In order to mitigate the impacts of road infrastructure on habitats, measures can be taken to directly provide links between fragmented habitats along with those that aim to improve road safety and reduce the impacts of traffic on animal populations by reducing traffic-related mortality [6] (Fig. 7.4). Mitigation measures can involve a combination of these and can potentially minimise the effects of roads depending on their purpose and the biodiversity present in the area. However, the presence of mitigation measures in a proposed road project does not necessarily mean that all effects will have been mitigated and that the road project should go ahead [1].

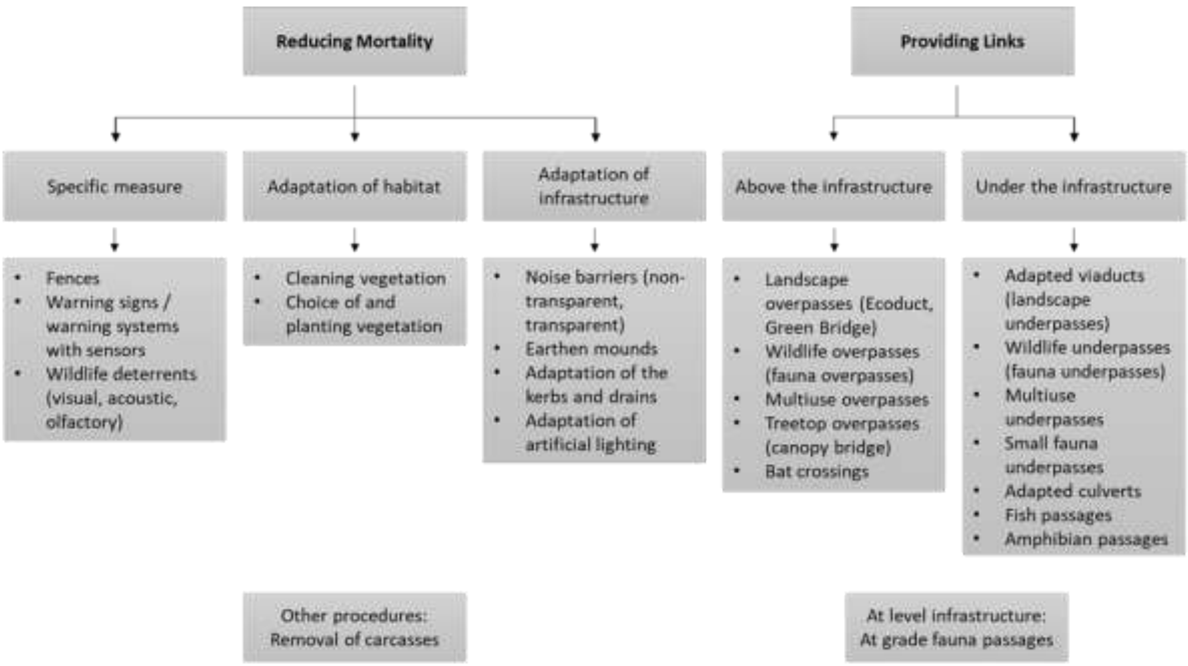


Figure 7.4: Measures to mitigate habitat impacts on wildlife. Adapted from [6] and [7].

7.2.1. Reducing mortality

Various measures that aim to reduce traffic-wildlife accidents and wildlife mortality are described below:

Fences (Fig. 7.5a) are often used to reduce wildlife vehicle collisions and thereby increase traffic safety. They are physical barriers that greatly reduce the mobility of fauna across transport infrastructure. They are often expensive to install and maintain. However, if planned and designed well, they can be very effective but they always have to be combined with wildlife passages (as discussed below).

- A fencing system must be planned and based on the ecology and behaviour of the target species.
- Since fences are expensive, they should be installed on parts of the infrastructure where collisions commonly take place to be the most effective.
- Even the best fences are not wholly sealed off from wildlife and animals can get trapped; therefore, it is advisable to have escape facilities to provide exits for the animals.
- Checking fences must be part of routine road inspection schedules.

Warnings (Fig. 7.5b) signal drivers to change their behaviour by decreasing their speed and increasing their attention in the hope of reducing the risk and severity of animal-vehicle collisions. While relatively inexpensive and commonly used by transportation agencies, there is little evidence to support their effectiveness [8]. Their low effectiveness is a result of driver habituation where drivers get used to the signs and tend to ignore them [9].

- *Standard (static) wildlife warning signs* aim to alert drivers to the potential presence of animals and are placed in areas where collisions occur often.
- *Enhanced wildlife warning signs* are bigger and convey specific messages or include more striking details.
- *Temporary wildlife warning signs* are more specific about where and when collisions occur and only activate at locations during periods when there is a high risk of collisions with the target species.
- *Warnings activated by animal detection systems*, which are devices with sensors that detect animals and activate warning signs for divers. In practice, they can only be used on short road sections (e.g., collision hotspots or fence openings).

Wildlife deterrents (Fig. 7.5c) are signals or cues that are intended to cause fear or discomfort in animals to trigger an increased alertness or flight response. Deterrents can be visual, acoustic, and/or olfactory. They are challenging to employ because these cues need to be developed in a way so that they are perceived and understood by animals. As such, they are not recommended, as their effectiveness is uncertain as well as highly susceptible to habituation by the animals.

- *Visual deterrents* are usually attached to delineators at road verges and either reflect or emit light when vehicle headlights shine on them. Their effectiveness is highly questionable as it is uncertain if animals can perceive the light reflected.
- *Acoustic deterrents* are often attached to delineator poles and will emit sounds like whistles, bells, chimes or even dogs barking or human voices. They are activated by the light of oncoming vehicles or by the presence of large animals through thermal cameras or movement sensors.
- *Olfactory deterrents* (‘scented fences’) are proposed to avert accidents on road infrastructure or to keep animals away from agricultural fields. These deterrents synthetically produce scents that mimic humans or other predators. Such products can only be used in targeted areas and for short durations as animals become easily habituated to them.

Clearing vegetation along road verges may help to reduce the number of collisions between vehicles and large animals (and also birds, when verges with low shrubs, that is not favourable for them [12] as it may lessen the attraction of these areas to animals as well as it may improve visibility of animals at verges to drivers. It is more appropriate for low density roads and railway lines. This measure must be done regularly and frequently in order to have some effectiveness.

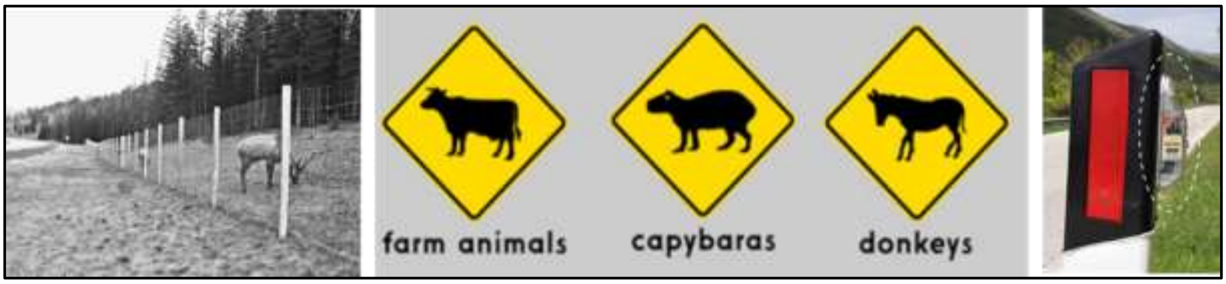


Figure 7.5: Examples of specific measures to reduce wildlife mortality – (a) fencing in Canada (source: [10]); (b) Venezuelan warning signs (source: [11]); and (c) European virtual fence combining visual and acoustic deterrents (from the left to the right of the figure; source: [7] – LIFE SAFE-CROSSING).

Choosing and planting vegetation along the road verges may help reduce the risk of animal collisions if the plants selected are unattractive to animals (e.g., no fruit- or berry-bearing plants). The vegetation should be planted sufficiently away from the roadway so that animals would be less likely to venture next to it. The selected vegetation should not burn easily to reduce the risk of forest fires by the road and it should also avoid or limit the introduction and establishment of invasive alien plant species as they often have negative environmental and social impacts (e.g., biodiversity loss, alteration of ecosystem services, and human health effects). These negative consequences mean that controlling the introduction, establishment, and abundance of invasive alien species is a policy priority in some countries, and as such strategies should be adopted to support the early detection of (e.g., through surveys) and rapid response to (e.g., removal) invasive alien species.

Noise screens are barriers usually constructed along roads close to human dwellings to reduce the traffic noise for the human residents though there are some built to protect avian breeding colonies. When built in high human-density areas it may not pose much of a fragmentation issue; however, in more natural locations it will pose problems for terrestrial animals.

- *Non-transparent screens* are constructed with concrete, wood or other materials that impede the free movement of land animals and thus they must be combined with wildlife passages (as discussed below).
- *Transparent screens* are built where there would be landscaping or shading concerns caused by a non-transparent screen. They are only to be used when equipped with dense stripe or point markings that reduce bird collisions. It is advisable to avoid constructing such structures as there is a high mortality to birds as they easily fly into them.

Earthen mounds are raised structures on the road verges to simulate a "buried road" creating a flight corridor above the traffic (Fig. 7.6), which reduces the mortality risk of flying vertebrates. They must be a minimum of 4 m high to guide flying species above the traffic and ought to be constructed on road verges of at least 12 to 15 m in width though if a retaining wall is used, then they can be reduced in width by a few metres [13].

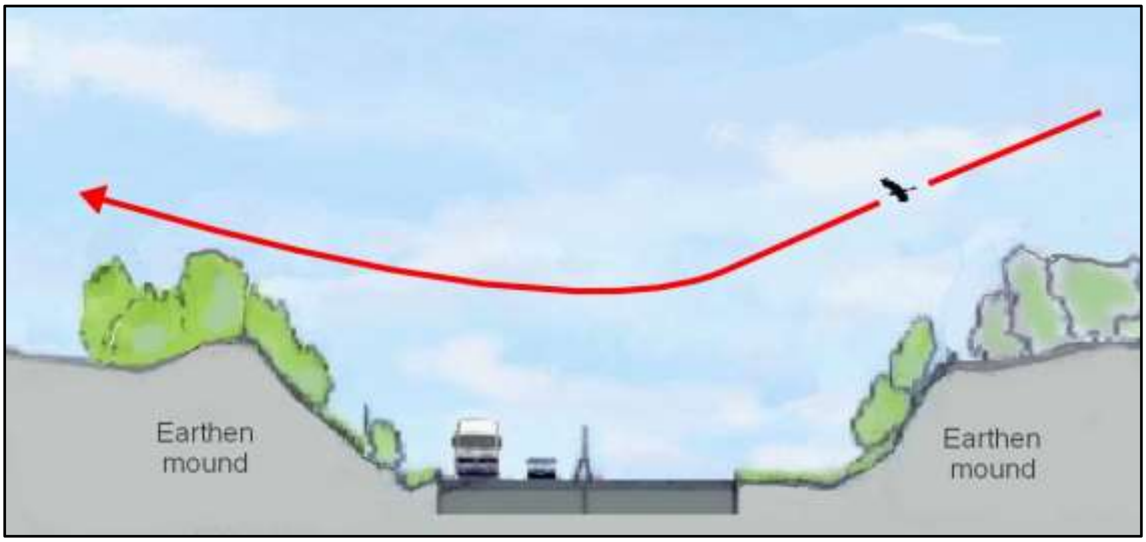


Figure 7.6: Earthen mounds on either side of a roadway, bird flying high above the traffic (Source: [14]).

Adaptation of curbs and drains can help small animals such as amphibians, reptiles, mammals or invertebrates escape these structures where they often become trapped and die.

- *Curbs* can be adapted by creating either gently sloping ones to allow animals access to the road verges or gaps in vertical curbstones to offer escape routes.
- *Drains* can be adapted by adding escape ramps with suitable grip that are higher than the surrounding terrain and a barrier to prevent predators from accessing them.

Adaptation of road lighting is proposed because light pollution impacts both biodiversity and the environment. Artificial lighting around transportation infrastructure contributes to habitat fragmentation and has different effects on biodiversity especially for nocturnal species. The guiding principle for the use of artificial lighting is to use as much as necessary and as little as possible [7].

- There are various international guidelines and recommendations on lighting characteristics according to the site zoning (e.g., city centres, protected areas, etc.).
- It is recommended to adopt an adaptive management approach to monitor and adjust the lighting as necessary to limit effects on biodiversity.

Another procedure to help reduce animal mortality due to road infrastructure is establishing a **carcass removal** protocol so that roadkill does not attract scavengers who would also be at risk of vehicle collisions. Such a protocol would facilitate statistical tracking of such accidents as well as the appropriate disposal of the carcasses.

7.2.2. Providing links

While the measures described below also aim to reduce traffic accidents involving wildlife, they likewise support efforts in biodiversity conservation, namely, restoring some ecological connectivity between fragmented natural areas. Ecological connectivity is the "unimpeded movement of species and the flow of natural processes that sustain life on Earth" [15]. It is a concept that also includes reducing the impacts of fragmented habitats (i.e., free movement over large areas) and protecting habitat corridors that (re)connect fragmented landscapes [16].

The magnitude of road impacts on biodiversity greatly depends on the characteristics of the infrastructure (e.g., traffic density and infrastructure type) and the species in the affected area (e.g., mobility and behaviour towards traffic and modified habitats). Restoring ecological connectivity across roads involves providing crossing structures that wildlife can use to get from one core natural area to another. The following should be kept in mind when designing such crossings [1], [17], [7]:

- A multiple species planning approach, in which mitigation measures take into account many or every species together, as it will provide better results than single species planning and likewise be the most cost-effective. For example, structures should be built within an individual's home range (i.e., structures for smaller animals at shorter intervals and structures for larger animals at greater intervals).
- If planning is concentrated on focal species, then it is advisable to focus on the species with the largest home range to achieve reasonable connectivity.
- A permeability plan, which describes how infrastructures permit or restrict movement, should be designed for each road structure to assess its connectivity.
- Suitable habitat should occur on both sides of the crossing points at local and landscape scales. While it is important to have suitable vegetation, it is highly advisable to avoid introducing invasive alien species because they will harm the local biodiversity.
- Effective land and resource management strategies need to be in place and applied around them.

Wildlife passages fall into two categories: those that cross over the transport infrastructure (**overpasses**) and those that cross under the transport infrastructure (**underpasses**). Choosing an overpass versus an underpass depends on many factors such as local topography, landscape, the requirements of the target species, the adjacent habitats being connected, and budget.

Overpasses are generally large structures over the transport infrastructure, which connect to separated habitats on each side of the infrastructure. They are often the best option in flat landscapes and reasonably effective at restoration of vegetation cover and microhabitats.

- *Landscape overpasses* (*ecoducts*, *green bridges*, Fig. 7.7a) are structures over transport infrastructure that connect habitats on both sides of said infrastructure enhancing ecological connectivity at the ecosystem level. Structurally, these are wider than wildlife overpasses to facilitate ecological restoration efforts. They are costly but are fairly effective at reducing fragmentation impacts.

- *Wildlife overpasses* (*fauna overpasses*, Fig. 7.7b) are structures over transport infrastructure that connect habitats on both sides of said infrastructure specifically providing a safe crossing point for wildlife at the population/metapopulation level. Structurally, these are narrower than landscape overpasses by convention. They are costly but are fairly effective at reducing fragmentation impacts.
- *Multiuse overpasses* are structures built over roadways that combine human and wildlife use. Since many small forestry or agricultural roads or cattle or pedestrian paths cross major transport infrastructures, they can be adapted to improve permeability and connectivity between habitats if the traffic intensity is low. However, these passages are no substitute for crossings designed and built specifically for wildlife that are free from human disturbances.
- *Treetop overpasses* (*canopy bridges*, Fig. 7.7c) are designed either by trees, rope-like ladder or walkway for climbing and/or arboreal species to allow them to cross the transport infrastructure above the traffic. These structures need to be wide and taut enough for animals to use with good connections to trees and/or bushes on either side of the roadway. They also need to be safe from predators and not be flammable.
- *Bat crossings* are apparatuses designed to facilitate safe passage over transport infrastructure for bats who particularly follow landscape elements such as trees. The effectiveness of these structures is unknown. Other measures such as underpasses, viaducts, and wildlife overpasses are recommended for bats.

Figure 7.7: Examples of providing links – (a) landscape overpass/green bridge (source: [18]); (b) wildlife crossing in Banff National Park, Canada (source: [16]); and (c) treetop overpass/canopy bridge (from the left to the right of the figure; source: [18]).

Underpasses are generally structures under the transport infrastructure, which are built mainly for drainage or human use; however, they can be adapted to connect separated habitats on each side of the infrastructure. They are often the best option for aquatic and semi-aquatic species and maintaining aquatic ecosystems (e.g., a stream or river); however, they are more challenging to vegetate due to the lack of sunlight. As many of these structures transport water, frequent inspections and maintenance are required to ensure they are functioning effectively for the target species.

- *Adapted viaducts* (*landscape underpasses*, Fig. 7.8a) are large transport infrastructures supported by pillars or arches that enable the preservation of ecological corridors or ecosystems associated with floodplains and river valleys below the structure. These can facilitate the free movement of a multitude of terrestrial and aquatic species. Viaducts can be constructed wherever low-lying ground needs to be crossed by transport infrastructure especially if there is a watercourse present. The area under a viaduct must not be used for storage of equipment or blocked by vehicles, fences or other obstructions.
- *Wildlife underpasses* (*fauna underpasses*) are structures constructed under transport infrastructure with lower traffic volumes than viaducts that provide safe crossing points for wildlife such as ungulates or large carnivores. They must be kept free from human disturbances and are particularly suitable for hilly areas or infrastructures on embankments. However, they may often lack sufficient light to guide flying species and water for vegetation rendering them potentially less suitable than wildlife overpasses.
- *Multiuse underpasses* are structures constructed under road infrastructure that combine human and wildlife use. Such underpasses must meet the requirements for the target species and be suitably located for their crossings. Small forestry roads, cattle or pedestrian paths may be adapted to improve permeability and connectivity between habitats if appropriate landscaping is provided. However, these passages are no substitute for crossings designed and built specifically for wildlife that are free from human disturbances. Multiuse hydraulic underpasses (e.g., a small span river bridge) may be used as alternatives to adapted culverts and should be constructed wide enough to preserve the riverbanks, especially for permanently flowing rivers. Banks must be large enough (about 2 m in width) to offer a usable ecological corridor through the road infrastructure for all animal sizes living there.
- *Small fauna underpasses* are structures built under transport infrastructure and are designed specifically for small animals such as reptiles, small mammals (e.g., foxes, badgers) or invertebrates. These structures are often built when the infrastructure is constructed over an embankment and placed as close as possible to the target species' defined crossing paths. These structures should be dark and sheltering material provided at entrances.
- *Adapted culverts* (Fig. 7.8b and 7.8c) are culverts that allow water streams and/or drainage to flow under transport infrastructure but also have modifications to enable aquatic and terrestrial wildlife crossings. Such culverts are frequently used by small land mammals, fish, and other aquatic species. When fish populations are present, the culverts need to be designed for fish passages (see fish passages below). If the culverts carry water, then they must be outfitted with dry ledges or shelves and appropriate landscaping, taking care of the connection between the ledges and the natural soil at the entrances for terrestrial animals. *Fish passages* are structures that are designed to preserve the connectivity of aquatic ecosystems (e.g., streams, rivers, lakes) and allow the free movement of fish and other aquatic species both upstream and downstream. These can be specifically designed or can be adapted from viaducts or large culverts to take into account water flow fluctuation, velocity and volume, type of watercourse, and ecosystem connectivity and species' requirements (e.g., sufficient water depth and air passage).

- *Amphibian passages* (Fig. 7.8d) are small structures constructed in close proximity to each other designed to allow the movement of amphibians (e.g., frogs, toads, newts) across roads. They are linked to smooth opaque guiding fences to prevent them from accessing the roadway and direct them to the entrance. These structures need to be sufficiently humid to avoid desiccating the animals, but also drain easily as flooded passages are not suitable to amphibians.

a *b* *c*

d

Figure 7.8: Examples of providing links – (a) adapted viaduct (source: [18]; (b) adapted culvert (source: [18]); (c) dry pipe, dry ledge and dry shelve inside the bridge (from left to right in the photograph; source: [19]) and (d) amphibian (salamander) passage (source: [20]).

There are also at level infrastructures called **at-grade fauna passages** (**level crossings**), which are areas where overpasses cannot be constructed to facilitate ungulate (hoofed animal) crossings. These crossings can only be built on fenced transport infrastructure and require an electronic animal detection system as well as a driver warning system ADDWS (Animal Detection and Driver Warning System) so that animals are directed across the infrastructure and drivers are alerted to their presence in the passage. They may only be suitable for larger animals (e.g., deer and boar) and on roads with low vehicular traffic density.

NOTA FOR LMIC :

In countries where funds are scarce (but the following argument is valuable for higher-income countries), the best solution is to choose simpler and cheaper types of mitigation that require the least management and intervention, over more efficient but sophisticated and fragile, more expensive and often less sustainable types of mitigation.

7.3. References

[1] Quintero, J. D., 2016. A Guide to Good Practices for Environmentally Friendly Roads. Arlington, Virginia, US: The Nature Conservancy–Latin America Conservation Council.

[2] BBOP (Business and Biodiversity Offsets Programme). 2009. Biodiversity Offset Design Handbook. Washington, DC: Forest Trends.

[3] PrincewaterhouseCoopers LLP. 2010. Biodiversity Offsets and the Mitigation Hierarchy: A Review of Current Application in the Banking Sector. On behalf of the Business and Biodiversity Offsets Programme and the UNEP Finance Initiative. London.

[4] Sone, S., Kadoyu, K., Inoue, R., Kurihara, M., and Matsue, M., 2013, No. 714, National Institute of Land and Infrastructure Report, Ministry of Land, Infrastructure, Transport and Tourism, Japan

[5] Juffe-Bignoli, D., Burgess, N. D., Hobbs, J., Smith, R. J., Tam, C., Thorn, J. P. R., and Bull, J. W. (2021). Mitigating the Impacts of Development Corridors on Biodiversity: A Global Review. Frontiers in Ecology and Evolution 9:683949. doi: 10.3389/fevo.2021.683949

[6] luell, B., Bekker, G. J., Cuperus, R., Dufek, J., Fry, G., Hicks, C., Hlaváč, V., Keller, V., B., Rosell, C., Sangwine, T, Tørsløv, N., Wandall, B. le Maire, (Eds.) 2003. COST 341—Habitat Fragmentation due to Transportation Infrastructure. Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions. Brussels: European Co-operation in the Field of Scientific and Technical Research.

[7] Infrastructure and Ecology Network Europe (IENE). 2022. '7 Solutions to reduce transport infrastructure impacts on wildlife.' Wildlife & Traffic A European Handbook for Identifying Conflicts and Designing Solutions. Paris, France: IENE

[8] Rytwinski, T., Soanes, K., Jaeger, J.A.G., Fahrig, L., Findlay, C.S., Houlahan, J., van der Ree, R., and van der Grift, E A., 2016. How Effective Is Road Mitigation at Reducing Road-Kill? A Meta-Analysis. PLoS ONE 11(11): e0166941. doi:10.1371/journal.pone.0166941

[9] Huijser, M. P., Mosler-Berger, C., Olsson, M., and Strein, M., 2015. Wildlife warning signs and animal detection systems aimed at reducing wildlife-vehicle collisions. In: van der Ree, R., Smith, D., Grilo, C. (Eds.), Handbook of Road Ecology. John Wiley & Sons. Oxford, pp. 198–212. https://doi.org/10.1002/9781118568170.ch15

[10] Ford, A.T., Clevenger, A. P., Huijser, M. P., and Dibb, A., 2011. Planning and prioritization strategies for phased highway mitigation using wildlife-vehicle collision data. Wildlife Biology, 17: 253-265. https://doi.org/10.2981/09-051

[11] Tryjanowski, P., Beim, M., Kubicka, A.M., Morelli, F., Sparks, T.H., and Sklenicka, P., 2021. On .the origin of species on road warning signs: A global perspective. Global Ecology and Conservation, 27: e0160. https://doi.org/10.1016/j.gecco.2021.e01600

[12] Guinard, E., 2013. Infrastructures de transport autoroutières et avifaune : les facteurs influençant la mortalité par collision (Doctorat, Ecole pratique des hautes études-EPHE PARIS).

[13] Cerema, 2020. Infrastructures de transports et oiseaux : enjeux, impacts et mesures d'atténuation. Bron, Cerema, 2020. Collection: Connaissances. ISBN: 978-2-37180-408-1, 54 pages.

[14] Cerema, 2021. Les passages à faune. Préserver et restaurer les continuités écologiques, avec les infrastructures linéaires de transport. Bron: Cerema, 2021. Collection: références. ISBN: 978-2-37180-525-5 (pdf).

[15] Convention on Migratory Species (CMS), 2020. Ecological Connectivity. Convention on the Conservation of Migratory Species of Wild Animals. https://www.cms.int/en/topics/ecological-connectivity

[16] Parks Canada Agency (PCA), 2022. What is ecological connectivity? Government of Canada – Parks Canada Agency. https://parks.canada.ca/nature/science/conservation/connectivite-connectivity

[17] Polak, T., Nicholson, E., Grilo, C., Bennett, J. R., and Possingham, H. P., 2019. Optimal planning to mitigate the impacts of roads on multiple species. Journal of Applied Ecology 56:201-213. https://doi.org/10.1111/1365-2664.13258

[18] Sabatini, J., 2018. Improved Animal Crossings Show a Huge Decline in Wildlife Collisions. Car and Driver. https://www.caranddriver.com/features/a22654629/these-animal-crossings-show-decline-in-wildlife-collisions/

[19] The Restoration of ecological continuity corridors on motorways. Summary report - Feedback on wildlife structures and monitoring in the VINCI autoroutes network. Vinci Autoroutes. June 2016, 60 pages. https://www.trameverteetbleue.fr/sites/default/files/references_bibliographiques/summary-report_feedback_en-vinci_web.pdf

[20] Hamed, K., 2022. How Did the Salamander Cross the Road? Introducing the Tennessee Valley Authority South Holston Weir Dam Salamander Underpass. The Tennessee Conservationist. https://digital.tnconservationist.org/publication/?i=758361&article_id=4327315&view=articleBrowser

Case studies appendix

Defragmentation Programme Netherlands

Defragmentation Programme Austria

8. MONITORING / EFFICIENCY EVALUATION

8.1. MONITORING: FOR WHICH PURPOSE?

Road-induced impacts and especially those which have negative effects on biodiversity, need to be mitigated. It must be managed as required by the Mitigation Hierarchy: the impact must be first avoided, if not mitigated. If the mitigation measures do not reduce the impacts enough or if no mitigation is possible, then it will be necessary to compensate. Mitigation measures must be evaluated to verify their efficiency by monitoring* into a larger process of evaluation*.

Monitoring is in this context used to measure after there identification:

- the raw and residual (after mitigation measure implementation) impacts on biodiversity currently existing from the construction to the maintenance / operation phases
- the mitigation measure efficiency (controlling their integrity and their functionality) to apply adjusted corrective actions on it if necessary

8.2. MONITOR PLANNING THROUGHOUT THE DURATION OF PROJECT

The monitoring programs of a road project to measure the impacts and the efficiency of the mitigation measures proposed in Design phase must follow a plan that extends from the beginning of the design phase to the maintenance and decommissioning phases (Fig. 8.1).

8.2.1. Before construction

The monitoring process begins when the design phase of a road project starts. At this step, the information to be collected concerns biodiversity stakes and existing threats from existing databases and if necessary from inventories in areas without too little knowledge about species and habitats. With those data are located the biodiversity stakes that are ranked in terms of number of sensitive species towards diverse road's impacts. Generally, several alternative routes are drawn, each of them containing its potential road position. They are as much as possible established to avoid as much as possible high biodiversity stakes areas, but the final route will be a trade-off between other items (landscape, agriculture, economy, natural and industrial risks, water protection, human settlements…).

At this step, with the progression of the project design, indicators species and natural habitats are to be proposed as well as where and how to monitor them and where to conduct robust inventories to obtain a reliable initial state of biodiversity, especially in the highest priority areas impacted before the road construction. At least 1 year of *in situ* inventories before construction must be applied to have a complete biological cycle. After the first inventories, it is recommended to choose indicators species and habitats. Two to three years monitoring of these indicators species and habitats would be ideal to observe interannual variations that could be large before construction. Having such information would avoid hypothesising the potential role of road construction in such variations.

8.2.2. During construction

Complementary inventories should be done where species or habitats are protected by laws and endangered to apply specific protection from accidental destruction, several weeks before construction phase starts (i.e. information panel and physical fences delineating protected flora species stations [= growing areas]) or their transplantation if destruction is not avoidable). These new measures need to be monitored during the construction phase. Therefore, ecological site surveillance needs to accompany the construction of the project as well as the implementation of the measures to make sure all works are done in an ecologically sound way.

Other kinds of monitoring must be implemented during this phase:

- all real impacts (direct destruction, dust on plants, engine noise…) on previously targeted species and habitats are mostly monitored during this phase.
- temporary measures as well as permanent measures (i.e. fauna passages, fences...) to also be monitored as soon as they are functional during this phase.

8.2.3. After construction

In many countries, monitoring ends at least 5 years (but 10 to 15 years are preferable) after construction during the maintenance/operation phase. During this phase, the measure effectiveness must be evaluated. If they are not efficient, a corrective adaptation of the mitigation measure must be proposed and tested if possible.

Compensation monitoring comes often late after construction in some countries (i.e. France…), usually because the project manager does not easily find all the compensation sites asked by the local authorities before the end of construction (lack of potential compensation sites, competition between projects…). This delay must be taken into account in their evaluations. The sites to be compensated must be monitored before and during the construction step. It provides with precision what will have to be compensated. Ideally, a major part of the compensation sites should have to be found before road construction, by the stakeholders or the authorities (e.g. local administrations) to gain time and to partly avoid an important overestimation in the price of these sites by the owners.

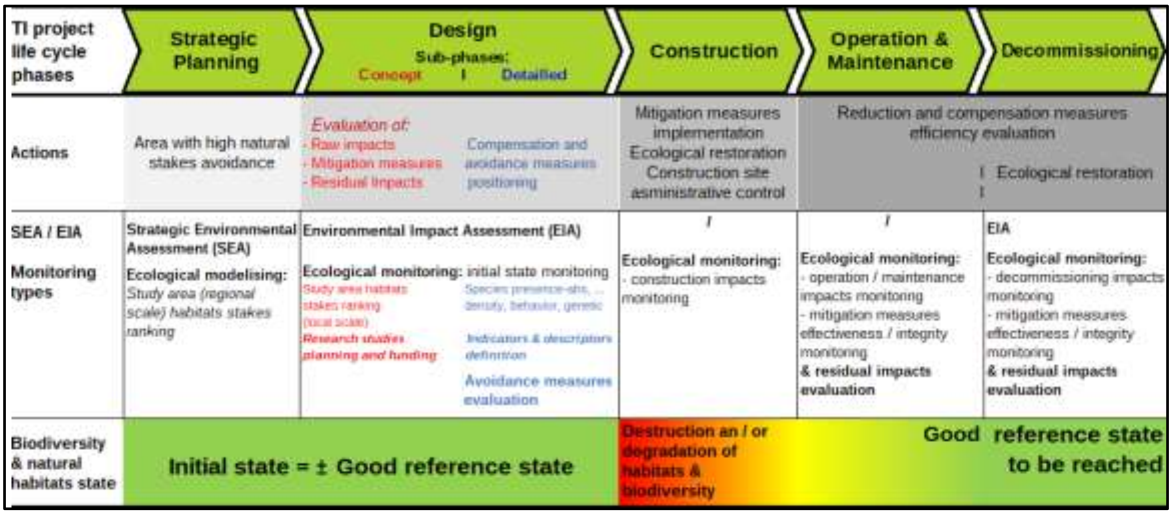


Figure 8.1: Evaluation/monitoring steps on life cycle of infrastructure of transport project (Source: Cerema in Biodiversity and Infrastructure. A handbook for action. IENE (in prep.))

8.3. How to monitor?

Biodiversity monitoring is important because it provides a basis for evaluating the integrity of the species and habitats, the parameters from roads generating effects on biodiversity and their responses to disturbances, and the success of actions taken to preserve or recover biodiversity.

Building steps

Biodiversity monitoring process building necessitate several following steps:

- identify target species, groups of species, populations and habitat to monitor
- identify biodiversity stakes
- identify raw and residual impacts (and/or the *ad hoc* mitigation measures efficiency) on these stakes
- identify objectives "what you want to evaluate" and "how to evaluate: which metrics"
- Once these identification steps are done, select indicators and descriptors: practical and realistic, meaningful. Monitoring scheme (also called protocol) must the most convenient in the limits of several parameters that restrain its deployment. A monitoring scheme is a trade-off between budget size, concision and monitoring duration, to show whether trends are moving dangerously close to unacceptable situations. It also has to reveal trends toward, or away from, biodiversity conservation
- Build a scheme, taking account of:
    - temporal scale
    - spatial scale (regional, community, species/population)
    - ecological functionality

Monitoring design

To evaluate the effect of a new or retrofitted road on biodiversity as accurately as possible, it is advisory to use the Before-During-After-Control-Impact (BDACI) methodology process (Fig. 8.2, [1]). BDACI approaches include time and impact factors, with a control site and a comparably impacted site, both represented by data before and after the impact. The same sites are preferably monitored Before, During and After road construction (here called Intervention). But in some cases, obtaining monitoring Before and even during construction is impossible, the minimal solution is to monitor a Control comparable before construction to obtain valuable but less robust results. Another constraint is that BDACI design (Fig. 8.2), is impossible to be carried in an entire TI project. It must be limited to small areas chosen among the scientific question, the habitats or the species to monitor, is not feasible, being also constraint by the necessity of a correct control and measures of diverses environmental and biological. Other methods are more adapted to landscape scale such as landscape ecology or the circuitscape.

The monitoring design is also function of the main objective of the monitoring that can be categorised into 3 types:

- Naturalist inventories: state of species populations, generally on a year-long survey period
- Monitoring / controlling: state of species populations on a long period of time (several years)

- Research studies: specific and detailed scientific questions

These three types of objectives induced different designs, mainly in terms of sophistication.

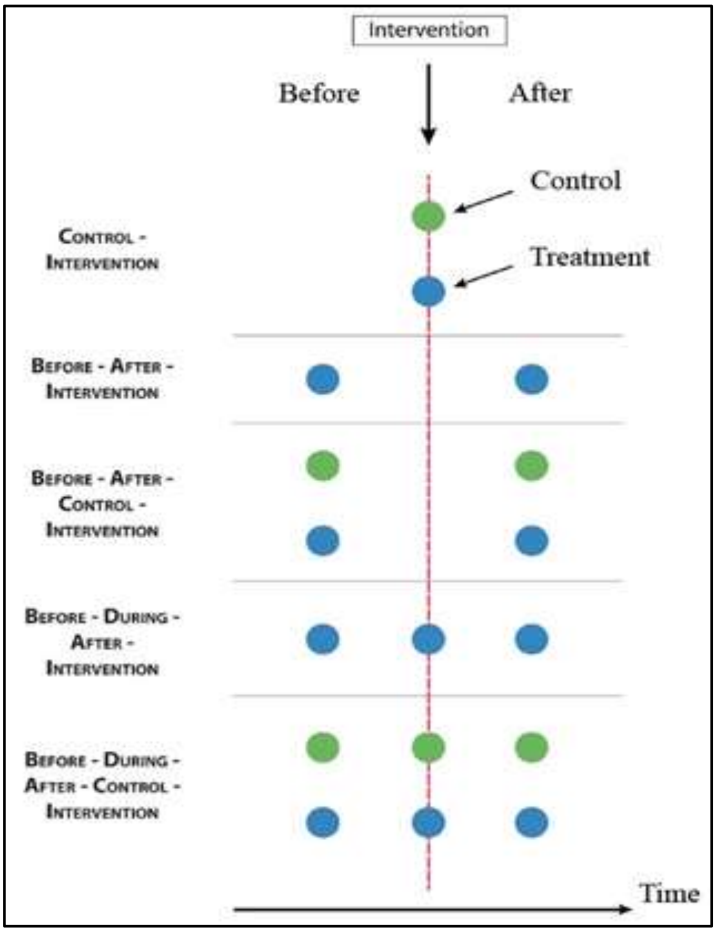


Figure 8.2: The several variants of schemes, from the less (Control Intervention -CI) to the most complete (BDACI) protocol. Source: UMS PatriNat, 2019, adapted by John Alertas.

Metadata about the monitoring informing at list WHO (realised it), WHEN (included frequency, and if possible effort in prospection), WHAT (species, group of species, habitats), WHERE and HOW (with which scheme, method, technique) (Fig. 8.3), in the database must be recorded. It provides crucial information to consider these data as comparable to other ones from different sites and surveys.

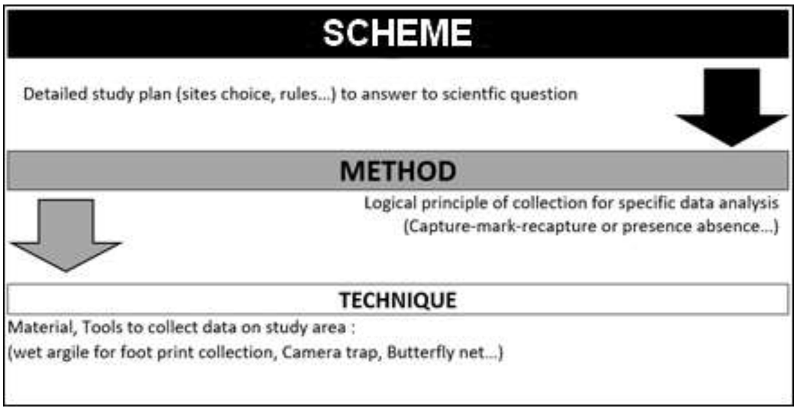


Figure 8.3: Scheme (= Protocol), method, technique definitions and organisation (Source: UMS PatriNat, https://campanule.mnhn.fr/concepts-et-definitions/, adapted by Cerema)

Recommendation:

In all cases, it is desirable to collect these data on an entire road network managed by a stakeholder, in a standardised way so that it can be reused in future similar studies [2] and [3], with the data being at least comparable across its network. Moreover, after the first control and possible modification cycle, the chosen schemes and methods must not be changed during the monitoring period in order to obtain comparable data throughout this period.

8.4. MAIN METHODS AND TECHNIQUES TO MONITOR AND EVALUATE BIODIVERSITY

There are many proven techniques for assessing biodiversity (wildlife more particularly) in the field of transport infrastructure (Tab. 8.1). The most frequently used technique is that of camera traps, as they provide an inexpensive way of finding out about the fauna crossing the infrastructure or using the wildlife crossing structures. Fauna can of course also be observed directly, using binoculars for example, or nets or dip nets, depending on the group to be surveyed. Observing indicators of presence (hair, footprints, etc.) is a simple and effective technique. For species that emit sounds, either audible or ultrasonic (bats, grasshoppers, etc.), audio recorders can be used to identify species, either by active listening while on site, or by passive listening by leaving the equipment in place for several hours or even several days. Techniques using environmental DNA are now inexpensive and allow a list of species to be obtained by simply taking a sample of water, soil or other elements of the environment.

Other more expensive techniques can be used. For example, thermal imaging cameras are very relevant, especially for understanding animal behaviour when approaching infrastructure. The use of drones, combined with cameras or thermal imaging cameras, is also a useful solution for surveying large species in a minimum of time. For very large species, radar or satellite images data can also sometimes be used.

Table 8.1: Summaries of some techniques for census by fauna taxonomic group. / : not relevant ; + : usable in specific situations but not suitable in most cases ; ++ : usable but other techniques may be more appropriate. +++ : highly suitable technique (Source: Cerema, adapted from a figure in Biodiversity and Infrastructure - A handbook for action (2023).

	Terrestrial inverterbrates	fishes and other aquatic animals	amphibians	Reptiles	Birds	Terrestrial mammals up to the the size of rabbit	Medium size mammals	large mammals	Otter and other semiaquatic animals	Mammals living on trees	Bats	Natural habitats	wildflowers
direct observation (with binocular or not)	+++	/	+++	+++	+++	+++	+++	+++	+++	+++	/	+++	+++
direct observation (nests)	+++	+++	+	+	+	++	/	/	++	/	+	/	/
direct observation (indicator of presence)	+++	+	++	++	+++	+++	+++	+++	+++	++	+++	+++	+++
camera trap (passive infrared sensor)	/	/	/	/	+ (large birds)	+	+++	+++	++	+++	+	/	/
camera trap (time lapse)	+	+	+++	+++	/	+++	++	+	+	+	/	/	/
Thermal camera	/	/	/	/	+	++	+++	+++	++	++	/	/	/
visual amplification techniques	/	/	++	++	++	++	++	+++	+	++	++	/	/
ultra-sensitive camera	+	/	++	++	+	+	++	++	++	++	++	/	/
drones	/	/	/	/	++	/	++	+++	/	/	/	/	/
mark and recapture markings	/	/	/	/	/	/	/	/	/	/	/	/	/
audio recording (audible)	+++ (only grasshopers)	+	+++	/	+++	+++ (if makes sounds often)	++ (if makes sounds)	++ (if makes sounds)	/	+++ (if makes sounds often)	+ (some species and social calls)	/	/
audio recording (ultrasound)	+++ (only grasshopers)	+ (+++ for marine mammals)	/	/	/	+	/	/	/	+	+++	/	/
radar techniques	++	/	/	/	++ (large birds)	/	+	+	/	/	/	/	/
satellite techniques	/	/	/	/	/	/	/	+	/	/	/	+++	+
environmental DNA	+	+++	+++	++	+	++	++	++	+++	+	+	/	+

NOTA FOR LMIC:

In countries where funds availability are low and the biodiversity data, other sources of informations such as concise landcover map, aerial and satellites pictures are rare, the monitoring design has to be adapted built with cheap tools and techniques that often provide poor quality or quantity of data. But this lack of data can be partly compensate by longer et stronger effort in prospection, i.e. doing longer transects and spending more time in the field study.

8.5. References

[1] Roedenbeck, I.A., Fahrig, L., Findlay, C.S., Houlahan, J.E., Jaeger, J.A., Klar, N., ... & Van der Grift, E.A., 2007. The Rauischholzhausen agenda for road ecology. Ecology and society, 12(1).

[2] Fagard, S., Quaintenne, G., Heurtebise, C. & Chavaren, P., 2016 Restauration des continuités écologiques sur autoroutes – Retour d’expérience des aménagements et des suivis faunistiques sur le réseau VINCI Autoroutes. https:// www.trameverteetbleue.fr/documentation/ references-bibliographiques/retour-experienceamenagements-suivis-faunistiques-sur

[3] Fagard, S., Vacher, J.-P., Chavaren, P., Quaintenne, G., Bourboulon, M. & Guinard, E. « Feedback on experience 2: Wildlife structures and monitoring on the VINCI Autoroutes network, 2023 ».

Case studies appendix

How to evaluate barrier effects (France)

How do we monitor in Canada?

Example - Disturbance at the Voleč ecoduct (Czech Republic)

Inuvik Tuktoyaktuk Highway (Northwest Territories - Canada)

The Rt. Hon. Herb Gray Parkway (Ontario, Canada): A Parkway in a Prairie

9. PERSPECTIVE & CONCLUSION

In the field of biodiversity monitoring techniques, technological innovations offer tremendous perspectives for gaining a better understanding of nature conservation issues. The miniaturisation of equipment will make it easier to conceal all kinds of sensors near transport infrastructures. The control of energy consumption will make it possible to keep these sensors in operation for longer. Artificial intelligence will make it easier to automatically recognise species taken in photos by camera traps or recorded by audio recorders. These automatic recognitions can be carried out directly in the data acquisition device, thus allowing easy data transmission thanks to a very limited file size and GSM[5] data transmission systems.

These large datasets offer new perspectives in the field of predicting population trends as a function of environmental parameters. Much progress has been made in recent years in modelling the evolution of the presence and distribution of species. This modelling is based on machine learning by making a program capable of learning from example data without being programmed. Once an algorithm has been implemented, the machine can learn and predict specific phenomena and become richer as it receives new data. They can now be described as 'intelligent' systems.

In France, Cerema was associated in 2022 with the french research centre in Ecology and Evolutionary Ecology (CEFE-CNRS) to build a statistical model capable of predicting road mortality at a relevant spatial scale to inform regional road network managers. This was achieved by incorporating environmental variables such as the presence of certain species groups, roads, and mortality data from opportunistic and protocol data into the model.

This type of modelling, which often requires large datasets, can be extremely relevant for assessing the impacts of an infrastructure on biodiversity. In addition to innovative inventory techniques, it is also useful to focus on concepts that are increasingly used in conservation ecology and that should be increasingly integrated to any assessment of the impact of an infrastructure on biodiversity. We will mainly talk here about research related to eco-ethology but also about new fields of research such as the ecology of fear, the ecology of movement...

Eco-ethology, also known as behavioural ecology, studies what behaviour an animal chooses to maximise its chances of survival and reproduction in a given environment. This discipline is therefore a major tool in the restoration of biodiversity because it allows the link to be made between the pressures linked to human activities and the chances of survival of an animal population.

When assessing the impact of an infrastructure on biodiversity, or assessing the effectiveness of a structure to restore ecological continuity, it is important to gather as much information as possible on the target species, such as their life traits and their behavioural adaptations to their environment. This exercise can sometimes be difficult because knowledge of both the ecology of the species and their behaviour is often fragmentary. Furthermore, the variability of behaviour

[5] GSM: **abbreviation for global system for mobile telecommunications**: a technical system for mobile phones used in many countries: The phone company has placed a large order for GSM network equipment (source: Cambridge dictionary)

within species must be taken into account. There are reckless individuals who will facilitate the dispersal of genes, and others who are more fearful. It is also important to take into account exceptional phenomena such as storms or floods, which can have major consequences both in terms of habitat modifications and of the ability of individuals to move.

A new process to rank and organise the route position of a road project is to be developed. The innovation is to build a biodiversity stake ranking map from a natural habitats map on the area concerned by this project. Some countries have a large amount of biodiversity data and are homogeneous enough to establish a probability of presence of the most sensitive species in each natural habitat of an area concerned by a road project. The number and the sensitivity level of the species living or potentially living in natural habitats determine the biodiversity stake level of these habitats that can be mapped. This map will provide a:

- high biodiversity stakes sites to be avoided by the road project, that can be obtained very soon during design phase (if the natural habitat map is available) with a nearly homogeneous level of knowledge about biodiversity on a short period of time
- inventory strategy on the area (to validate the potential high-stake areas), prioritising the duration of inventories, the target species and of their position, all determined by the quality of the knowledge available and the sensitivity of the species that potentially live there

The reliability of this method is conditioned by the quality and the amount of the data available in the country and the region. The geographical distribution of the knowledge on fauna and flora species and also natural habitats must not be too heterogeneous in the study area and should not include too many zones without data.

As described in this report, there is a "global infrastructure tsunami" planned for the coming decades; another 25 million km of paved roads are planned for construction by 2050, set in a century of global climate and biodiversity crisis. Immense development is specifically expected in LMICs, where – due to the lower level of development – large valuable natural areas are still intact at the moment. Linear transport infrastructure causes habitat loss and fragmentation, which are among the most severe biodiversity threats, impacting populations of wild living animals and causing - in the long term - population decline, degradation and extinction. Therefore, nature values have to be taken seriously into account right from the beginning of infrastructure planning, especially in areas with so far almost untouched natural areas.

The main recommendations to develop infrastructure in the most sustainable way are:

- Do it right from the beginning! Avoid to repeate the mistakes already done!
- Use the existing knowledge and experiences!
- Monitor and correct errors
- Aim for binding strategic and spatial plans (joining Green and Grey Infrastructure)
- Aim for good cooperation between different stakeholders (especially other linear infrastructures and spatial planning)

Aim for good cooperation between environmentalists and technicians (right from the beginning!)

There are ways to avoid, mitigate or compensate for the negative impacts of linear transport infrastructure. There is a lot of knowledge, best practices, lessons learned, success stories and failures. To reduce the impacts of these planned 25 million km of paved roads, we have to learn from the experience, the successes but also the mistakes made globally so far.

This report and case studies appendix is an attempt to help to use the most sustainable way for this planned development. The lack of LMIC case studies is a real gap in this report, one of the aim of TC3.4 next cycle should be to collect several of these case studies to propose a short note to complement this report.

10. FURTHER READING

10.1. HANDBOOKS

- 'Wildlife and Traffic' Handbook original printed edition (see Case studies appendix Chapter 9):
  - Iuell, B., Bekker, G.J., Cuperus, R., Dufek, J., Fry, G., Hick, C., Hlavác, H., Keller, V., Rosell, C., Sangwine, T. Torslov, N., Wandall, B. 2003. Wildlife and Traffic. A European Handbook for Identifying Conflicts and Designing Solutions. KNNV Publishers.
- And new online edition (in prep.):
  - Rosell, C., Seiler, A., Chrétien, L., Guinard, E., Trocmé, M., Hlavac, V., Hofland, A., Mot, R., Reck, H., Sangwine, T., Sjolund, A., Georgiadis, L., Hahn, E., Bekker, H., Bíl, M., Böttcher, M., O'Malley, V., Autret, Y., van der Grift, E. (Eds)., 2023. *Biodiversity and Infrastructure. A handbook for action. IENE - Infrastructure and Ecology Network Europe*. https://biodiversityandinfrastructure.org/
- Retour d'expérience des aménagements et des suivis faunistiques sur le réseau VINCI Autoroutes – Rapport, 2016: (language: French) https://www.trameverteetbleue.fr/documentation/references-bibliographiques/retour-experience-amenagements-suivis-faunistiques-sur.
  (see Chapter 7- Reference n°2).

  A new edition is available since April 2023, in French: "Retour d'expérience n°2 des aménagements et des suivis faunistiques sur le réseau VINCI Autoroutes, 2023" and in English « Feedback on experience 2: Wildlife structures and monitoring on the VINCI Autoroutes network, 2023 », https://www.trameverteetbleue.fr/documentation/references-bibliographiques/retour-experience-ndeg2-amenagements-suivis-faunistiques.

- The originality of this work from Vinci-Autoroutes french motorway stakeholder is a review of the experience of a latest generation motorway (A89 south of France) and of the restoration of ecological transparencies on the most important French motorway network, within the framework of a procedure called Paquet Vert Autoroutier (PVA), the "biodiversity" component of which aims at restoring the ecological disruptions generated by the motorways in service.

- **Cerema publications** (France):
  We have chosen 3 recent handbooks published by the Cerema (see all publications (some are translated in English) on biodiversity topics here: https://www.cerema.fr/fr/centre-ressources/boutique/general?boutique%5B0%5D=thematique%3A5075&keyword=&ref=&sku=&isbn=)
  - ***Permettre à la faune de franchir les infrastructures linéaires de transport - Exemples de requalifications d'infrastructures*** The aim of this book is to present a methodology for restoring ecological transparency by illustrating it with numerous case studies of projects throughout the country. It is intended for project owners and project managers to assist them in restoring the ecological transparency of their Linear Transport Infrastructures (LTI) in a sustainable manner. Available here:https://www.cerema.fr/fr/centre-ressources/boutique/permettre-faune-franchir-infrastructures-lineaires-transport

- ***Passages à faune - Préserver et restaurer les continuités écologiques avec les infrastructures linéaires de transport*,**. Reducing the impact of terrestrial transport infrastructures on biodiversity means maintaining existing ecological continuities when designing new projects and restoring ecological functions that were previously interrupted. This comprehensive guide is intended for infrastructure operators and, more broadly, for all those concerned by the preservation of biodiversity. Available (in French and in English) here: https://www.cerema.fr/fr/centre-ressources/boutique/passages-faune
- ***Linear transport infrastructures and Reptiles*** - Application to three significant protected species. This document, illustrated with 3 species of reptiles and a few examples of road impact reduction measures, also aims to enable a project stakeholder, designer or decision maker to assess the various measures of the ERC doctrine that must be implemented in order to best preserve reptiles.

10.2. The basic Principles for Sustainable Transport and other Linear Infrastructure (LTI)

Basic Principles for Sustainable Transport and other Linear Infrastructure (LTI) (see Case studies appendix Chapter 9).

10.3. Web sites and other sources of information

In this section are indicated the main worldwide sources of information (handbook, website links…)

https://ipbes.net/global-assessment:

IPBES is to perform regular and timely assessments of knowledge on biodiversity and ecosystem services and their interlinkages at the global level. Also addressing an invitation by the Conference of the Parties of the Convention on Biological Diversity (CBD) to prepare a global assessment of biodiversity and ecosystem services building, inter alia, on its own and other relevant regional, subregional and thematic assessments, as well as on national reports.

https://europabon.org/?page_id=2513 :

The EuropaBON monitoring database explicitly describes current workflows of monitoring efforts delivering biodiversity information in Europe (monitoring networks). This database maps how biodiversity data collected in monitoring schemes across Europe flows through different institutions and programs and gets processed to produce Essential Biodiversity Variables (EBVs), Essential Ecosystem Services Variables (EESVs) and other EU policy-relevant indicators. Some examples of EU level biodiversity data workflows are the reporting of the Habitats and the Water Framework Directives, the Wild Bird Indicators produced in the Pan-European Common Bird Monitoring Scheme or the European grassland butterfly indicator produced in the European Butterfly Monitoring Schemes.

https://handbookwildlifetraffic.info/transport-ecology-guidelines-portal/?fwp_category=publications

As well as the old Cost341 Wildlife and Traffic, you will find in this IENE website the main last handbooks and guides from many European countries...

https://www.biodiversityinfrastructure.org/

…and its new “web edition” : Biodiversity and Infrastructure. A handbook for action (2023). IENE - Infrastructure and Ecology Network Europe.

https://transportecology.info/

Untitled “Quantifying and mitigating the ecological impacts of linear infrastructure and traffic”, this website provides for practitioners as well as researchers “A globally-relevant open access resource to share information, knowledge and experience in ecologically-friendly transport planning and management.”

https://portals.iucn.org/library/node/51263

Complete Title: « Addressing ecological connectivity in the development of roads, railways and canals »
Published on August 2023, this IUCN technical report provides good and clear explanations of the differents items and processes dedicated to ecological continuities preservation and mitigations from linear transports infrstructures impacts. , with interesting case studies.

11. GLOSSARY

This glossary is an extract of the PIARC Road Dictionary (https://www.piarc.org/en/activities/Road-Dictionary-Terminology-Road-Transport). These additional terms related to road ecology issue have been included in the PIARC Road Dictionary. Their definitions were taken from the BISON / IENE Glossary and TC 3.4 WG 3 work, which constitutes the third deliverable with the Full Report and the collected Case Studies (in the separated Appendix of the Full Report).

Term	***Definition***
abiotic	*Relating to things in the environment that are not living*
association	*In ecology, a group of organisms (plants and animals) that live together in a certain geographical region and constitute a community with a few dominant species*
biotic	*Involving, caused by, or relating to living things in the environment*
bioaccumulation	*The accumulation over time of a substance and especially a contaminant (such as a pesticide or heavy metal) in a living organism*
biodiversity	*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 as the processes linking ecosystems and species. Synonym: 'Biological diversity'*
Biodiversity Net Gain (BNG)	*Biodiversity Net Gain an approach to development and land management that aims to leave the natural environment in a measurably better state than it was beforehand*
compensation measure	*Measure or action taken to compensate for a residual adverse ecological effect which cannot be satisfactorily mitigated. See also 'Mitigation'*
conservation	*The protection or wise use of natural resources that ensures their continuing availability to future generations; the intelligent use of natural resources for long-term benefits*
ecology	*The science (branch of biology) of the relationships between organisms and their environments. Also the advocacy of protection of the air, water, and other natural resources from pollution or its effects; environmentalism*

Term	**Definition**
ecosystem	*Dynamic complex of plant, animal and micro-organism communities and their non-living environment, interacting as a functional unit*
ecosystem services	*Benefits provided to society by ecosystems. They are usually classified as provisioning (for example the production of food and water), regulation or maintenance (such as the control of climate, nutrient cycles…), and cultural, which includes the non-material characteristics of ecosystems that affect the physical and mental states of people*
environmentally responsible transportation	*Transportation options that minimise environmental impact such as mass public transportation (light rail, subway, electric/hybrid/biodiesel/buses) and electric/hybrid vehicles*
evaluation	*The process of judging or calculating the quality, importance, amount, or value of something*
fragmentation	*The breaking up of a habitat, ecosystem or land use unit into smaller parcels*
greenfield	*Undeveloped land or land that has not been impacted by human activity*
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*
invasive alien species	*Animals and plants that are introduced accidentally or deliberately into a natural environment where they are not normally found, with serious negative consequences for their new environment. These species are subject to common action at a European Union level under the European regulation and included on the 'List of invasive alien species of Union concert'. See also 'Alien Species'*
mitigation	*Action or activity intended to remedy, reduce the severity of, eliminate or offset known adverse negative impacts to the environment. For infrastructures of transport, it means measures to eliminate, reduce, control or offset the adverse effects of a project or designated project, and include restitution for any damage caused by those effects through replacement, restoration, compensation or any other means.*

Term	***Definition***
(grey) network	*Grey infrastructure refers to purely technical, built infrastructure elements in cities and settlement areas. These include roads, railways, water supply and disposal facilities, energy supply and waste disposal (see: https://www.forschungsinformationssystem.de/servlet/is/518193/#:~:text=Graue%20Infrastruktur%20bezeichnet%20rein%20technische,-e)* *Grey infrastructure involves engineered assets that provide one or multiple services required by society, such as transportation or wastewater treatment. (International Institute for sustainable development)* *(see: https://www.iisd.org/savi/faq/what-is-grey-infrastructure/)* *Familiar urban infrastructure such as roads, sewer systems and storm drains is known as 'grey infrastructure'. Such conventional infrastructure often uses engineered solutions typically designed for a single function (see: https://websites.fraunhofer.de/CIPedia/index.php/Grey_Infrastructure)*
(trophic) network	*A succession of organisms in an ecological community that are linked to each other through the transfer of energy and nutrients, beginning with an autotrophic organism such as a plant and continuing with each organism being consumed by one higher in the chain. A set of interconnected food chains within an ecosystem. A synonym for food chain.* *A chain or trophic network is an ecological term describing the different participants involved in a process of production and consumption of food.* *- Trophic: describes everything relating to the nutrition of a living tissue or organ.* *- Trophic relationship: is the link that unites a predator and its prey in an ecosystem.*
No Net Loss (NNL)	*'No Net Loss' is a goal for a development project, policy, plan or activity in which the impacts on biodiversity it causes are balanced or just weighed by measures taken to avoid and minimise the impacts, to restore affected areas and finally to offset the residual impacts, so that no loss remains.*

Term	***Definition***
phenology	*The study of phenomena or happenings. It is applied to the recording and study of the dates of recurrent natural events (such as the flowering of a plant or the first or last appearance of a migrant bird) in relation to seasonal climatic changes. Phenology thus combines ecology with meteorology.* *The weather factor that has the greatest influence on recurrent events in temperate climates is almost always temperature; in tropical areas it may be rainfall, humidity, or some other factor. The length of day, which fluctuates throughout the year but is always the same in a single locality on the same date in every year, often determines the average date of natural events but not their variation from year to year. With resident species, these local events are influenced by previous weather conditions in the area; with migrant animals, dates of arrival are affected more by conditions at the start of and during their migrations.* *In addition to comparisons of the same event in different years in one locality, phenology is also concerned with studies of the times of the same event in different localities in the same year (when differences of geographic position, soil, slope, shelter, etc., are involved) and of the sequence of different events in one locality during the annual cycle of climatic and biological changes. Phenological observations are of importance to farmers and gardeners and to beekeepers who want to know when nectar-secreting flowers are at their peak production. The best date for spraying for insect pests, particularly of fruit trees in the spring, is determined by the state of development of the leaf and flower buds, which varies from year to year. The study and application of this is a branch of phenology. Phenological records also have medical applications: they are used to assess the flowering seasons of plants whose pollens cause hay fever, for example.*

species	*In biology, classification comprises related organisms that share common characteristics and are capable of interbreeding. This biological species concept is widely used in biology and related fields of study. There are more than 20 other different species concepts, however. Some examples include the ecological species concept, which describes a species as a group of organisms framed by the resources they depend on (in other words, their ecological niche), and the genetic species concept, which considers all organisms capable of inheriting traits from one another within a common gene pool and the amount of genetic difference between populations of that species. Like the biological species concept, the genetic species concept considers which individuals are capable of interbreeding, as well as the amount of genetic difference between populations of that species, but it may also be used to estimate when the species originated.*

List of chapters with their case studies in the Appendix part

Chapters with case studies in the Appendix part	**Case studies title**
4. REGULATIONS / LAWS	- *Regulations in European Union* - *Regulations in Canada* - *Regulations in Japan*
5. STUDY MANAGEMENT DURING THE LIFECYCLE OF ROAD INFRASTRUCTUR	- *Protection of migration corridors in spatial planning in the Czech Republic* - *Spatial Planning – the crucial tool* - *Good and bad examples from Austria* - *Detailed environmental processes in life cycle phases of road projects in Europe* - *Planning stages / construction / operation (maintenance) in Canada* - *Detailed environmental processes planning of road projects in Japan*
6. OVERVIEW OF MITIGATION MEASURES FOR FAUNA, FLORA AND NATURAL HABITATS	- *Wildlife Mitigation and Road Infrastructure in Canada* - *Improving road safety by judiciously extending large wildlife exclusion fences and adding wildlife crossings in the right-of-way of a national highway near the Quebec City area, Canada* - *Migration Study of Selected Animal Species on Operated Sections of Motorways, Expressways and Selected 1st Class Roads (HBH, 5/2017) (Slovakia)* - *Project LifeSaveCrossings (EU)* - *EU Defragmentation Map* - *Defragmentation Programme Netherlands* - *Defragmentation Programme Austria*
7. MONITORING / EFFICIENCY EVALUATION	- *How to evaluate barrier effects (France)* - *How do we monitor in Canada?* - *Example - Disturbance at the Voleč ecoduct (Czech Republic)* - *Inuvik Tuktoyaktuk Highway (Northwest Territories - Canada)* - *The Rt. Hon. Herb Gray Parkway (Ontario, Canada): A Parkway in a Prairie*

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