Documents for the mitigation of habitat fragmentation caused by transport infrastructure

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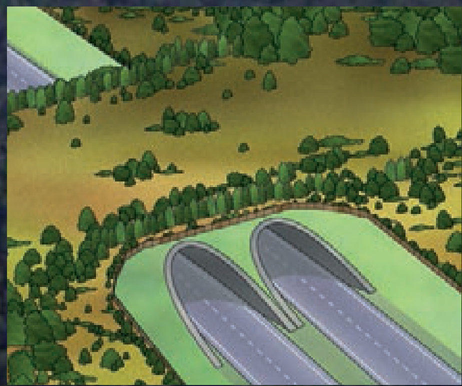
TECHNICAL PRESCRIPTIONS FOR WILDLIFE CROSSING AND FENCE DESIGN (SECOND EDITION, REVISED AND EXPANDED)



GOBIERNO DE ESPAÑA
MINISTERIO DE AGRICULTURA, ALIMENTACIÓN Y MEDIO AMBIENTE

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Contents

1 Presentation

1.1 Background

In recent decades, remarkable progress has been made in the study and prevention of impacts by transport infrastructure on the natural environment. Roads and railway lines are amongst the greatest threats to biodiversity conservation in Europe, as they act as barriers to wildlife movement and generally intensify **habitat fragmentation**.

The barrier effect of roads not only affects the natural environment. It also has serious **road safety** implications due to wildlife-vehicle collisions (WVC) with large mammals at points where roads intersect corridors between ecological networks, which concentrate wildlife movements.

To develop **safer transport networks** with **minimal impact on wildlife** is the goal of many research and monitoring projects. Monitoring and research has improved knowledge about the mechanisms involved in these impacts and the measures that can be applied to minimize them. In Europe, the basis for the integration of knowledge on this issue was the COST 341 Action (1999-2003). This scientific and technological cooperation project, an initiative of the European Commission and the *Infra Eco Network Europe*, led to the compilation of a large amount of information on these aspects, collated in the document *Wildlife and Traffic. A European handbook for identifying conflicts and designing solutions* (Iuell et al. 2005), which sets out the common guidelines defined by experts from different countries on the basis of the results of pilot projects.

Spain participated in the COST 341 project via its **Working Group on Habitat Fragmentation caused by Transport Infrastructure**, promoted by the National Committee on the Natural Heritage and Biodiversity. In 2006, this group published the first edition of the present document, *Technical Prescriptions For The Design Of Wildlife Crossings And Fencing*, which was also the first volume of a series entitled *Documents for the mitigation of habitat fragmentation caused by transport infrastructure*, six volumes of which have now been published. This document was drafted on the basis of the COST 341 handbook, but it also included information from Spain's first monitoring projects and publications on the issue. The format of the document was quite different from the European handbook. It presented the information in file format, with numerous diagrams and graphics to facilitate the implementation of the technical prescriptions by those responsible for road and railway infrastructure design and environmental impact assessment (EIA).

The publication of this document was a milestone incentive for the construction of wildlife crossings. It was a point of reference for the elaboration of draft measures and impact statements milestone environmental (EID) and helped to reduce the barrier effect and wildlife mortality in linear transport infrastructure. Hundreds of wildlife crossings based on this technical document have been built throughout Spain, helping to intensify to ecological connectivity and reduce the effects of habitat fragmentation caused by roads and railway lines. These structures are key components of the 'green infrastructure', defined by the European Commission as a strategically planned network of high quality natural and semi-natural areas in combination with other environmental elements, designed and managed to provide a wide range of ecosystem services and safeguard biodiversity.

1.2 Rationale

Ten years after the publication of the first edition of this document, an update was considered necessary in the light of the large amount of new information now available on measures aimed at mitigating habitat fragmentation. Over the years, measures aimed at reducing the impacts of transport infrastructure on wildlife have been implemented throughout Europe. There is now a large amount of published literature, and significant progress has been made in the diagnosis of new conflicts, assessment of the effectiveness of measures in place and the implementation of new technologies and materials. In the same period, more than a dozen international conferences have been held on ecology and transport in Europe, the USA and Australia. In Spain, four seminars on the same issue have been held, where a large amount of information about new measures and innovative concepts has been presented.

In this context, the publication of an updated document is justified by the need to modify the contents to reflect current knowledge and good practices, and to provide renewed encouragement for the most effective measures that mitigate the barrier effect and roadkill, and at the same time, avoid unnecessary costs associated with the implementation of measures that are ineffective, unproven or inadvisable in the light of monitoring at sites where they have been implemented.

1.3 Scope

This document is primarily applicable to studies and projects for new road and railway infrastructure, and the improvement of existing ones. In particular, it is intended for use in prior information studies and their corresponding environmental impact studies (EIS), and projects for corrective measures to be included in their design and construction. It is also applicable to other aspects of land planning and management related to linear transport infrastructure such as urban development, planning and management of protected natural areas, other green infrastructure, and habitat defragmentation initiatives aimed at mitigating the barrier effect and roadkill.

This document does not cover the measures to be applied during the pre-planning stages covered by strategic environmental assessments, which include the choice of the route alignment (discussed in Document 3 of the series, *Technical prescriptions for the mitigation of habitat fragmentation in planning and routing*, published in 2010), or impact compensation measures. Nor does it cover every aspect construction-related aspect or the environmental monitoring after the road comes into operation —part of the environmental monitoring program (EMP), in-service environmental monitoring, or the assessment of the effectiveness of the measures, covered in Document 2, *Technical prescriptions for monitoring and evaluating the effectiveness of corrective measures to mitigate the barrier effect of transport infrastructure*, published in 2008. The issue of defragmentation aimed at mitigating the barrier effect of operating infrastructure is addressed in Document 5, *Defragmenting habitats. Guidelines to mitigate the effects of roads and railways in operation*, published in 2013.

1.4 Objectives

This document contains technical prescriptions for the design of wildlife crossings and fencing that facilitate wildlife movements across roads and railway lines and mitigate road safety hazards.

In addition to the compulsory prescriptions, the document also makes recommendations for the enhanced effectiveness of these measures and alternative designs or adjustments that optimise the adaptations to different landscape contexts, ecological connectivity requirements and the sensitivity of each species. Decisions about crossing density, location and size should be based on these technical prescriptions, and adapted to each situation. They should be taken in conjunction with project, construction and transport route managers, wildlife, ecology and habitat restoration experts.

1.5 Users

This document is addresed to professionals involved in the planning, design, construction, maintenance and operation of roads and railway lines, and also technicians involved in the environmental assessment and monitoring of linear infrastructure works.

It may also be useful for professionals involved in wildlife and biodiversity conservation, urban planning and landscaping. Finally, it may be of interest as a point of reference for undergraduate and post-graduate students working on these issues and civil engineering as well.

2 General aspects and frame of reference

2.1 Background information used to draft this document

The information included in the first edition of this document was essentially based on *Fauna y Wildlife and Traffic. A European handbook for identifying conflicts and designing solutions* (Iuell et al. 2005), drafted under the European COST 341 project '*Habitat fragmentation caused by transport infrastructure*'. The technical prescriptions contained in Chapter 7 of this manual ('*Wildlife crossings and other technical solutions*') was the basic source of information for the first edition of the document, whose proposed measures were drafted on the basis of the results of monitoring and evaluations of their effectiveness in several European countries, defined by a team of public works, ecology and wildlife management experts in various organizations from sixteen European countries, and the Infra Eco Network Europe organization, the promoter of the project. The information provided by Spain was based on the experience of the members of the Working Group on habitat fragmentation caused by transport infrastructure.

For the present edition of the document, this information has been expanded on the basis of a comprehensive review of:

- Literature on measures aimed at preventing impacts of road and rail infrastructure on wildlife, as well as the prevention of accidents caused by animals.

- Ph.D. theses and monographs on the same issue, some unpublished, drafted in several European countries.

- Communications at Spanish conferences organised by the Working Group on habitat fragmentation caused by transport infrastructure.

- Communications at subsequent biennial international conferences:

– *ICOET - International Conference on Ecology & Transportation.*

– *IENE Conference on Ecology and Transportation.*

– *AENET International Conference Australasian Network on Ecology and Transportation.*

- Results of studies and monitoring projects, particularly in Spain, on monitoring measures taken to reduce impact on wildlife, conducted on highways and high speed railway lines.

- Manuals and technical regulations published in other European countries, including the recently published *Handbook of Road Ecology* (Van der Ree et al 2015), the first one with a worldwide scope.

2.2 Effects of road infrastructure on wildlife and habitats

Habitat fragmentation caused by transport infrastructure is the result of a several effects and processes that are summarized in detail in Document 4 *Indicators of habitat fragmentation caused by linear transport infrastructure*, which include:

- Habitat loss.

- Habitat size reduction.

- Edge effects: pollutants, noise, light pollution, anthropic frequentation and other processes that cause a loss of habitat quality.

- Side effects: the creation of new habitats, funnelling of animal movements, proliferation and spread of exotic species, etc.

- Filter and barrier effects.

- Wildlife roadkill and other infrastructure-related mortality.

- Induced urban development.

The measures included in this document concerned with these effects are primarily aimed at reducing roadkill and the risk of accidents caused by wildlife, and mitigating the barrier effect of roads and railway lines (see section 3.1 for more information).

2.3 Reducing impacts at different stages of infrastructure lifecycle

2.3.1 Impact prevention, correction and compensation: basic concepts

The measures presented in this document are primarily intended for the correction of impacts and their application when drafting information studies or alignment projects and the corresponding impact mitigation projects. This section contains an overview of the context for the different types of measures aimed at minimizing the environmental impacts of infrastructure, which can be classified as preventive, corrective or compensatory, depending on their basic purpose.

Preventive measures

Preventive measures can be applied at any stage of the infrastructure's lifecycle. However, the most serious impacts can be prevented by a careful choice of the route or the choice of an alternative transport mode that may even circumvent the need to construct a new road or railway line.

This work is done at the road or railway line planning stage as part of the land and spatial planning (plans and programmes related to transport routes), and also during the strategic environmental assessment. Other key stages for the prevention of impacts are the route design, the drafting of the informative study, the detailed alignment design project and the environmental impact assessment. The main aim during these stages prior to the final construction project is to prevent the main types of impact which may significantly affect or disturb particularly sensitive habitats and landscapes which are valuable on account of their natural state, their uniqueness or their rarity, or impacts which may pose a threat to the conservation of local populations of a particular species. It is also essential to prevent effects on areas of major importance for ecological connectivity which might not contain particularly relevant habitats, but may be of strategic importance for facilitating wildlife movements between habitat patches that would be hindered in the absence of these dispersal corridors.

Mitigation measures

Mitigation measures are aimed at minimizing impacts that could not be fully prevented. They include most of the measures described in this document aimed at reducing traffic hazards caused by large mammals-vehicle collisions, minimizing the barrier effect and reducing mortality caused by the infrastructure and its traffic. Most of the corrective measures are defined in the informative study and the project design, particularly in the environmental impact assessment process, covered by the Environmental Assessment Act 21/2013, of December 9, in force at the time of publication of this document, and the current regional legislation covering the same issue. The Environmental Impact Declaration (EID) issued by the respective authorities are based on the diagnosis and assessment of impacts set out in the environmental impact studies (EIS). These are basic tools for ensuring that the construction projects include the measures designed to minimize impacts. The EID and EIS must therefore define in the most specific possible terms the type and location of wildlife crossings needed to permeabilize the road, and the fences needed to funnel the wildlife towards these structures.

Compensatory measures

These measures, used to offset impacts that could not be fully mitigated, have been imple-

Examples of ecological connections (a watercourse and hedgerows in cropland) that funnel wildlife movements through a territorial matrix. Photos: C. Rosell. Cos Agents Rurals, Government of Catalonia.

mented more widely on the basis of Article 6 of the Habitats Directive 92/43/EEC, which obliges the application of impact compensatory measures in the case of projects that affect areas in the Natura 2000 network. This possibility is only permissible if the project must go ahead for imperative reasons of overriding public interest, where there are no other alternatives to implement the plan or project that might not affect elements of the Natura 2000 network, whose overall coherence can be guaranteed by the application of these compensatory measures.

The aim of these measures is to ensure full compensation for the loss or disturbance of habitats by replacing the area of the eliminated or disturbed habitats with an equivalent area of high quality habitats which perform similar functions. In practice, this aim is very difficult to achieve, all the more so in the case of alternative habitats expected to play a key role such as facilitating wildlife movements through them. These types of measures, with little guarantee of success in the case of Natura 2000 Network sites, should therefore be exceptional and restricted to a minimum, with the utmost priority placed on preventing effects on such zones, as stated in the Directive.

2.3.2 Action to be taken during an infrastructure lifecycle

The design and construction of wildlife crossings and fences lie within the broader framework of steps aimed at minimizing the impact of roads and railways on the natural environment, implemented at any point in an infrastructure's lifecycle, from the initial planning stage to its operation (see chart on the next page).

The design of the measures aimed at making the infrastructure permeable to wildlife lies primarily within the context of the environmental impact assessment, which is usually done on the basis of the informative study or the alignment planning project, and is completed during the detailed design of the measures and the execution of the construction project. The descriptive files containing the technical prescriptions for the construction of wildlife crossings and fencing are particularly useful at these stages.

2.3.3 Maintenance, monitoring and evaluation of effectiveness

In order to ensure the effectiveness of the measures designed to mitigate impacts, their construction must be closely monitored, they must be well maintained and their effectiveness must be assessed once they are operative.

Environmental monitoring and control during construction

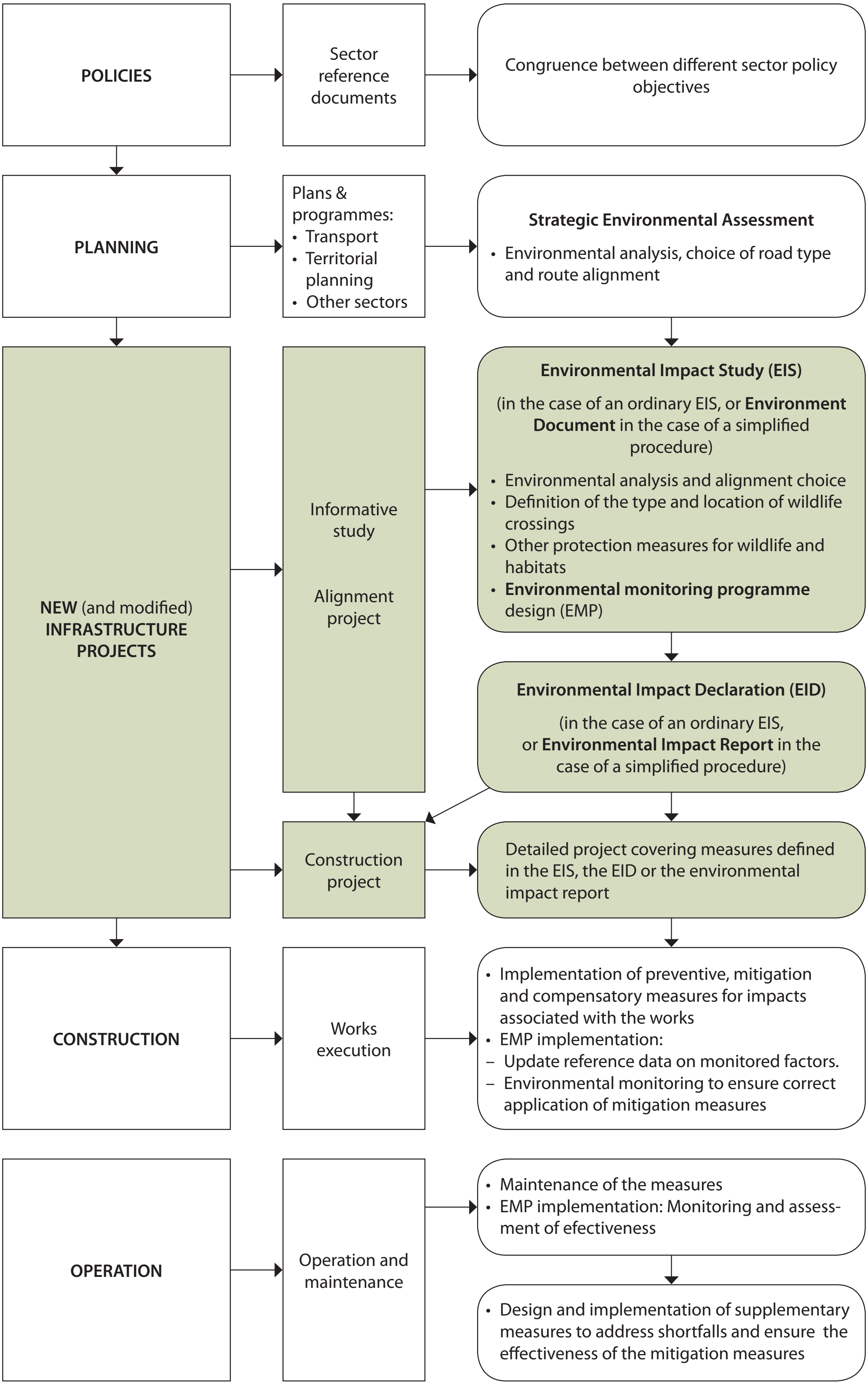
Monitoring during construction is part of the Environmental Monitoring Programme (EMP). It is crucial to ensuring that the measures are properly installed or built. The EMP also facilitates the application of impact preventive measures during this stage (earth movement, noise, blasting, etc.).

Maintenance of the measures

Maintenance once the infrastructure is in operation is essential to ensure that the measures are effective. Maintenance of wildlife crossings and fences includes aspects such as conservation of vegetation at the entrances and on the surface of the crossing, repairs to broken mesh, etc. The timetable for these checks and maintenance tasks must be included in the overall infrastructure maintenance plan to ensure the long-term operativity of the measures.

Monitoring and evaluation of effectiveness

Monitoring and assessment of the effectiveness of the measures is another key aspect. It helps experts to decide whether the measures have been implemented or constructed properly, and also to design and apply any necessary improvements. The description of the detailed environmental monitoring programmes and methods and techniques aimed at defining the variables and standards for the evaluation of the effectiveness of measures lies beyond the scope of this document. These aspects are discussed in detail in Document 2 of the series, *Technical prescriptions for monitoring and evaluating the effectiveness of mitigation measures for the barrier effect of transport infrastructure*.



Actions aimed at assessing and minimising environmental impacts, in particular those that affect wildlife species and their habitats throughout the linear transport infrastructure lifecycle. The project stage (highlighted in green) is the relevant context for the implementation of the measures described in this document.

3 Catalogue of technical measures and prescriptions

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3.1 Basic purpose of the measures included in this document

The measures set out in this document essentially focus on two objectives (see chart on the next page):

a) To create connections between habitats fragmented by infrastructures in order to facilitate wildlife movements and ecological connectivity

This goal can be achieved by constructing or adapting structures used exclusively by wildlife, set transversally to the road or railway line, or by sharing the wildlife crossing with other uses such as drainage or forestry or livestock tracks. This document describes eleven types of wildlife crossing (Files 1 to 11), four overpasses and seven underpasses. Six of them are exclusively for wildlife, while the rest are shared, with recommendations on their adaptation for use by wildlife. Some of the structures (particularly ecoducts, wildlife overpasses and modified viaducts) facilitate the physical continuity between habitat fragments severed by infrastructure, and thus permit the conservation or restoration of ecological connectivity.

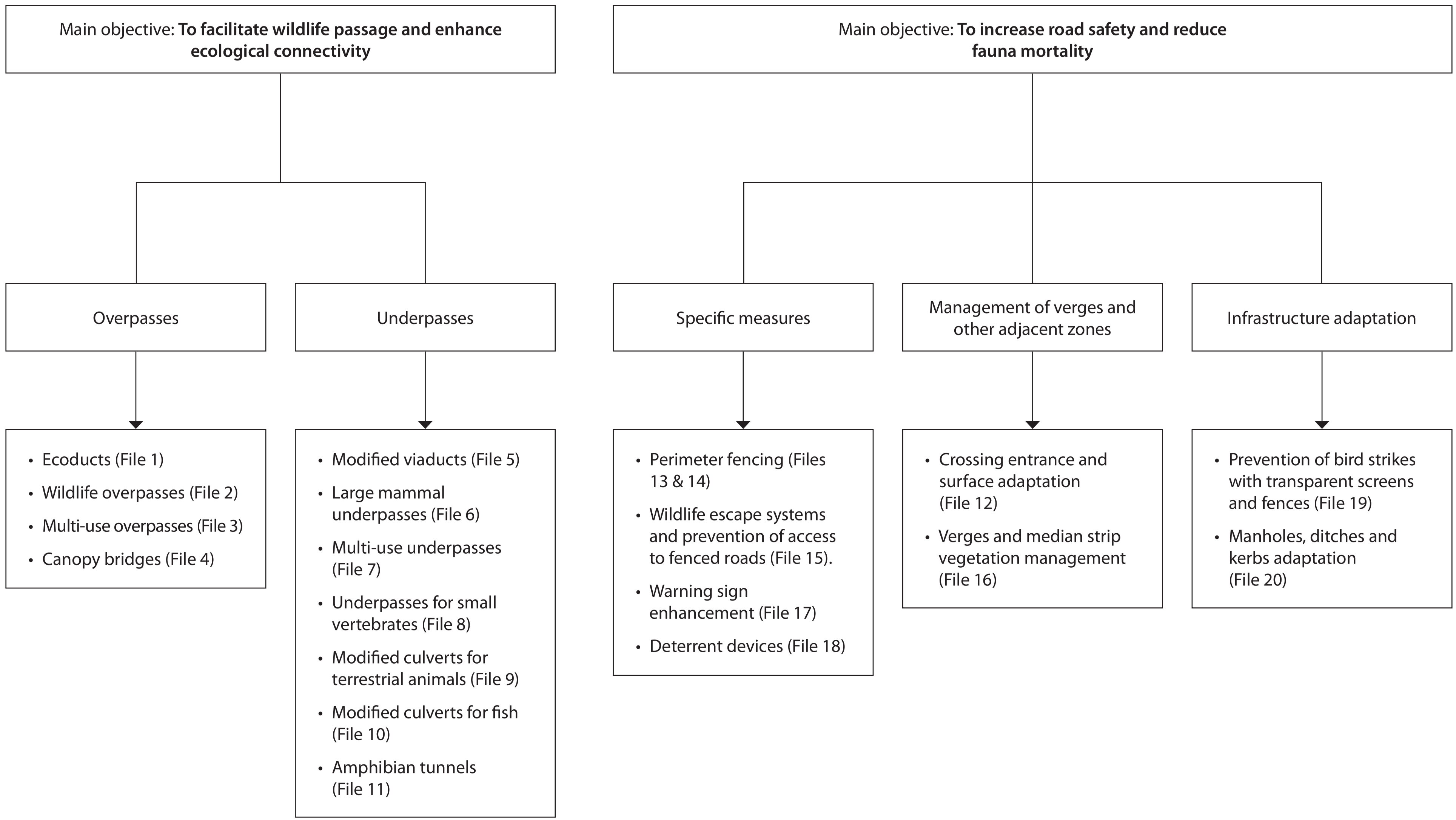
A descriptive file on adapting crossing entrances is also included (File 12).

b) To increase road safety and reduce mortality caused by traffic or other infrastructure-related elements

The main causes of roadkill associated with road and rail infrastructure are wildlife-vehicle collisions (WVC). The measures aimed at reducing these impacts and increasing road safety are based on the installation of fences that funnel animals towards safe crossing points (Files 13, 14 and 15) and other methods that prevent WVC and accidents caused by large mammals such as verges management measures (File 16), signposting and deterrent devices (Files 17 and 18). These verges and adjacent habitat manage ment measures are particularly suitable for infrastructure where perimeter fencing cannot be installed or is inadvisable. This is the case with many conventional roads that have WVC hotspots in certain sections despite their low traffic density and a minor barrier effect.

Specific measures are also proposed for the reduction of roadkill caused by elements associated with the infrastructure such as bird collisions with transparent screens and drain catchpits that can trap small animals (Files 19 and 20). Finally, there are several files with measures for specific species and taxonomic groups: tortoises (File 21), bats (File 22), semi-aquatic mustelids (File 23), brown bears (*Ursus arctos*) (File 24) and the Iberian lynx (*Lynx pardinus*) (File 25).

In practice, both types of measures must be combined in order to optimise the achievement of their goals and design integrated solutions which jointly ensure the permeability of the road to wildlife and the mitigation of road safety hazards.



Types of measures to be implemented to reduce the impact of road infrastructure on wildlife. Adapted from Iuell *et al.* (2005). Files 21 to 25 supplement the prescriptions with a summary of the most suitable measures for certain species that are particularly vulnerable to the impact of roads and railway lines.

3.2 Wildlife groups requiring specially designed measures

● Species or taxonomic groups requiring special consideration in the analysis of the impact of transport infrastructure on wildlife:

a) Species that may pose a significant **road safety hazard**: all ungulate species, in particular, roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*), which cause most accidents involving animals in Spain.

b) Species that require large foraging areas, uninterrupted by barriers: ungulates such as red deer (*Cervus elaphus*), roe deer, wild boar, etc. and medium and large carnivores such as bears, wolves (*Canis lupus*), the Iberian lynx, otters (*Lutra lutra*), etc.

c) Species with seasonal migration routes to breeding grounds that may be interrupted by the barrier effect of transport infrastructure, and are thus highly susceptible to WVC: amphibians are one of the most heavily affected groups.

d) Other species that are threatened or are of special conservation interest which, while not included in the above-mentioned taxa, are particularly sensitive to the effects of transport routes, and identified as priorities in Directive 92/43/EEC, or listed as 'Endangered' and 'Vulnerable' in the Spanish Catalogue of Endangered Species (EAEC), under Royal Decree 139/2011 of February 4, on the List of Species Deserving Special Protection and the Spanish Catalogue of Endangered Species, or equivalent categories under other legislation, especially at the regional level.

In Spain, **endangered species** that are most vulnerable to roadkill and the barrier effect are Hermann's Tortoise (*Testudo hermanni*), long-fingered bat (*Myotis capaccinii*), European mink (*Mustela lutreola*), brown bear and Iberian lynx. The technical requirements and prescriptions for fences and wildlife crossings for all these species are summarised in a set of files (Files 21 to 25), which set out the most appropriate measures.

● In all cases, the habitats and dispersal requirements of the species or groups concerned must be studied in order to identify the possible barrier effect of the road or the factors which may cause mortality or loss of habitat quality.

3.3 Selecting the location of wildlife crossings

● The identification of points in the infrastructure that require the construction of wildlife crossings must be based on the analysis of four factors which essentially define the sections where wildlife movements intersect with roads. The factors to be assessed are listed below.

- **Factor 1. Identification of important habitats** for wildlife groups requiring special attention (see Section 3.2). Aspects to be analysed:

  a. Species distribution.

  b. Habitat distribution in the landscape and degree of fragmentation.

- **Factor 2. Identification of areas of importance for ecological connectivity,** particularly for wildlife movement. Aspects to be analysed:

  a. Presence of land uses that are compatible with wildlife movements.

  b. Presence of landforms that funnel wildlife movements, in particular gullies and ridges.

  c. Presence of watercourses that funnel the longitudinal movements of many aquatic and semi-aquatic and terrestrial animal species.

  d. Information about common wildlife routes based on field surveys and input from local experts.

- **Factor 3. Identification of WVC and roadkill hotspots**. This aspect is assessed on the basis of data on operating infrastructure which lies parallel or close to new roads, or data on the road itself when it is the focus of improvement projects.

- **Factor 4. Identification of areas to be defragmented,** in particular those indicated in land use planning and natural spaces management documents, plans aimed at improving connectivity (amongst others) and those identified in Document 6, *Identifying areas to be defragmented in order to reduce the impact of linear transport infrastructures on biodiversity*.

● Landscape analyses, especially Geographic Information Systems (GIS), permit an overall assessment of the effects of the listed factors, and provide an overview of the importance of different sectors of the landscape for ecological connectivity and wildlife movements. By overlapping this information with the route alignment, we can detect the sections that run through highly sensitive areas and the points that require wildlife crossings or habitat interconnection structures. GIS tools that facilitate these types of analyses include Conefor (http://www.conefor.org/), widely used in Spain.

- Wildlife crossings should be located wherever the analysis of the above-mentioned factors shows they are necessary to:

  – Facilitate safe crossing points to prevent encroachment by wildlife that can entail a road safety hazard.

  – Prevent isolated fragments of listed species' habitats.

  – Facilitate animal access to basic resources (food, shelter, breeding, etc.) in order to maintain a particular population.

  – Allow the road to be crossed when it intersects with regular wildlife routes.

- In the case of road improvement or enlargement projects, planners must consider the option of building new wildlife crossings at roadkill and WVC hotspots, as well areas targeted for defragmentation (see Factor 4 above). Another solution in such cases is the adaptation of existing transversal structures such as tunnels, viaducts and other infrastructure with suitable dimensions and characteristics, which can be adapted for use by wildlife.

3.4 Density of wildlife crossings

- The permeabilization of road infrastructure to wildlife must not only be guaranteed in sections that affect habitats of high conservation interest, but also all types of natural habitats, including those consisting of agricultural environments —which can also be extremely important for biodiversity conservation, as in the case of steppes— or by means of transformations that are compatible with the presence of wildlife. However, the intensity of such actions will differ, depending on the importance of the habitats affected. The permeability requirements are listed in Table 3.1 for orientation purposes.

- The crossings densities listed in Table 3.1 can be adjusted slightly, depending on the characteristics of each project. A detailed analysis is required to define the specific location of each structure. For this purpose, we must consider the identity of the reference species and the landscape context, striving to ensure that the crossing locations coincide as closely as possible with regular wildlife routes and areas of importance for fauna dispersal.

- In the assessment of the overall permeability of the infrastructure, sections that pass through tunnels and large viaducts should be regarded as totally permeable sectors, as they are not a barrier for wildlife.

- In the permeability analyses, all types of appropriate crossings for reference wildlife groups must be considered, including exclusive and multi-use crossings that have been successfully adapted to facilitate wildlife passage.

- In general, permeability analyses should consider the installation of appropriate crossings for all the species that inhabit a particular area. However, in some cases a permeability diagnosis focused on a single species may be necessary. In such situations, more specific analyses can be employed to consider the mobility and foraging areas of the reference species. Some manuals recommend that the distance between two large carnivore crossings must not exceed the average distance travelled each day by an individual animal. For example, evidence on brown bear movements in Croatia has determined a maximum distance of 1.4 km between two crossings, whereas in the case of the wolf, it could be up to 2.2 km. Other recommendations propose that the maximum distance between two crossings should be equal to the square root of the home range of the reference species.

3.5 Choice of the structure type

The type of structure should be determined by a multi-criteria analysis that considers at least three aspects:

- The importance of the road section for ecological connectivity in general and wildlife movements in particular.

Table 3.1. Wildlife crossing densities proposed for different habitats and reference groups (see Section 3.5, criterion 3). These densities are for indicative purposes, and their exact location must be defined by adjusting it as closely as possible to the location of the habitats and the regular routes of the reference species, the sectors of importance for connectivity and any linear landscape elements (valley floors, river banks, ecotones, etc.) that can funnel fauna movements.

Habitat types	Minimum crossing densities for different fauna groups	
	Large mammal crossings	Small vertebrate crossings
Forests and other habitat types of importance for the conservation of ecological connectivity	1 crossing per km	1 crossing per 500 m
Habitats transformed by human activity (including areas containing crops, plantations or peri-urban structures)	1 crossing per 3 km	1 crossing per km

- The relief of the area in the sector where the wildlife crossing is to be installed.

- The reference species or taxonomic groups.

Criterion 1. Importance of the section for ecological connectivity and wildlife movements

● The connectivity analysis must look the entire study area and consider the distribution of the habitats of greatest importance for the dispersal of the reference species or taxonomic groups. The evaluation should be implemented at two levels: regional (1: 25,000 or 1: 50,000 scale landscape analysis), and more detailed local scale (1: 5,000 scale or less).

● These general guidelines should be specified and adapted to the local contexts. Exclusive wildlife crossings may also be required in road sections that cross environments of apparently little importance for connectivity when specific studies substantiate their major importance for wildlife movements.

● Only large structures —tunnels, false tunnels, well-designed viaducts and ecoducts— are appropriate in cases where full connectivity between habitats on both sides of the road must be ensured by maintaining the continuity of the vegetation cover.

● In addition to the detailed analysis of the study area, the study must also take into consideration any documents that identify ecological connectors and diagnoses of sections with a high incidence of areas requiring defragmentation and WVC or accidents caused by animals. These may have been previously defined in land use management documents, urban planning, connectivity plans and other documents such as the management of protected natural areas.

Criterion 2. Topographic constraints

The topographic constraints in specific sectors that require crossings, in particular the alignment of the road with respect to the relief, may oblige the option of over- or underpasses. In this regard, the following considerations should be taken into account:

● The crossings entrances should preferably be on the same level as the adjacent landscape. Thus, if the road runs through a cutting, an overpass must be chosen, whereas if the roadway is on an embankment, an underpass must be chosen.

● There are two options in flat sections:

- Raising the road surface on a viaduct or an embankment beneath which the wildlife underpass can be built.

- Overpasses with access ramps on a gentle slope. The area needed for the construction of these ramps may affect land that lies outside the public domain (8 m in the case of motorways and 3 m in conventional, multi-lane and service roads), and thus may require the expropriation of additional land.

- Sectors where the road runs across a hillside with a cut/fill section are not suitable as crossing locations, although in exceptional cases overpasses may be designed in the form of false tunnels adapted to the topographical conditions.

Criterion 3. Target species or fauna groups

● Wildlife crossings should be designed to be used by the largest possible number of species or taxa. To facilitate the selection of the most suitable type of crossing for each situation, we have identified relatively homogeneous groups in terms of crossing types and dimensions required to cross the road infrastructure. The reference groups for each type of wildlife crossing are described below.

- Structures suitable for all fauna

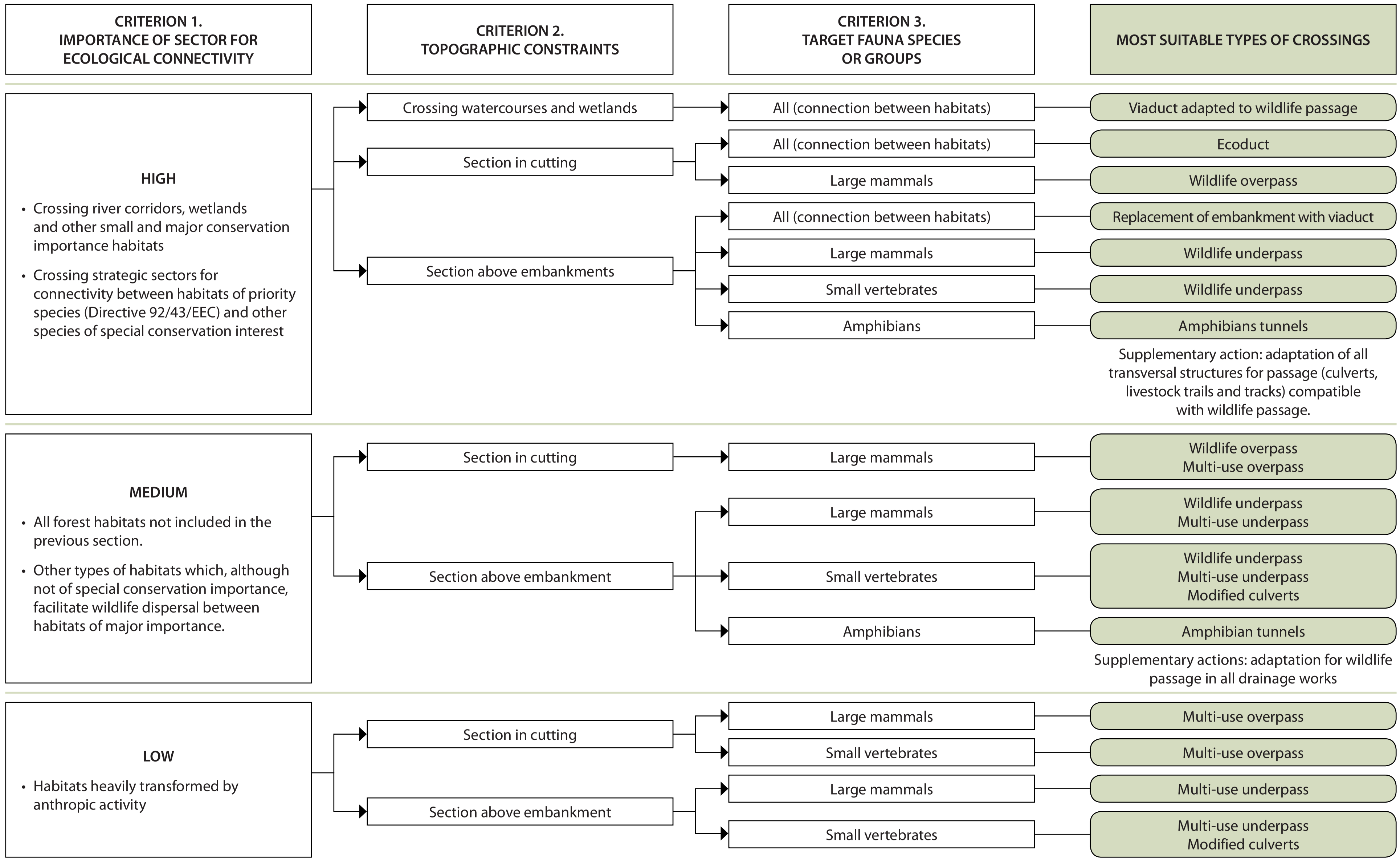
Only two types of structures can facilitate the passage of all types of vertebrates and act as habitats for invertebrates: ecoducts and modified viaducts that permit total connection between the habitats on either side of the road.

- Large mammal crossings

Crossings particularly suitable for ungulates (deer, cattle and wild boar) and large carnivores (brown bear, wolf and lynx). They are also suitable for the other vertebrate groups, with the exception of fish fauna. They can be used by amphibians if specific adaptations are made such as opaque fences that funnel animals towards the crossing (see File 11).

- Small vertebrate crossings

Crossings suitable for medium-sized carnivores such mustelids, foxes (*Vulpes vulpes*), etc. and the other mammal groups, with the exception of ungulates and large carnivores. They can also be used by reptiles and amphibians if specific adaptations for this group are made, such as opaque fences that funnel animals towards the crossing (see File 11). The Iberian lynx can also use these structures if they are properly adapted. However, in order to optimize their effectiveness, large mammal crossings at strategic points are recommended. Wild boar crossings sometimes use small vertebrate crossings, although large mammal

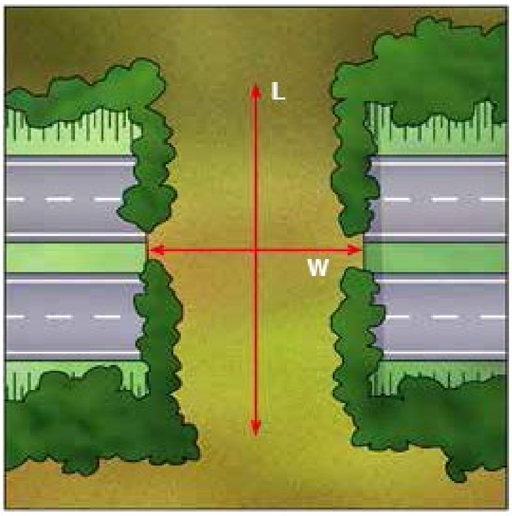


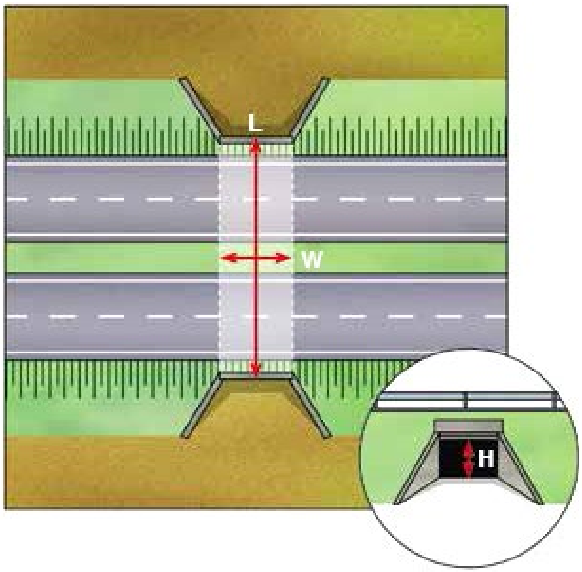
Incorporation of criteria for the choice of a wildlife crossing type and location to new infrastructure projects.

Table 3.2. Suitability of wildlife crossing types described in the Catalogue of measures for different species or taxa. Adapted from Iuell *et al.* (2005).

	Ecoducts (File 1)	Wildlife overpasses (File 2)	Multi-use overpasses (File 3)	Canopy bridges (File 4)	Modified viaducts (File 5)	Large mammals underpasses (File 6)	Multi-use underpasses (File 7)	Underpasses for small vertebrates (File 8)	Modified culverts for terrestrial animals (File 9)	Modified culverts for fish (File 10)	Amphibian tunnels (File 11)
Ungulates											
Cervids and bovids	●	●	○	—	●	●	○	—	—	—	—
Wild boar	●	●	○	—	●	●	○	○	○	—	—
Carnivores											
Brown bear	●	●	○	—	●	●	○	—	—	—	—
Lynx	●	●	○	—	●	●	○	○	○	—	—
Wolf	●	●	●	—	●	●	●	—	○	—	—
Fox	●	●	●	—	●	●	●	●	○	—	—
Badger	●	●	●	—	●	●	●	●	●	—	○
Otter	○	○	○	—	●	●	●	●	●	—	○
Marten and stone marten	●	●	●	○	●	●	●	●	●	—	○
Polecat and weasel	●	●	●	—	●	●	●	●	●	—	○
Genet	●	●	●	—	●	●	●	●	●	—	○
Lagomorphs											
Hare	●	●	●	—	●	●	●	●	○	—	—
Rabbit	●	●	●	—	●	●	●	●	○	—	—
Bats	●	●	●	—	●	●	●	○	○	—	—
Insectivores											
Hedgehogs	●	●	●		●	●	●	●	○	—	—
Shrews	●	●	●	—	●	●	●	●	○	—	○
Rodents											
Squirrel	●	●	●	—	●	●	●	—	—	—	—
Dormouse	●	○	○	○	●	—	—	—	—	—	—
Mice and voles	●	●	●	—	●	●	●	●	○	—	○
Reptiles											
Snakes	●	●	●	—	●	○	○	○	○	—	—
Lizards	●	●	●	—	●	○	○	○	○	—	—
Tortoises	●	●	●	—	●	○	○	○	○	—	—
Amphibians	○	○	○	—	●	○	○	○	○	—	●
Fish	—	—	—	—	—	—	—	—	—	●	—
Running birds	●	○	○	—	●	○	○	—	—	—	—
Terrestrial invertebrates											
Dry habitat species	●	●	●	—	●	○	○	○	—	—	—
wet habitat species	○	○	○	—	●	○	○	○	○	—	○

● optimum solution ○ can be used if adapted to local conditions — not applicable





Defining the width, length and height of crossings.
For structures running beneath the road with several cells separated by walls, the width and the openness index (section/length) of each one should be calculated individually.

crossings are more effective and are thus recommended for this species.

- **Amphibian crossings**

  Crossings designed exclusively for this group, which should include funnelling structures composed entirely of opaque elements (see File 11). They can also be used by small mammals (insectivores and rodents) and some mustelids.

- **Structures for fish**

  Only structures that allow the river channel to be kept intact —basically modified viaducts (see File 5) and in some cases correctly adapted culverts (see File 10)— are applicable.

● For some species that are listed as 'Endangered' (or taxa that include them) and are particularly vulnerable to the effects of roads, the most suitable types of wildlife crossings are listed in Files 21 (tortoises), 22 (bats), 23 (semiaquatic weasels), 24 (brown bear) and 25 (Iberian lynx).

● Large mammal and small vertebrate crossings require fences that funnel animals towards them in order to be effective. The type of fencing varies with the target species and reference groups (Files 13 and 14). Wildlife crossing monitoring projects have identified the requirements of the different species that use them. On the basis of these conditions, Table 3.2 shows a summary of the suitability of the various types of wildlife crossings described in the document for each species or taxonomic group.

3.6 Crossing dimensions

● The minimum and recommended size and type of each crossing is shown in Tables 3.3. and 3.4. These prescriptions are indispensable to ensure that the crossings are effective for all the taxa for which they are intended.

Table 3.3. Dimensions of above-road fauna crossings.

Crossing type	Uses	Target fauna groups[1]	Crossing size[2]	
			Minimum	Recommended
Ecoducts	Specifically for fauna	All except amphibians & aquatic fauna	W: 80m	—
Large mammal overpasses	Specifically for fauna	Large mammals	W: 20 m and W/L > 0.8*	W: 40-50 m
Multi-use overpasses	Wildlife crossing + drainage + track/livestock trail	Large mammals	W: 10 m and W/L > 0.8*	W: 20-50 m
Canopy bridges	Specifically for fauna	Arboreal mammals (squirrels)	—	—

[1] For more information on taxa included in each target fauna group, see section 3.5.3.
[2] W: Width; L: Length.
* See additional notes in paragraph 3.6.

Table 3.4. Dimensions of below-road fauna crossings.

Crossing type	Uses	Target fauna groups[1]	Crossing size[2]				
			Minimum (W x H)				Recommended (W x H)
Modified viaducts	Multi-use	All	—				—
Large mammal underpasses	Specifically for fauna	Large mammals	- Wild boar + roe deer: 7 x 3.5 m and openness index: >0.75 - Red deer: 12 x 3.5 m and openness index: >0.75				15 x 3.5 m
Multi-use underpasses	Wildlife drainage + track/livestock trail	Large mammals	- Wild boar + roe deer: 7 x 3.5 m and openness index: >0.75 - Red deer: 12 x 3.5 m and openness index: >0.75				15 x 3.5 m
Underpasses for small vertebrates	Specifically for fauna	Small vertebrates	2 x 2 m				—
Modified culverts for terrestrial animals	Wildlife crossing + drainage	Small vertebrates	2 x 2 m				—
Modified culverts for fish	Wildlife crossing + drainage	Fish	—				—
Amphibian tunnels	Specifically for fauna	Amphibians	Length (m):	<20	20-30	30-40	40-50
			Section H x W (m):	1 x 0.75	1.5 x 1	1.75 x 1.25	2 x 1.5

[1] For more information on taxa included in each target fauna group, see section 3.5.3.
[2] W: Width; L: Length; openness index (W x H)/L.

- The recommended dimensions should be applied when a particular type of crossing needs to be more effective due to its location at a strategic point for the conservation of a species or for other reasons.

- It is not advisable to build crossings that are more than 70 m long, except in exceptional circumstances where no other alternatives are technically feasible, and they are intended for species with less strict size requirements.

- Whenever possible, crossings should be built perpendicular to the infrastructure in order to reduce their length and facilitate visibility of the exit at the opposite end. On the other hand, adapted underpasses and culverts must respect the natural alignment of the watercourse in order to prevent its modification.

- The dimensions set out in Tables 3.3 and 3.4 refer to the width and height of the structure's section, respectively (see Figure of page 28) and its openness index. This index, calculated from the width-length ratio of the crossing, or section (width x height) and length, shows that the longer the crossing (in the case of broad roadways), the greater the width required for the structure.

Additional notes:

Dimensions are one of the key factors in the effectiveness of crossings for certain species (particularly ungulates and large carnivores), however their location with respect to habitats used by the reference species is equally if not more important. A crossing that is badly located or poorly integrated into the surroundings will not be as effective as desired, even if the dimensions are correct. Nevertheless, the dimensions are the basis for the construction project and they largely determine the structure's potential for restoration, integration and also its cost.

The dimensions presented in the first edition of the Spanish version of this document were based on the results of crossing monitoring across Europe, analysed by wildlife and transportation experts from the 19 participant countries in the COST 341 Action, set out in the COST 341 document *Wildlife and Traffic. A European handbook for identifying conflicts and designing solutions* (Iuell et. al., 2005). In the case of underpasses, a broad sample of monitoring results from Spain showed that the minimum dimensions c ould be smaller than those prescribed in the European manual, although these were maintained as recommended in areas of major importance for connectivity.

In the case of large mammal overpasses, no changes were made with respect to the European manual, since no data were available from additional monitoring that could justify such modifications. In the case of multi-use overpasses, i.e., adaptations of existing structures to restablish livestock routes or tracks, the minimum width was found to be 10 m, enough to permit the addition of 2 m vegetated strips on either side. In order to encourage greater use of these structures by wildlife, the width-length ratio was maintained, as in the case of the wildlife overpasses.

Subsequent monitoring data from Spain has been studied for this edition of the document, but not enough information has been found to justify changes except for a variation in the dimensions of the amphibian crossings, deleting the minimum diameter for circular structures given that crossings with rectangular sections are recommended (see File 11).

For large mammal overpasses, the application of the > 0.8 H/L ratio requirement, in addition to the width, often implies the construction of large structures which are not feasible in some cases. Therefore, in the absence of a sufficiently large number of monitoring data to justify the modification of the prescriptions with respect to the European handbook, the H/L ratio may in exceptional cases be less than the stipulated figure when justified by a detailed study of the ecological conditions of the section where the structure is to be located, focusing particularly on its importance for ecological connectivity and the characteristics of the species and the status of their populations. Whatever the case, in order to reduce the costs of large overpasses, false tunnels are recommended as they can recycle a large volume of soil from earth movements in cuttings, reduce costs, and obviate the need to create earth stockpiles.

The H/L ratio for multi-use overpasses may also be less than that stipulated in the case of crossings that are wider than 20 m. However, they should be adapted, insofar as possible, in accordance with the recommendations for large mammal overpasses.

3.7 Descriptive files for each solution

Ecoducts and wildlife crossings

File 1: ECODUCTS

File 2: WILDLIFE OVERPASSES

File 3: MULTI-USE OVERPASSES

File 4: CANOPY BRIDGES

File 5: MODIFIED VIADUCTS

File 6: LARGE MAMMAL UNDERPASSES

File 7: MULTI-USE UNDERPASSES

File 8: UNDERPASSES FOR SMALL VERTEBRATES

File 9: MODIFIED CULVERT FOR TERRESTRIAL ANIMALS

File 10: MODIFIED CULVERT FOR FISH

File 11: AMPHIBIAN TUNNELS

File 12: WILDLIFE CROSSING ENTRANCE AND SURFACE ADAPTATION

Road safety improvement and wildlife mortality mitigation measures

File 13: FENCES FOR LARGE MAMMALS

File 14: FENCES FOR SMALL VERTEBRATES

File 15: WILDLIFE ESCAPE SYSTEMS AND PREVENTION OF ENTRANCE TO FENCED ROADS

File 16: VERGER AND MEDIAN STRIP VEGETATION MANAGEMENT

File 17: WILDLIFE WARNING SIGN REINFORCEMENT

File 18: DETERRENT DEVICES

File 19: PREVENTION OF BIRD STRIKES WITH TRANSPARENT SCREENS AND FENCES

File 20: ADAPTATION OF DITCHES AND OTHER ELEMENTS TO REDUCE SMALL ANIMAL MORTALITY

Specific recommendations for certain species and groups

File 21: SPECIFIC RECOMMENDATIONS FOR TERRESTRIAL TORTOISES

File 22: SPECIFIC RECOMMENDATIONS FOR BATS

File 23: SPECIFIC RECOMMENDATIONS FOR SEMI-AQUATIC MUSTELIDS

File 24: SPECIFIC RECOMMENDATIONS FOR BROWN BEARS

File 25: SPECIFIC RECOMMENDATIONS FOR THE IBERIAN LYNX

Target species and groups

- Suitable for all types of terrestrial species, including ungulates and large carnivores. Also used as a habitat by invertebrates and other small organisms.

Other groups that can use ecoducts

- Amphibians, if appropriate fences are built (see File 11) and there are microhabitats with the appropriate moisture levels for this group.

- With suitable adaptations, they can be used to funnel bat and bird flight paths, and facilitate movement of partridges and other running birds.

Uses

- Wildlife crossing and connection between habitats on either side of the road.

- Some anthropic uses such crossings for livestock, pedestrian, cycle and forestry track can be compatible if they are properly integrated into the structure and do not disturb the fauna.

Basic features and prescriptions

- Ecoducts are overpasses above infrastructure whose large dimensions and restored surface permit optimum integration into the surroundings, connecting the vegetation cover and the habitats on both sides of the infrastructure.

- To ensure their utility, ecoducts should be located in areas habitually used by wildlife for movement, and in areas with little disturbance by human activity.

- Road sections in cuttings are the best location for these structures, since their entrance points can be set on the same level as the surrounding land. In addition, considering that ecoducts require large volumes of earth, they can also absorb the material excavated to construct the cutting.

- To facilitate the passage of the largest possible number of wildlife species, the ecoduct surface must be fully restored to ensure the presence of a similar diversity of habitats and microhabitats to the surroundings, including those of greatest importance for rare and declining species. A layer of topsoil (if possible from the same area) must be laid on the structure surface with sufficient depth to facilitate habitat restoration.

Photo: GIASA, Andalusia government.

- It is important to reduce disturbance to animals by the lights and noise of moving vehicles. Opaque screens or dense shrub plantations must be installed along the verges for this purpose.

- Suitable drainage of the ecoduct surface must be ensured on a gentle slope (2-3%) from its central longitudinal axis towards the edges, with a layer of insulating material to protect the base to ensure its durability.

Dimensions

- Minimum width: 80 m.

- Minimum thickness of topsoil for planting herbaceous species: 0.3 m; shrubs: 0.6 m; trees: 1.5 m.

Construction types

- False tunnels, archs and other construction types similar to those used in bridge-building. A parabolic-shaped design facilitates the detection of the crossing access points by animals, although this is more expensive than a rectangular design (Figure 1.2).

Adaptation

Structure surface

- Plantations on the structure surface must be diversified, combining the open spaces of the central sections with longitudinal strips of trees and shrubs, denser and higher in the sections near the sides of the structure to guide bat and bird flight (Figure 1.1).

- Only native species from the same region should be used for revegetation, replicating the local habitat features. The species should also be adapted to the ecoduct surface which in some places and seasons can be very dry.

- Wherever possible, trees and shrubs already growing in the area prior to construction must be used. The soil should also be from the same area and its surroundings in order to make the most of the seed bank and minimize the risk of introduced exotic species.

- If linear separations are required, hedgerows, dry wall stone or wooden fences that do not interfere with the wildlife movements must be used. Safety fences or security barriers must be avoided.

- Piles or rows of stones and logs set along the structure provide shelter and micro-habitats for wildlife and encourage the presence of invertebrates, reptiles and other small animals. These elements are particularly useful during the initial period, when revegetation has not been completed. Other characteristic features of the surrounding landscape such low dry stone walls can play the same role (Figure 1.9).

Lateral screens and fences

- Screens along the ecoduct prevent disturbance by vehicles. They should consist of dense plantations or completely opaque screens that provide continuity to the perimeter fence along the edge of the ecoduct. These screens should be at least 2 m high (Figure 1.5).

- Where appropriate, a space should be left between the screen and the nearest row of vegetation to facilitate maintenance.

- The screen or panel material must be highly durable, with a low risk of damage by vandalism. Treated timber, stained concrete and metal are suitable (Figure 1.7).

Entrances

- Plantations and perimeter fences must be installed to guide wildlife towards the crossing entrance point (see File 12). These entrance zones should be treated to encourage their full integration into the local environment and provide continuity to the vegetation between the structure surface and the habitats in the adjacent areas. Provision must therefore be made for expropriation or land stewardship agreements to restore habitats outside the public domain of the roads.

- The entrances must be on the same level as the adjacent land. To ensure optimum integration of the ecoduct with its surroundings, the topography must be adapted to ensure a smooth transition onto the structure (Figure 1.4).

- On flat land, the entrance should include gentle ramps (15% maximum slope, up to 25% in the case of ecoducts in mountain areas).

- Ecoduct entrances should not be near or perpendicular to busy roads, as this hinders their use by wildlife and increases the risk of generating WVC hotspots.

- To attract wildlife to the ecoduct, important habitats can be restored at the entrance. Small ponds, for example, can be used as breeding grounds by amphibians or as watering holes by other animals (Figure 1.8).

- Boulders, tree trunks or the like can be placed at the entrance to prevent uncontrolled access by vehicles. Transversal barriers (e.g. timber or metal rods set 50-70 cm above the ground) that do not obstruct the passage of wildlife are another alternative.

- Signposts indicating the prohibition of vehicular traffic are recommended, where applicable.

Maintenance

- During the first few years, regular watering is essential to ensure that the vegetation takes root.

- Regular mowing in the central section of the structure should be planned to prevent excessive vegetation growth. Less frequent brush cutting along the hedgerows should also be planned. Controlled livestock grazing is an appropriate option for vegetation maintenance, avoiding overgrazing and effects on trees and shrubs.

- The perimeter fencing must be correctly installed and maintained, with regular repairs to any damage.

- The misuses of the ecoduct and its surroundings must be monitored, including the prevention of fences installed on adjacent properties which may hinder entrance by animals to the crossing or facilitate vehicle access to areas reserved for wildlife. Should this occur, the appropriate corrective measures must be designed to prevent the effectiveness of the ecoduct from being reduced.

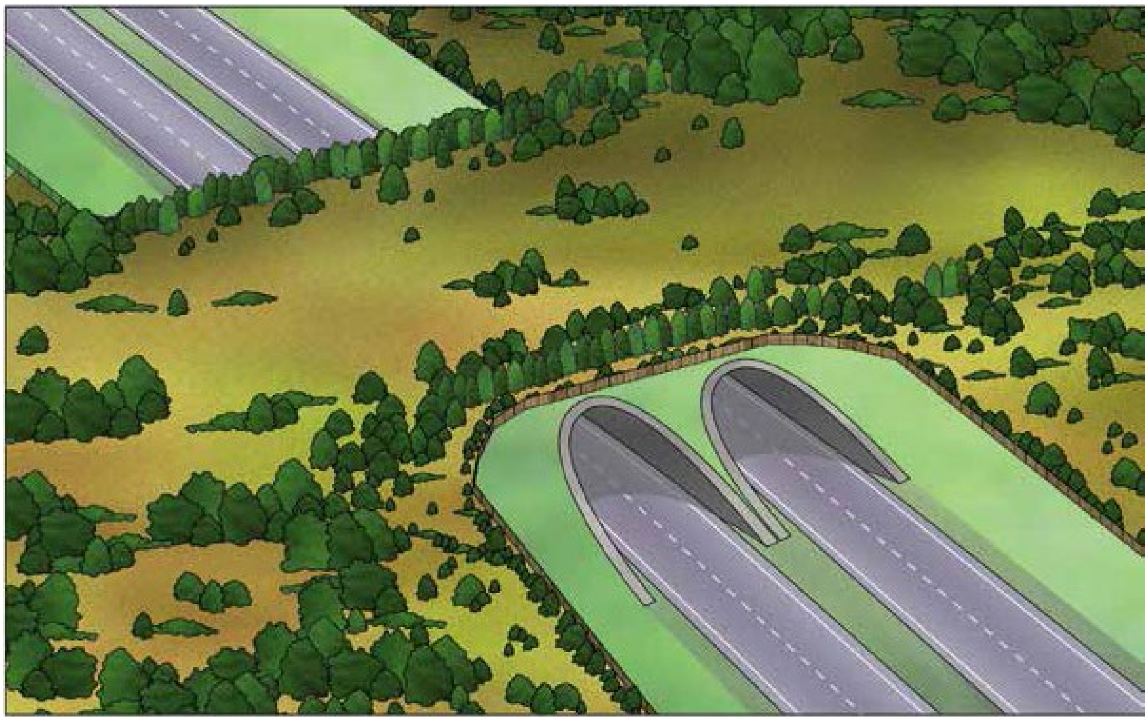


Figure 1.1. Diagram of a ecoduct.

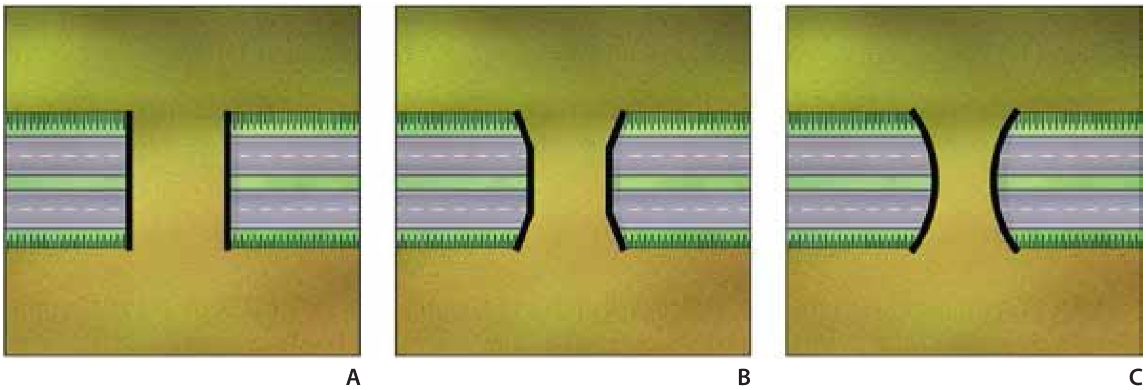
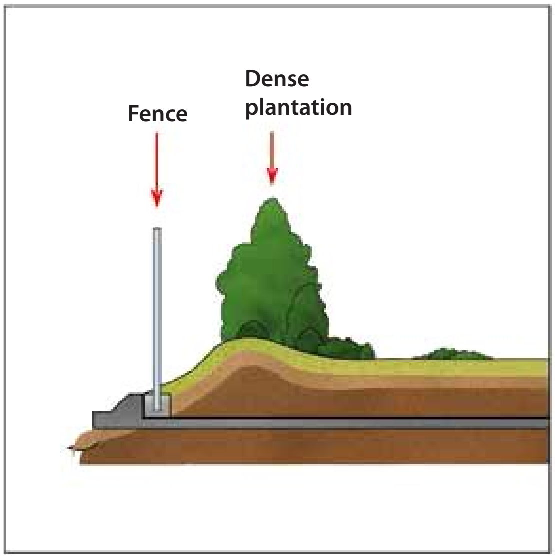


Figure 1.2. Alternative plans for ecoduct designs.

Figure 1.3. Archs on a roadway in operation to facilitate the construction of an ecoduct. Photo: H. Bekker.

Figure 1.4. The ecoduct surface and access zones should have similar topographic profiles to the surrounding landscape. Photo: Minuartia.



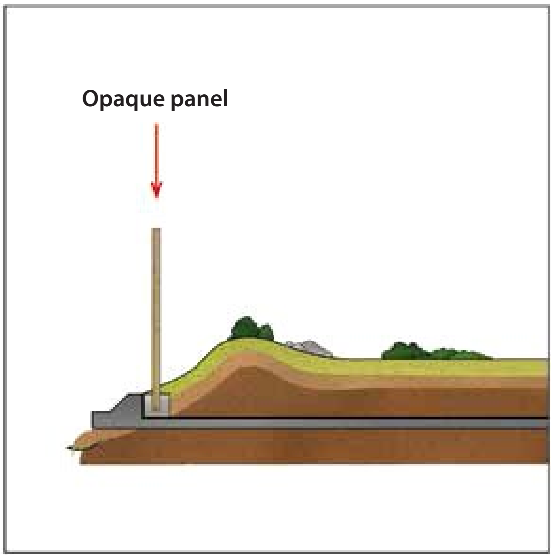


Figure 1.5. Details of an ecoduct section showing screening options. In Option A, a mesh fence is complemented with a dense vegetation screen to reduce disturbance by vehicle noise and lights. In Option B, more suitable in arid conditions, an opaque screen serves both purposes.

Figure 1.6. Vegetation screens reduce disturbance by traffic. Photo: V. Hlavac.

Figure 1.7. Treated timber or stained concrete fences require less maintenance than vegetation. Photo: C. Rosell.

Figure 1.8. Pond near ecoduct access attracts wildlife. Photo: H. Bekker.

Figure 1.9. Low dry wall constructions provide micro-habitats for small animals along the edge of the ecoduct. Photo: S. Vanpee - IRSTEA.

Figure 1.10. In environments with an agro-forestry mosaic, restoration work can also include pasture and dryland crops if necessary to provide continuity to the important habitats in the vicinity of the road.
Photo: Territory and Sustainability Department, Government of Catalonia.

Figure 1.11. Two alternative systems using boulders and tree trunks to avoid vehicle movement across the ecoduct. Another option is to install metal or timber barriers at a suitable height and signs prohibiting vehicular traffic. Photos: Javier Cantero and CEDEX.

Target species and groups

- Ungulates, large carnivores (bear, wolf and lynx).

Other users

- All other terrestrial fauna.

- Amphibians, if the structure has appropriate fencing (see File 11) and microhabitats with the moisture required by this group .

- With appropriate adaptations, these overpasses can guide bat and bird flight paths and facilitate the movement of partridges and other running birds.

Uses

- Exclusively for wildlife.

Basic features and prescriptions

- Wildlife overpasses are structures that include a complete surface restoration, and are solely for wildlife passage. To prevent interference by human activity, no other uses are permitted.

- The main difference between this type of crossings and ecoducts is that they are narrower, which implies limitations for habitat restoration. The primary function of an ecoduct is to interconnect habitats on either side of a road, whereas these wildlife overpasses provide a crossing point for wildlife despite the possible lack of thorough continuity between habitats.

- To ensure that the crossing serves its purpose, it should be located in areas used regularly by wildlife for movements, with little disturbance by human activity.

- Road cuttings are optimum locations for these structures, as the access point can be on the same level as the adjacent land. In addition, these overpasses require large volumes of earth, and they can thus absorb the excavated material generated by the roadworks.

- It is important to reduce disturbance to animals caused by the lights and noise of moving vehicles. Opaque screens or dense shrub plantations must be installed for this purpose on both sides of the structure.

Photo: Highways Department, Government of Madrid.

- The wildlife overpass surface must be drained on a gentle slope (2-3%) from its central longitudinal axis towards the edges, with a layer of insulating material to protect the base and ensure its durability.

Dimensions

- Minimum width: 20 m and width/length ratio greater than 0.8.

- Recommended width: 40-50 m.

- Lateral screen height: 2 m.

- Minimum topsoil depth for herbaceous plantations: 0.3 m; for shrub plantations: 0.6 m.

Construction types

- Similar to ecoducts, false tunnels, archs and other construction types used in bridge-building. A parabolic-shaped design facilitates the detection of the crossing entrance points by animals, although it is more expensive than a rectangular design.

Adaptation

Overpass surface

- Vegetation plantations on the structure surface must be diversified, combining the open spaces of the central sections with longitudinal strips of trees and shrubs, denser and taller in the sections near the sides of the structure to guide bat and bird flight (Figure 2.1).

- Only native species from the same region should be used for revegetation, restoring the local habitat features, adapted to the ecoduct surface, which in some places and seasons can be very dry.

● Wherever possible, trees and shrubs already growing in the area prior to construction must be used. The soil should also be from the same area and its surroundings in order to make the most of the seed bank and minimize the risk of introducing exotic species.

● Vegetation maintenance may not be feasible when the overpass is located in an arid environment, unless drought resistant species are used. In such cases, the installation of inert structures such as rows of stones or tree stumps can provide shelter for smaller animals along the sides of the overpass (Figures 2.2 and 1.9).

Screens and perimeter fencing

● Screens for the overpass prevent disturbance by vehicles. They should consist of dense plantations or completely opaque screens that give the fence along the edge of the ecoduct a sense of continuity. These screens should be at least 2 m high (Figure 2.5).

● Where appropriate, a space should be left between the fence and the nearest row of vegetation to facilitate maintenance.

● The screen or panel material must be extremely durable, with a low risk of damage by vandalism. Treated timber, stained concrete or metal are suitable materials (Figure 2.5 and 1.7).

● On very large overpasses, the opaque screens can be replaced by dense shrub plantations, accompanied by wire mesh fencing, to minimize interference by vehicle movement along the road.

Entrances

● Plantations and perimeter fences must be installed to guide wildlife towards the crossing entrance point (see File 12). These entrance zones should be adapted to ensure their full integration into the local environment and provide continuity to the vegetation between the structure surface and the habitats in the adjacent areas. Provision must therefore be made for expropriations or land stewardships agreements that may be necessary to restore habitats outside the public domain of the roads.

● The entrances must be on the same level as the adjacent land, although to ensure the optimum integration of the overpass with its surroundings, the topography must be adapted to ensure a smooth transition onto structure.

● On flat land, the entrance should include gentle ramps (15% maximum slope, up to 25% in the case of overpasses in mountainous areas, Figure 2.4).

● Overpass entrance points should not be near or perpendicular to busy roads, as this hinders their use by wildlife and increases the risk of generating WVC hotspots.

● Boulders, tree trunks or the like can be placed at the entrance to prevent uncontrolled access by vehicles. Transversal barriers (e.g. timber or metal rods set 50-70 cm above the ground) that do not obstruct the passage of wildlife are another alternative (Fig. 1.11).

● Signposts indicating the prohibition of vehicular traffic is recommended, where applicable.

Maintenance

● During the first few years, regular watering is essential to ensure that the vegetation takes root.

● Regular mowing in the central section of the structure should be planned to prevent excessive vegetation growth. Less frequent bush cutting along the hedgerows should also be planned. Controlled livestock grazing is an appropriate option for vegetation maintenance, avoiding overgrazing and effects on trees and shrubs.

● The perimeter fencing must be correctly installed and maintained, with regular repairs to any damage.

● Potential misuse of the overpass and its surroundings must be monitored and corrected, including the prevention of fences installed on adjacent properties which may hinder entrance by animals to the crossing and vehicle access to areas reserved for wildlife. Should this occur, the appropriate corrective measures must be designed to prevent the effectiveness of the overpass from being reduced.

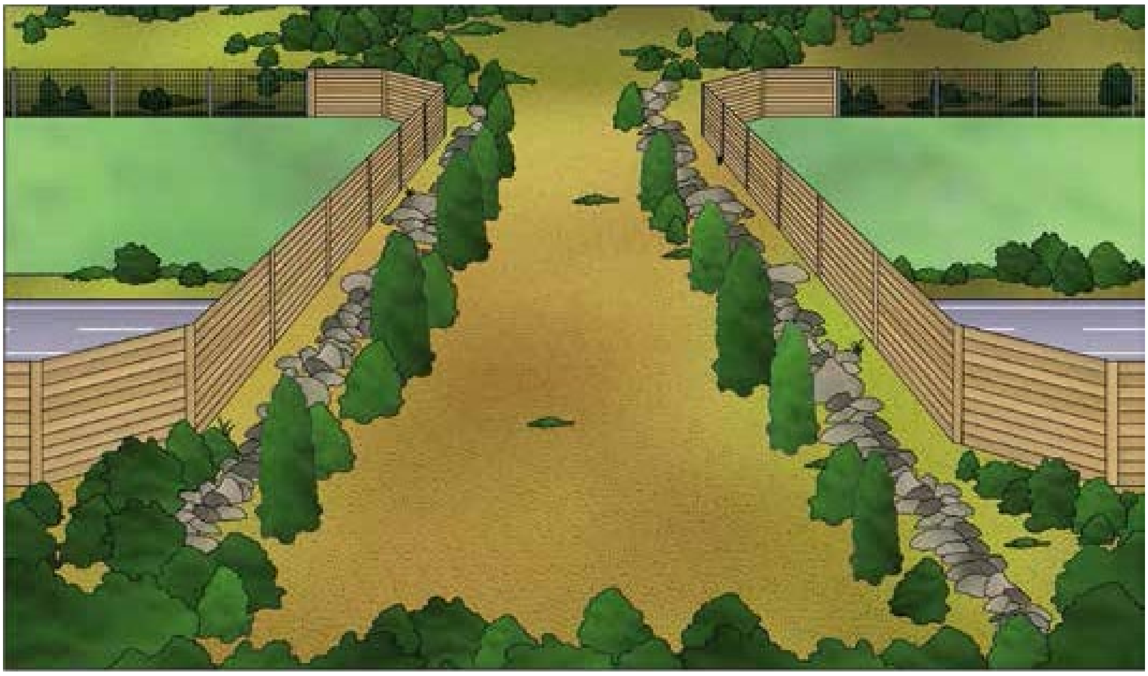


Figure 2.1. Diagram of an wildlife overpass.

Figure 2.2. Wildlife overpass with several measures providing shelters that favour its use by small animals. Photo: S. Vanpee - IRSTEA.

Figure 2.3. Wildlife overpass located in a section between cuttings, enabling excavated earth to be recycled. Photo: M. Fernández-Bou.

Figure 2.4. Wildlife overpass located on flat land, with access ramps on a gentle slope. Photo: P. Farkas.

Figure 2.5. Screens on crossings must be in perfect continuity with the road perimeter fence. Photo: C. Rosell.

Figure 2.6. Screens are sometimes used to attach decorative elements or information for road users about biodiversity-related initiatives. Photo: C. Rosell.

Figure 2.7. Wildlife overpass insulation and surface drainage. Photo: C. Rosell.

Common bad practices and mistakes

Figure 2.8. Motorized vehicle movements across an exclusive wildlife overpass and lateral screens that are not completely opaque. Photo: C. Rosell.

Target species and groups

- Ungulates, large carnivores (bear, wolf and lynx).

Other target groups

- All other mammals and reptiles.
- Appropriate structures can guide bat and bird flight paths and facilitate the movement of partridges and other running birds.

Photo: Territory and Sustainability Department, Government of Catalonia.

Uses

- Multi-use: Wildlife crossing, livestock, pedestrian, cycle, forestry track with low traffic density.

Basic features and prescriptions

- Overpasses that restore tracks and livestock trails can be easily adapted to encourage wildlife passage, and can be very effective with low traffic density and little disturbance by human activity.
- Modifications basically consist of a layer of natural soil on the platform base or at least two lateral strips covered with natural substrate and, if possible, revegetation on both sides of the paved surface.
- It is important to mitigate disturbance to animals caused by vehicle lights and noise on the road below. Opaque screens must therefore be installed on both sides of the structure, using treated wood or stained concrete panels if greater durability is required.

Dimensions

- Minimum width: 10 m and width/length ratio >0.8.
- Recommended width: 20-50 m.
- Minimum width of revegetated lateral strips or natural soil: 1 m.
- Lateral screen height: 2 m.
- Minimum topsoil depth for herbaceous plantations: 0.3 m; for shrub plantations: 0.6 m.

Adaptation

Overpass surface

- If the structure is used by both wildlife and vehicles, the central section can be paved or covered with gravel, but the lateral strips must be covered with soil and, where feasible, planted with tall herbaceous shrubs to guide bat and bird flight paths (Figures 3.1 and 3.2).
- If linear elements are required to separate uses, hedgerows, dry stone walls or timber fences that do not interfere with wildlife movement can be installed. The use of safety barriers or similar (Figure 3.3) should be avoided.
- The track must be located along the centre of the structure (Figure 3.2 A and B) or one of its edges if it is wide enough. In such cases, a naturalized strip at least 2 m wide must be installed between the track and the screens (Figure 3.2 C).
- Only native species from the same region and the surrounding habitat should be used for revegetation. Species should be chosen for their proven adaptation to the overpass surface conditions, particularly in terms of drought resistance.
- Wherever possible, the soil should also be from the same area and its surroundings in order to make the most of the seed bank and minimize the risk of introducing exotic species.
- Vegetation maintenance may not be feasible when the overpass is located in an arid environment, unless drought resistant species are used. In such cases, the installation of low dry stone walls or rows of stones along the edges of the structure can provide shelter for smaller animals and guide the wildlife movements (Figures 2.2 and 1.9).

Screens and perimeter fencing

- Opaque screens must be installed along the sides of the overpass, ensuring complete continuity of the perimeter fence. These screens should be at least 2 m high (Figure 2.5).

- A corridor should be left between the fence and the nearest row of vegetation to facilitate maintenance.

- The screen or panel material must be extremely durable, with a low risk of damage by vandalism. Treated timber, stained concrete or metal are suitable materials (Figure 2.5 and 1.7).

Entrances

- Plantations and fences must be installed to guide wildlife towards the crossing entrance point (see File 12).

- These entrance zones must be on the same level as the adjacent land, although to optimise integration of the overpass with its surroundings, the topography must be adapted to ensure a smooth transition onto the structure.

- On flat land, the entrance should be on a gentle ramp (15% maximum slope, up to 25% in the case of overpasses in mountainous areas, Figure 2.4).

- Overpass entrance points should not be near or perpendicular to busy roads, as this hinders their use by wildlife and increases the risk of creating WVC hotspots.

- Efforts must be made to prevent subsequent urban planning decisions from reducing the utility of the overpass.

Maintenance

- If the lateral strips are revegetated, during the first few years, regular watering is essential to ensure that the vegetation takes root. Regular mowing is also necessary.

- Proper fence installation and maintenance must be planned to ensure that any damage is detected and repaired.

Figure 3.1. Diagram of a multi-use overpass.

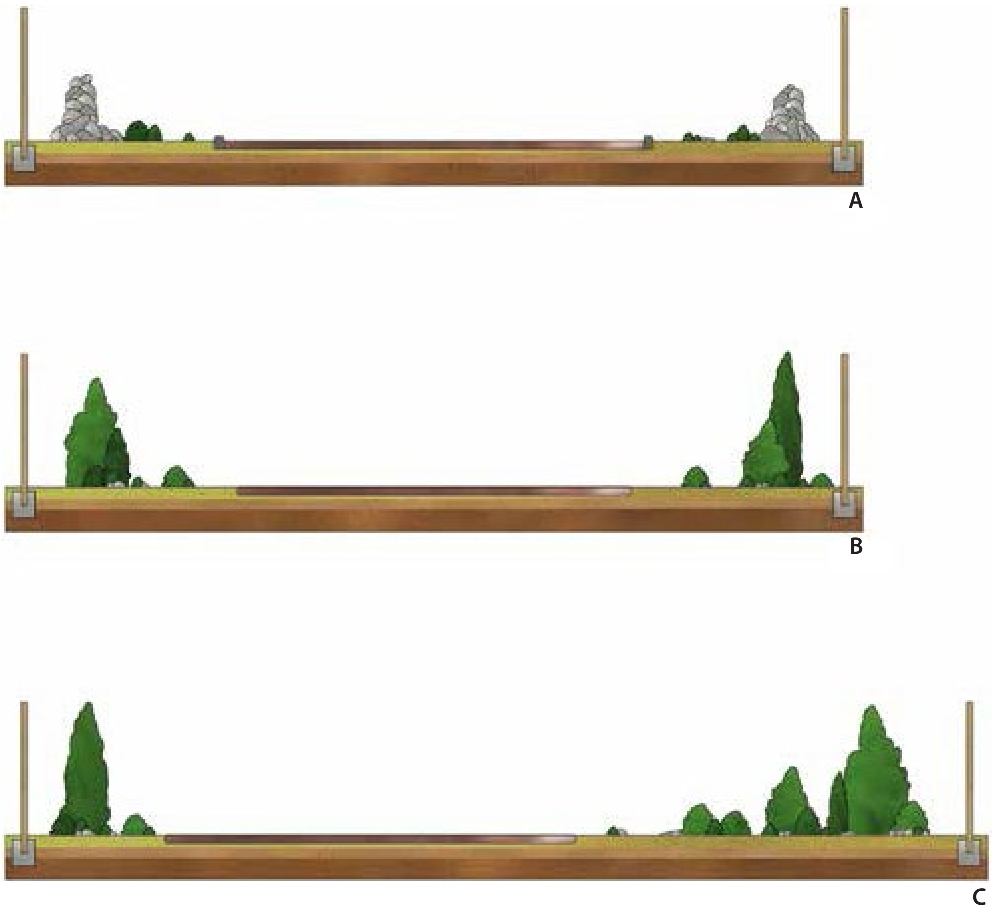


Figure 3.2. Section of tracks and verges on a multi-use overpass. The track should be set in the central section (A and B) or, if the structure is wide enough, along one side (C). In the case of overpasses in arid zones, the vegetation can be replaced by low dry stone walls or rows of stones to guide the wildlife movement and provide shelter for small animals (A).

Figure 3.3. Overpass with track in the centre of the structure and two revegetated lateral strips to encourage its use by wildlife. Photo: Territory and Sustainability Department, Government of Catalonia.

Figure 3.4. Fox using an overpass. Photo: ADIF.

Common bad practices and mistakes

Figure 3.5. Overpass that could have been adapted for wildlife by installing timber screens and revegetating the lateral strips. Photo: F. Navàs.

Figure 3.6. The lateral strip intended for use by wildlife should be covered with soil, not the gravel employed in this case. The location is also unsuitable due to the proximity of buildings. Photo: F. Navàs.

Target species and groups

- Squirrels (*Sciurus vulgaris*) and other arboreal mammals.

Uses

- Exclusively for wildlife.

Basic features and prescriptions

- Highly specific crossing aimed at reducing squirrel roadkill in particular sections where a road runs through a forest area. Also applicable in peri-urban or urbanised rural areas with a major presence of this species and a high incidence of road mortality.

- This crossing requires the construction of a mesh bridge (Figure 4.1 A) or suspended cables (Figure 4.1 B) that allow animals to cross on both sides of the road. In the case of roads with heavy traffic, platforms for animal use can be installed on road sign support structures (Figure 4.1 C).

- In the case of local roads and conventional railway lines, rope, timber or platform crossings can be installed between the branches. For wider roads (i.e., greater distance between trees), more stable and resistant structures are required.

- The design must consider the stability of these crossings to ensure that the animals do not fall off.

- This type of crossings must be employed with caution in regions with forest fire prevention regulations covering road and railway easements, which prohibit continuity between the canopies on either side of the road and the adjacent forest habitats. In such areas, the material employed must be metal or fireproof to reduce the risk of propagation.

Dimensions

- Cables with a diameter of at least 4 cm.

Photo: H-Bekkker.

- Mesh bridges: two parallel cables, spaced 20 - 30 cm apart, with mesh between them.

- 30 cm wide platform base.

Construction types

- Three types of devices can be used, depending on the road width. The most versatile structure is a mesh bridge, which can also be used by weasels and martens (*Martes martes*). On narrower roads, simple cables attached to trees are useful.

Adaptation

- No special adaptation is required apart from maintaining the continuity between the tree cover and the crossing.

Possible variations to the basic proposal

- Canopy bridges should not be accessible to predators. To reduce the risk of predation by birds of prey, an additional rope can be installed at the top of the crossing.

Maintenance

- Regular inspection to check for excess wear of the components (ropes, cables, platforms, tree trunks or support poles) and replacement of deteriorated material.

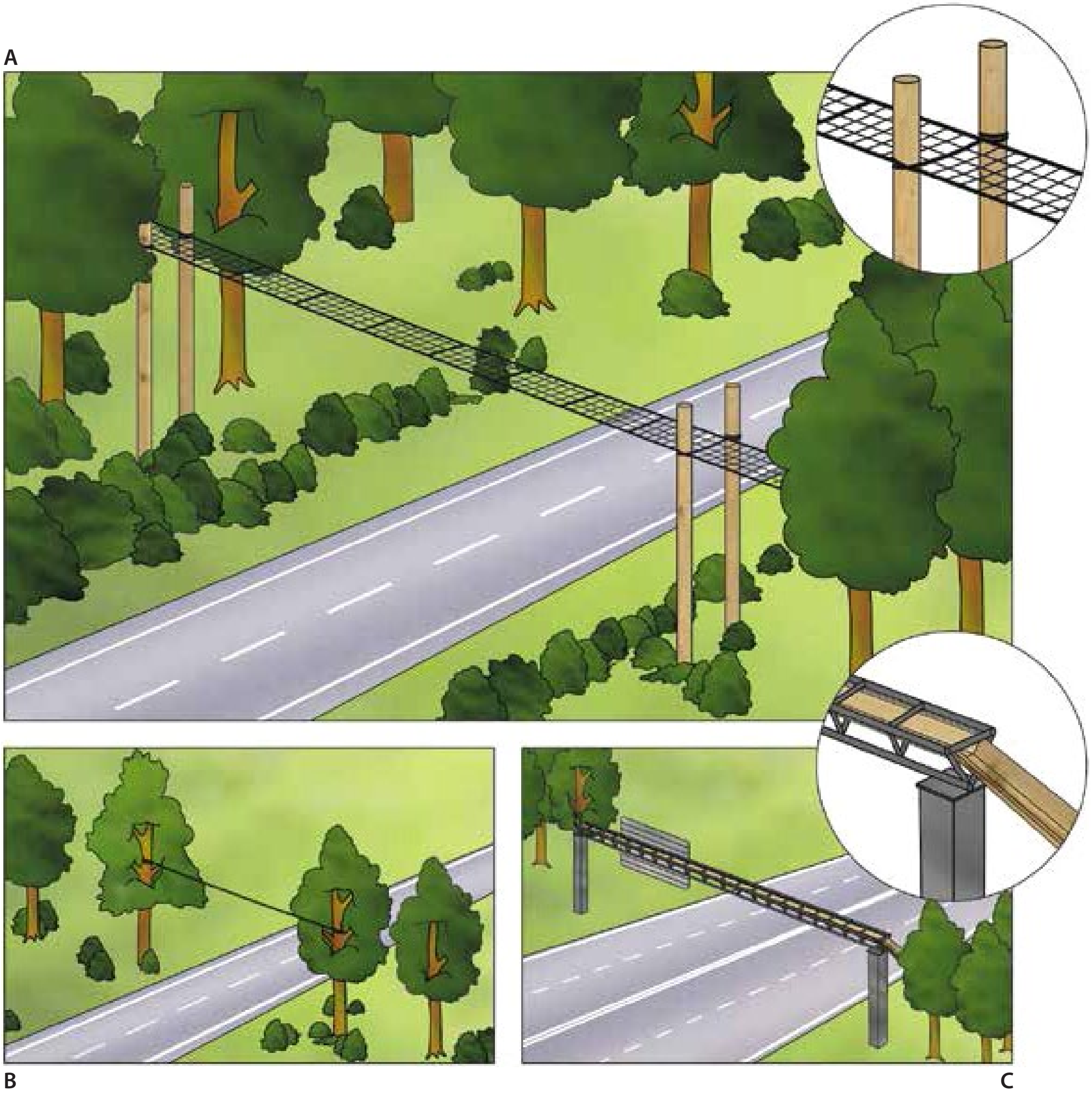


Figure 4.1. Diagram of different types of canopy bridges, depending on the road width. A: mesh bridge crossing. B: cable suspended between trees. C: platform for use as a wildlife crossing installed on road sign structures.

Figure 4.2. Timber platforms installed on a motorway sign post. Photo: H. Bekker.

Figure 4.3. Mesh bridge crossing. In areas with a high fire risk, fire-resistant material must be used to prevent propagation. Photo: Kylie Soanes.

Target species and groups

- Suitable for all types of species (including ungulates, large carnivores and also aquatic fauna) if a watercourse or stream runs beneath the structure. Also used as habitats for invertebrates and other small organisms.

Uses

- Multi-use: wildlife passage, habitat connecting between either side of roads, drainage and anthropic uses compatible with wildlife such as livestock, pedestrian, cycle and forestry tracks.

Basic features and prescriptions

- Viaducts set on piles preserve intact —or with only slight disturbance— habitats associated with watercourses, which host a remarkably rich biodiversity and also funnel wildlife movements. They also prevent disturbance to marshes and other types of wetlands.

- Viaducts are an alternative to embankments with underpasses beneath the road, which have a greater barrier effect and do not facilitate the restoration of the habitat continuity like a viaduct.

- The adaptation of a viaduct for wildlife passage essentially minimises impact on the riparian vegetation and the riverbed during the construction stage, while an oversized structure can preserve the habitats along the watercourse and its banks and maintain the shape of the land, using artificial stabilization structures as little as possible.

- Watercourse channelling must be avoided. Channelling, if absolutely necessary to ensure the viaduct's stability, must be done using structures that are compatible with fauna movement (revegetated riprap, geotextile mesh, etc.) with properly restored dry lateral strips.

Dimensions

- The length of the viaduct must not only adapt to the water conditions but also be long enough to span the entire zone occupied by riparian vegetation, if possible extended 10 m further on either side.

Photo: Territory and Sustainability Department, Government of Catalonia.

- The viaduct piles and abutments must be at least 5 m from the riparian vegetation in order to minimise the impact on the natural habitats.

- The height of the viaduct must be at least 5 m if it is above shrubs or herbaceous plant communities, and 10 m if it runs above trees.

Construction types

- Various

Adaptation

Conservation of habitats located under the structure

- To ensure the continuity of habitats in the river environs and wetlands, degradation of plant communities beneath the viaduct and its sorroundings must be avoided as far as possible. To achieve this goal, construction systems such as incremental launching, successive cantilevering and self-supporting false works should be used in areas of major conservation importance. When conventional trusses are used, only the vegetation beneath the foundations should be removed.

- All tracks used on the works site must be planned and built to avoid the destruction of important habitats and minimize the barrier effect on wildlife species that use the watercourse.

- During the construction stage, when disturbance to existing vegetation is unavoidable, the habitats must be restored, re-establishing the original shape of the land and revegetating the surface with native species from the same habitat.

- Whenever possible, the piles and abutments should be outside the zone occupied by the riparian vegetation, leaving additional margins on both sides. In these areas, the existing plant communities or agricultural zones must be maintained, avoiding uses that are incompatible with wildlife movements (Figure 5.3).

- Piles or rows of stones and logs set along the viaduct provide shelter and micro-habitats for wildlife and encourage the presence of invertebrates, reptiles and other small animals (Figure 5.4). These elements are particularly useful during the initial period, when revegetation is still incomplete. Other characteristic features of the surrounding landscape such as low dry stone walls can play the same role.

Access adaptation

- Revegetation and a perimeter fence must be installed to guide wildlife from the surrounding habitats to the viaduct (see File 12).

- Perimeter fencing beneath the viaduct must be avoided, since a significant reduction in the effective width of the sectors where wildlife can move through the infrastructure would occur (Figure 5.9).

- Large stone blocks can be placed beneath the viaduct if there is a risk of the land being used by vehicles.

Possible variations to the basic proposal

- Road infrastructure beneath viaducts adapted for wildlife passage should be avoided. This option should only be considered in the case of large structures and low or moderate traffic density. In such cases, the road should be located near one of the viaduct abutments. Vegetation screens must also be planted at some distance from the roadway to reduce disturbance by vehicle traffic, and the verges must be mown to mitigate WVC (see File 16).

- In the case of viaducts where a high rate of bird roadkill is envisaged, elements must be installed on the viaduct edges to prevent flight paths from intersecting with vehicles.

- Some viaducts include noise barriers in the form of lateral screens that reduce the effect of traffic noise on the surroundings. In such cases, transparent screens that cause bird roadkill must be avoided or painted graphically to alert birds to their presence (see File 19).

Maintenance

- Regular inspection of the land beneath the viaduct must be planned to check for obstacles that may hinder the passage of animals and prevent inappropriate uses such as as equipment parking areas, temporary storage of farm material, etc.

- If the land affected during the construction stage has been restored, all revegetation must be properly maintained to ensure that the plants take root.

- Proper fence installation and maintenance must be planned to ensure that any damage is detected and repaired.

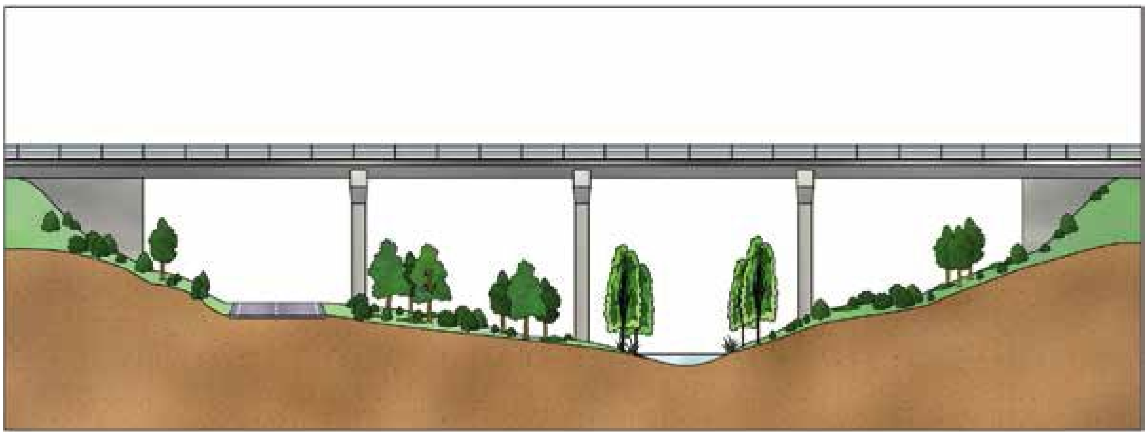


Figure 5.1. Distribution of different uses under a viaduct: watercourse, revegetated areas kept dry, and a road located near one of the viaduct abutments. Piles must be located outside the river channel to preserve the continuity of the riparian corridor. If a road runs beneath the viaduct, its verges must be mown to reduce WVC, with no fencing that may hinder wildlife movements.

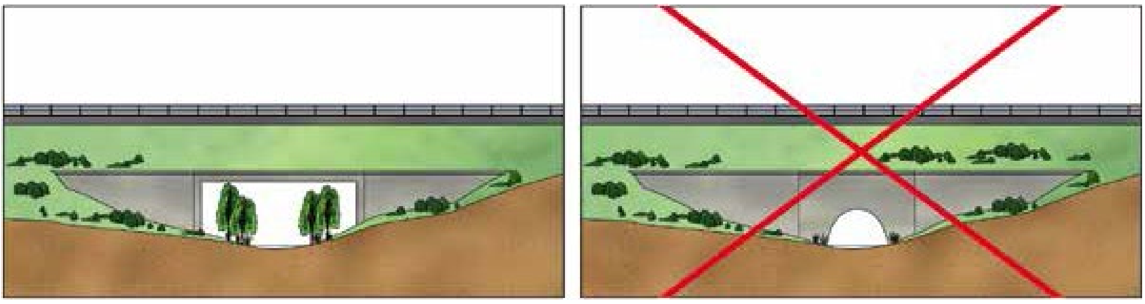


Figure 5.2. Frame bridges and archs are less suitable than viaducts for roads that cross a river valley. If such structures are used, their size should permit the continuity of the riparian vegetation.

Figure 5.3. Viaduct that allows a complete continuity of forest and riparian habitats. Photo: C. Rosell.

Figure 5.4. Logs placed to provide microhabitats for small animals beneath the viaduct. Photo: Parc de l'Alba Centre Direccional.

Common bad practices and mistakes

Figure 5.5. Destruction of watercourse habitats during construction. Photo: C. Rosell.

Figure 5.6. Works track that has interrupted the continuity of the watercourse. Photo: R. Campeny.

Figure 5.7. Incorrect location of viaduct piles in the watercourse. Photo: F. Navàs.

Figure 5.8. Inappropriate use of land beneath a viaduct. Photo: C. Rosell.

Figure 5.9. Long section of perimeter fencing under a viaduct which prevents animal passage. Photo: Minuartia.

Figure 5.10. Bridge with a concreted zone underneath that prevents the continuity of the riparian vegetation. Photo: Minuartia.

Target species and groups

- Ungulates, large carnivores (bear, wolf and Iberian lynx).

Other target groups

- Small mammals and reptiles (including chameleons and tortoises). Amphibians, if there is enough ambient moisture, appropriate fencing and microhabitats with the moisture required by this group (see File 11).

- Suitable adaptations can guide bat and bird flight paths and facilitate the movement of partridges and other running birds.

Uses

- Exclusively for wildlife.

Basic features and prescriptions

- Underpasses are highly effective as wildlife crossings but pose more difficulties for habitat connection, as they only permit a limited vegetation growth.

- They are suitable for restoring permeability in sections where the infrastructure runs along an embankment.

- Their location must coincide as closely as possible with regular wildlife routes.

- Vehicles must not use these structures, and disturbance by human activity must be minimised.

Dimensions

- Minimum height: 3.5 m.

- In areas where wild boar and roe deer are present, minimum width: 7 m and openness index (W x H/L) > 0.75.

- In areas where red deer is present, minimum width: 12 m and openness index: (W x H/L) > 1.5.

- Recommended width for optimised effectiveness: 15 m.

- These underpasses must be as short as possible. Therefore, they must be built perpendicular to the road whenever possible, and must not be more than 70 m long.

Photo: C. Rosell.

Construction types

- Open section structures: Framebridge or arch. Box underpasses are less suitable as they cannot retain the natural substrate. In addition, such frames require wide walls to separate different cells, which reduces the usable width of each one.

Adaptation

Interior adaptation

- The underpass interior must be well drained in order to avoid flooding, even after periods of heavy rain, since the presence of a sheet of water hinders the passage of many species. If seasonal floods are envisaged, the base of the structure must be adapted to ensure permanent dry strips at least 1 m wide.

- The underpass base should be covered by natural substrate. Structures with an open section such as frames or vaults are therefore preferable.

- Revegetation is only viable in the sections nearest the entrances, since the conditions in the central section of the underpass are unsuitable for vegetation growth. Rows of stones, tree stumps, logs or dry branches can be placed along both sides of the structure to provide shelter for small animals and facilitate its use.

Entrances

- Revegetation and perimeter fencing must be installed to funnel wildlife from the surrounding habitats towards the underpasses (see File 12).

- Underpass entrance points should not be near or perpendicular to busy roads, as this hinders their use by wildlife and increases the risk of generating WVC hotspots.

- If the road infrastructure above the crossing carries heavy traffic, opaque screens must be installed at the top of the structure to reduce disturbance caused by vehicle traffic.

- The material used for these screens must be highly durable and have a low risk of damage by vandalism.

- Large boulders, tree trunks etc. at the underpass entrance prevent uncontrolled access by vehicles. Transversal barriers (e.g. timber or metal rods set 50-70 cm above the ground) that do not obstruct the passage of wildlife are another alternative (Fig. 1.11).

- Signposts prohibiting vehicular traffic should be installed.

Possible variations to the basic proposal

- If closed section structures are used, the concrete surface should be covered with natural material.

Maintenance

- Proper fence installation and maintenance must be planned to ensure that any damage is detected and repaired.

- Maintenance work should include monitoring for inappropriate use of the underpass and its surroundings (e.g., by vehicles or for temporary construction material storage) which may hinder its use as a wildlife crossing point. Rubbish and any other such material must be removed.

Figure 6.1. Diagram of a large mammal underpass.

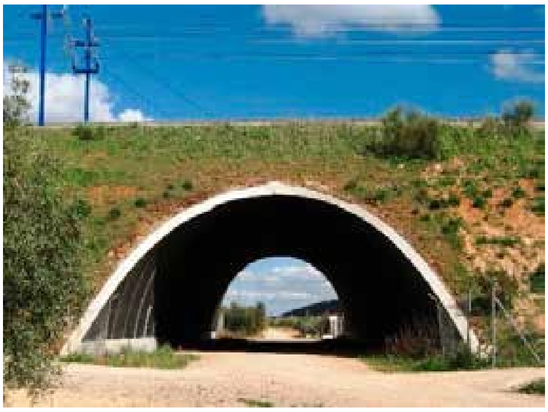


Figure 6.2. Broad single arch underpass without partitions. Photo: ADIF.

Figure 6.3. Natural soil underpass base. The lack of light and moisture do not allow vegetation growth inside the structure. Photo: C. Rosell.

Figure 6.4. Revegetation facilitates the integration of the underpass with its surroundings. Photo: Territory and Sustainability Department, Government of Catalonia.

Figure 6.5. Structure with well adapted entrance. Photo: M. Fernández Bou.

Figure 6.6. Iberian lynx using an underpass. Photo: Project LIFE + Iberlince.

Figure 6.7. A mongoose group using an underpass. Photo: Development and Environment Department, Government of Castilla y León.

Figure 6.8. Red deer using an underpass. Photo: CEDEX. Autonomous University of Madrid.

Common bad practices and mistakes

Figure 6.9. Flooded underpass base hinders its use by wildlife. Photo: C. Rosell.

Figure 6.10. Incorrect fencing of the underpass walls permits animal access to the embankment. Photo: C. Rosell.

Target species and groups

- Ungulates, large carnivores (bear, wolf and iberian lynx).

Other target groups

- Small mammals and reptiles (including chameleons and tortoises). Also amphibians, if there is enough ambient moisture, suitable fencing (see File 11) and microhabitats with the moisture required by this group.

- With appropriate adaptation, this type of underpass can guide bat and bird flight paths and facilitate movement by partridges and other running birds.

Uses

- Multi-use: Wildlife crossing, livestock, pedestrian, cycle, forestry track and drainage.

Basic features and prescriptions

- These underpasses restablish forestry and livestock tracks that can be adapted to encourage their use as wildlife crossing points.

- Optimum structures combine wildlife crossing with drainage, livestock trail or pedestrian, cycle or forestry track with low traffic density.

- Modifications to encourage their use as wildlife crossings basically include leaving natural soil on the floor or maintaining two unpaved lateral strips for animals to move freely on a base with a similar surface texture to the surroundings. The entrances must also be adapted.

Dimensions

- Minimum height: 3.5 m.

- In areas where wildboar and roe deer are present, minimum width 7 m, and openness index (W x H/L) > 0.75.

- In areas where red deer is present, minimum width: 12 m; and openness index (W x H/L) > 1.5.

Photo: C. Rosell.

- Recommended width for optimised effectiveness: 15 m.

- Minimum width of lateral strips with natural soil: 1 m.

- These underpasses must be as short as possible. Therefore, they must be built perpendicular to the road whenever possible, and must not exceed 70 m long.

Construction types

- Open section structure: Frame bridge or arch. Box underpasses are less suitable due to their lack of a natural soil base. In addition, such frames require wide walls to separate different cells, which reduces the width of each one.

Adaptation

Underpass interior

- The underpass interior must be well drained in order to prevent flooding, even after periods of heavy rain, since the presence of a sheet of water is an impediment to many species. If seasonal floods are envisaged, the base of the structure must be adapted to include permanent dry ledges at least 1 m wide.

- If wildlife use is combined with traffic, the central surface may be paved or covered with gravel, but the lateral strips must have a layer of natural soil.

- Revegetation is only viable in the sections nearest the entrance, since the conditions in the central section of the underpass are unsuitable for vegetation growth.

- No kerbs or other vehicle-wildlife separations must be installed. Safety barriers and similar must be avoided as far as possible.

Location of the section for vehicle traffic

- The vehicle track should be located in the centre of the structure, allowing animals to access the two unpaved strips on either side.

- This distribution may vary in the case of large underpasses, with a 2 m wide unpaved strip on one side reserved for wildlife, then the vehicle roadway and finally another strip for wildlife occupying the rest of the structure.

Entrance adaptation

- Plantations and perimeter fences must be installed to guide wildlife towards the underpass entrance point (see File 12).

- To encourage use by bats, see recommendations in File 12.

- Underpass access should not be near or perpendicular to busy roads, as this hinders their use by wildlife and increases the risk of generating WVC hotspots.

- If the road infrastructure above the crossing carries heavy traffic, opaque screens must be installed at the top of the structure to reduce disturbance by vehicles.

- The material used for these screens must be extremely durable and have a low risk of damage by vandalism.

Possible changes to the basic proposal

- Rows of stones, tree stumps, logs or dry branches can be placed along the sides of the structure to provide shelter for small animals and facilitate its use.

Maintenance

- Proper fence installation and maintenance must be planned to ensure that any damage is detected and repaired.

Figure 7.1. Diagram of a multi-use underpass.

Figure 7.2. Railway underpass used by low-frequency rail traffic and wildlife. Photo: V. Hlavac.

Figure 7.3. Restoration of a forest track, made compatible with wildlife use. Photo: M. Fernández Bou.

Figure 7.4. Unpaved track and fence tied in with the underpass wing walls encourages wildlife usage. Photo: M. Fernández Bou.

Figure 7.5. Cattle underpasses can also be adapted to facilitate their use by wildlife. Photo: E. Perapoch.

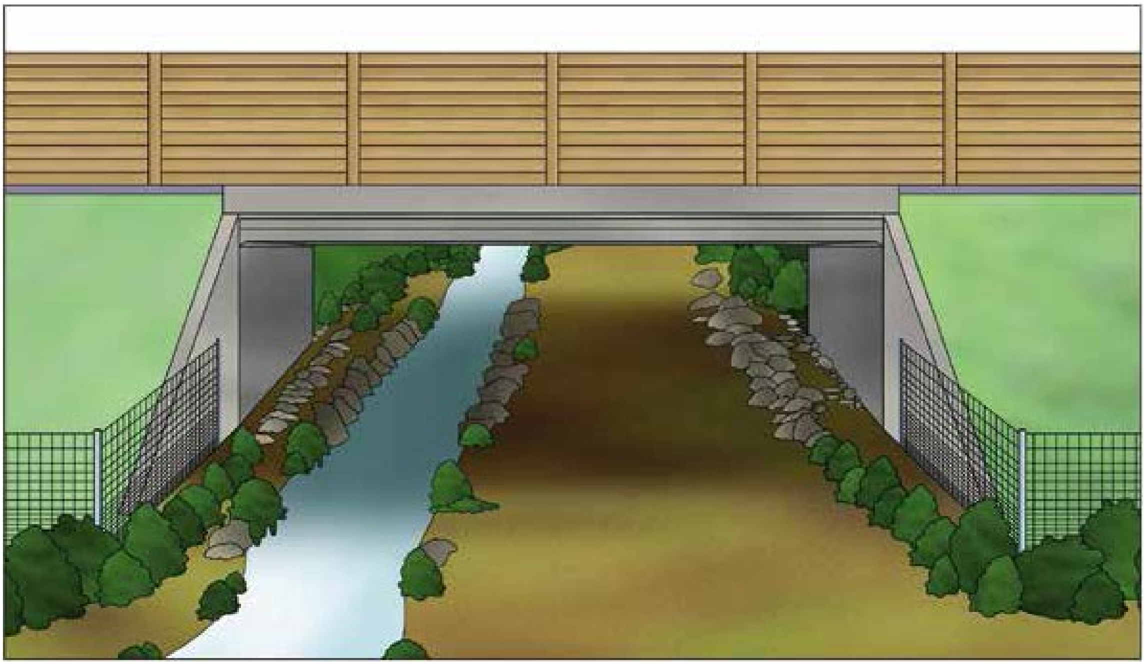


Figure 7.6. A ditch along one side of the structure leaves a large section free for use by wildlife.

Common bad practices and mistakes

Figure 7.7. Riprap hinders the passage of wildlife. Photo: F. Navàs.

Figure 7.8. Inappropriate use of an underpass to park machinery. Photo: M. Fernández Bou.

Target species and groups

● Carnivores small and medium size as weasels, genet (*Genetta genetta*), etc. and lagomorphs (rabbits and hares).

Other target groups

● Small mammals and reptiles, including chameleon (*Chamaleo chamaleon*) and tortoises. Also amphibians, if there is enough ambient moisture, proper fencing (see File 11) and microhabitats with the moisture required by this group.

● This type of underpass may be suitable for small bat species with agile, low flight, e.g., *Rhinolophus spp*, *Myotis spp*. and *Plecotus spp*. (See File 22).

● It can also facilitate the passage of partridges and other running birds (see File 22).

● Not suitable for large carnivores or ungulates, although wild boar have become habituated to its use in some regions.

Uses

● Exclusively for wildlife.

Basic features and prescriptions

● Specific underpasses must be built for small and medium sized species beneath sections of road that require greater permeability for small vertebrates but do not have enough culverts that can be adapted for such fauna. These structures can also be built beneath roads already in operation in roadkill hotspots for valuable species that may use these types of underpass.

● Appropriate for road sections on embankments.

● Preferably built using box or rectangular frames, which provide a larger base than pipe structures.

Dimensions

● Minimum: 2 x 2 m.

● These underpasses must be as short as possible. Therefore, they must be built perpendicular to the road whenever possible, and must not be more than 70 m long.

Photo: M. Fernández Bou.

Construction types

● Frame bridge, arch and box underpasses.

Adaptation

Interior

● The underpass interior must be well drained in order to prevent flooding, even after periods of heavy rain, since the presence of a sheet of water is an impediment to many species. If seasonal flood periods are envisaged, the base of the structure must be adapted to include permanent dry strips at least 50 cm wide, (File 9).

Entrances

● Plantations and fences must be tied in with the underpass wings to funnel wildlife towards the entrance point (see File 12).

● To encourage use by bats, see recommendations in File 12.

● Underpass access should not be near or perpendicular to busy roads, as this hinders their use by wildlife and increases the risk of generating WVC hotspots.

● If the road infrastructure above the crossing carries heavy traffic, opaque screens must be installed at the top of the structure to reduce disturbance by vehicles.

● The material used for these screens must be extremely durable and have a low risk of damage by vandalism.

Possible variations to the basic proposal

- Rows of stones, tree stumps, logs or dry branches can be placed along the sides of the structure to provide shelter for small animals and facilitate its use.

Maintenance

- Proper fence installation and maintenance must be planned to ensure that any damage is detected and repaired.

- Regular maintenance work must be planned including the removal of rubbish, built-up sediment and other material that may block the crossing path.

Figure 8.1. Diagram of an underpass for small vertebrates.

Figure 8.2. Rows of dry branches provide shelter for small animals. Photo: P. Robles.

Figure 8.3. Iberian hare using a wildlife underpass. Photo: ADIF.

Figure 8.4. Correct installation of the fence makes the entrance easier to locate by fauna. Photo: M. Fernández Bou.

Figure 8.5. Underpass entrance-embankment integration. Photo: M. Fernández Bou.

Target species and groups

- Potentially suitable for all types of wildlife, depending on size and also degree and frequency of water cover.

- Drains that are permanently covered with water and have lateral ledges are only suitable for small mammals and some carnivores, particularly semi-aquatic mustelids: European mink (*Mustela lutreola*) and otter, and also for marten (*Martes foina*) and genet.

Other target groups

- Lagomorphs, small mammals, reptiles and amphibians, the latter if there is sufficient moisture and suitable fencing is installed (see File 11).

- If the culvert has the appropriate dimensions (see section 3.6) and is properly adapted, it can be used by ungulates and large carnivores (see also File 7). Lateral ledges or shelves are not suitable for ungulates.

- This type of structure may be suitable for small bat species with agile, low flight, e.g., *Rhinolophus spp*., *Myotis spp*. and *Plecotus spp*. (see File 22).

Uses

- Multi-use: Wildlife crossing and drainage.

Basic features and prescriptions

- Drain adaptation is an effective way to facilitate the passage of small and medium sized vertebrates (particularly mammals) as these structures coincide with thalwegs and valleys that funnel the movements of many species. Furthermore, these structures are usually undisturbed by human presence.

- Drain adaptation is a particularly good practice for roads in Mediterranean regions, since torrential rainfall requires large structures which are completely dry for most of the year.

- Few changes are required to adapt them to facilitate fauna movement, basically the use of suitable material (corrugated steel is not compatible with fauna passage), lateral ledges must remain dry to prevent the structure from being completely flooded, and adaptation of the entrances (Figure 9.1).

Photo . C. Rosell.

- Structures with pits or manholes at one or both of the entrances are not adaptable to the passage of wildlife (see File 20).

- The water carrying capacity of the culvert must not be reduced by the adaptations.

Dimensions

- The culvert dimensions depend on the water flow. They must have a minimum section of 2 x 2 m (or 2 m in diameter in the case of circular structures, which are less desirable) for adaptation to wildlife passage.

- In the case of habitat defragmentation projects for roads in operation, the adaptation of culverts less than 2 m width could be considered only when target species are mustelids (badger, European mink, otter, etc.).

- Minimum width of ledges: 0.5 m. Height defined by the ordinary flood level.

- Recommended slope of entrance ramps to lateral ledges: 30º. Maximum: 45º.

- Modified culverts must have at least the dimensions stipulated for multi-use underpasses (File 7) if they are to be used by ungulates.

Construction types

- Frame bridge, arch or box underpasses. Pipe structures are less recommendable, but they can also be adapted.

Adaptation

Interior

- If the base of the structure is expected to be covered by water permanently or for long periods of time, two lateral platforms or ledges on either side of must be installed and remain dry, even in periods of peak flow, with a suitable connection with the surrounding habitat.

- In the case of culverts composed of several cells, the lateral ledges or platforms must be installed in the two outermost sections at least.

- Permanently flooded culverts can be adapted for large mammals by channelling the watercourse through the centre or side of the structure, as shown in File 7 (Figure 7.6).

- A flat base covered with concrete should be built in round drain pipes.

Entrances

- The lateral ledges or dry sections with a natural base must be well connected to the surroundings at both ends. If the entrance is on a different level from the ground, access ramps must be built to connect the interior with the banks of the watercourse outside.

- To facilitate animal access from the surroundings into the structure, obstacles in the form of steps, undercuts etc. must be avoided. Stone riprap is one of the best resources to ensure continuity between the concrete base of the structure and the adjacent land. It also helps to prevent one of the common problems: gullies in the bed at the culvert outlet, which prevent or hinder animal movements.

- If the entrance is at the top of an embankment, the usual staggered outlets should be replaced by stone beds or more open lateral walls of the outlet to generate a 30º slope (Figures 9.7 and 9.8). Another option if none of the previous solutions is viable, is the construction of small ramps or platforms that allow animals using the structure to access the slopes easily.

- The installation of grids, rods or other elements that block the entry of plant debris and other objects to the culvert can hinder or completely stop the passage of animals. If they must be installed, they should be designed to permit entrance to the lateral ledges.

- Some mammal species, particularly semi-aquatic mustelids such as the European mink and otter, move along waterways and amongst the riparian vegetation that provides them with shelter. In order to lead these animals towards the adapted culvert, there must be continuity between the entrance to the structure and the riparian vegetation (see File 12).

- Fences should be installed along the edges of the structure, with no discontinuity, and thus guide the wildlife towards the entrance (see File 12).

- To encourage use by bats, see recommendations in File 22.

Possible variations to the basic proposal

- An alternative to the construction of lateral concrete ledges is the installation of raised platforms or shelves (e.g. in treated wood or precast concrete to ensure durability), set above the waterline and anchored to the walls or the top of the structure (Figures 9.2 C, 9.5 and 9.6).

- If an existing corrugated steel culvert must be adapted, its base must be fully rendered with concrete.

- In the case of habitat defragmentation projects on roads in operation, in which culverts that may be completely flooded are adapted for otters and European mink, two small dry pipes (up to 40 cm in diameter) can be installed at the top of both sides of the structure (Figure 9.2 D). This measure is not suitable for other species.

- In areas where watercourses undergo prolonged flooding, the lateral ledges should be constructed in the form of steps in order to remain operative and adapt to changes in the water level (Figure 9.2 B).

Maintenance

- Proper fence installation and maintenance must be planned to ensure that any damage is detected and repaired.

- Regular maintenance work must be planned for these culverts including the removal of rubbish, built-up sediment and other material that may block the crossing path.

This monitoring is particularly necessary after floods.

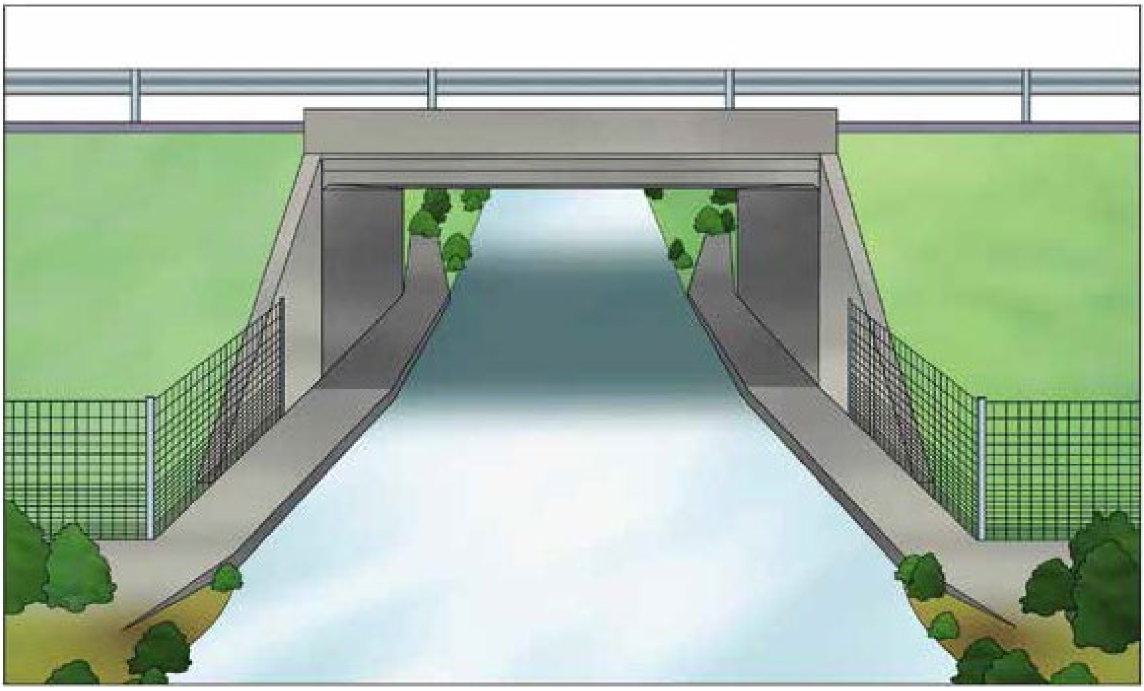


Figure 9.1. Diagram of a culvert adapted for terrestrial wildlife.

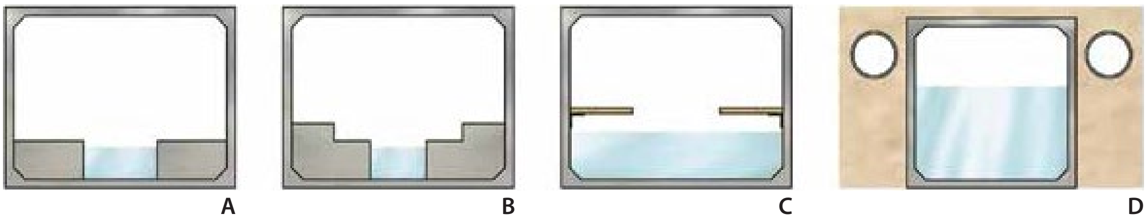


Figure 9.2. Cross sections of culverts with dry platforms. Lateral concrete ledges can have different heights if there are major variations in the water level (B). Platforms (C) allow culverts to be adapted without reducing their section. Option D is not recommended for general use. It is only applicable to facilitate use by the European mink and otter.

Figure 9.3. A ramp facilitates optimal connection between the dry ledges in the culvert and the surrounding natural habitats. Photo: H. Bekker.

Figure 9.4. Interior of a culvert with dry lateral ledges. Photo: F. Navàs.

Figure 9.5. Platform that facilitates animal movement through a culvert. Photo: Development and Environment Department, Government of Castilla y León.

Figure 9.6. Otter using a ledge inside an adapted culvert. Photo: V. Hlavac.

Figure 9.7. Stone bed replacing a stepped culvert outlet. Photo: C. Rosell.

Figure 9.8. Protective culvert outlet on an embankment with sloping side walls adapted to facilitate movement by wildlife. Photo: C. Rosell.

Common bad practices and mistakes

Figure 9.9. Canal fences prevent animals from returning to the surroundings. Photo: F. Navàs.

Figure 9.10. Lack of ramps connecting the dry ledges with the adjacent areas. Photo: F. Navàs.

Figure 9.11. Stepped outlet: a trap for wildlife. Photo: F. Navàs.

Target species and groups

- Fish and other aquatic organisms.

Uses

- Multi-use: Wildlife crossing and drainage.

Basic features and prescriptions

- All structures that channel a permanent watercourse must be adapted to facilitate the downstream and upstream movement of fish and other aquatic fauna. The latter is essential for species that swim up rivers to spawn.

- The main impediments to mobility by fish are erosion at the culvert outlet caused by a drop or interior turbulence, excess water velocity or insufficient depth to allow fish to swim.

- The purpose of basic adaptations of culverts is to eliminate all obstacles for fish, facilitate their movement through the structure and ensure that it provides similar conditions to the main watercourse. For this purpose, the structure must be as short as possible and replicate the water depth, speed, turbulence, width and angle of the natural watercourse. Structures with insurmountable drops must not be adapted.

- Culverts adapted for fish should preferably have an open section (bridges or archs) that allow the natural bed to be maintained. Structures with closed sections (boxes or pipes) must be oversized and embedded in the ground to leave the base 15-20 cm below the level of the watercourse bed (Figure 10.1).

- Structures containing pits, manholes, stepped exit channels or interior steps or partitions cannot be adapted for fish.

- Adaptations must not diminish the water carrying capacity of the culvert.

Dimensions

- Adaptation is only recommended for drainage structures with a slope of less than 30 °.

- The minimum water depth varies with the fish species in each watercourse. In general, a minimum depth of 20 cm must be maintained, although experts should be consulted to adapt the dimensions to the swimming limitations of the fish species present in each river or stream.

Photo: M. Fernández Bou.

- The height of the obstacles that fish can overcome when swimming upstream varies with the ability of each species and the physical state and size of the individual fish. Salmon, mullet and some barbel species have the best swimming and leaping ability (15-30 cm.). In contrast, species with a limited ability to overcome obstacles include threespined stickleback (*Gasterosteus aculeatus*), freshwater blenny (*Salaria fluviatilis*), iberian loach (*Cobitis paludica*) and Mediterranean barbel (*Barbus meridionalis*).

Construction types

- Frame bridge or arch. Closed section structures (both round and rectangular) are less suitable, but can be adapted to facilitate fish movements.

Adaptation

Interior

- The slope must be adapted to ensure that the water velocity inside the culvert is similar to the natural watercourse.

- Height differences inside or at the outlet of the culvert must be avoided, since drops of just 5-10 cm can prevent some species and age groups from moving upstream.

- At least one part of the culvert must be covered by water to facilitate fish movement. A deeper channel may have to be dug to ensure permanent water circulation in periods of low water flow.

- Drains should also include adaptations to permit the passage of terrestrial fauna (see File 9).

Outlets

- The construction of small dammed areas facilitates fish movement at the culvert outlet.

- If the culvert is for irrigation canals or ditches, planners should consider the installation of grating or other systems to prevent waterborne sediment from building up at the mouth, while still allowing fish to swim freely.

Variations to the basic proposal

- If the recommended construction types (open or closed section structures embedded in the ground) are not viable, designers must ensure that there is no discontinuity, erosion, undercutting or other such elements that may prove insurmountable for fish. Stone beds and attenuating bowls are options that prevent erosion below the culvert outlet and ensure continuity between the base of the structure and the natural bed of the watercourse.

- In some cases, baffles can be installed inside the culvert to reduce the water velocity and turbulence and also increase the depth of the water. Baffles are set across the direction of the water flow to dissipate kinetic energy and thus reduce the water speed and turbulence. The assessment of hydraulic engineers is necessary to ensure the correct number and size of deflectors, especially their height.

Maintenance

- Regular maintenance work must be planned for these culverts, including the removal of rubbish, built-up sediment and other material that may block the flow. This is particularly necessary after floods.

- Regular dredging is necessary in dammed outlet zones in order to prevent silt build-up.

- Debris retention systems at the entrance to culverts for irrigation ditches or canals must be cleared regularly in order to prevent the excessive build-up of waterborne solid matter.

- Culverts with interior baffles must be maintained regularly to ensure that broken panels and built up sediment do not diminish their utility. Broken panels can also harm fish fauna.

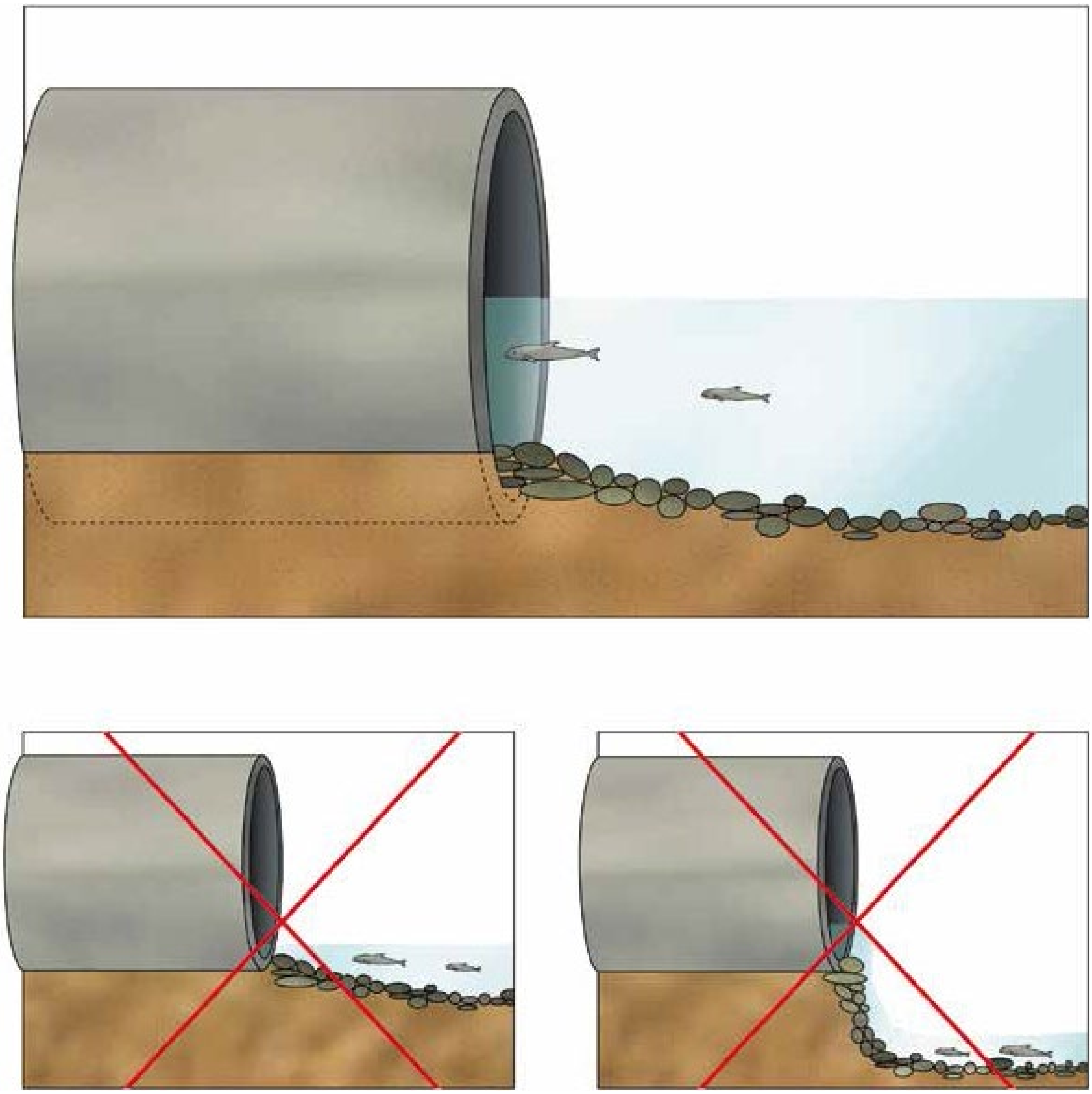


Figure 10.1. Top, culvert pipe adapted to facilitate aquatic fauna passage. Bottom, two alternatives that hinder up-stream movement by fish due to shallow water or a significant height differerence.

Common bad practices and mistakes

Figure 10.2. Drains located on a ford, hindering fish movements. Photo: F. Navàs.

Figure 10.3.Step inside a culvert hindering the movement of aquatic fauna. Photo: J. Dufek.

Figure 10.4. Excessive step that can only be surmounted by strong adult fish. Photo: J. García Molinos.

Figure 10.5. Erosion at the base of a structure, generating an insurmountable obstacle for aquatic fauna. Photo: M. Clavero.

Target species and groups

- Amphibians.

Other target groups

- Small carnivores, mammals and some reptiles.

Uses

- Exclusive for wildlife.

Photo: J. Niederstrasser.

Basic features and prescriptions

- Amphibians have unique requirements, as they cannot orient their movements to find the entrance to a wildlife crossing. The effectiveness of these structures thus largely depends on specific fencing that intercept and guide them towards the crossing (Figure 11.1).

- Major amphibian hotspots are located on road sections where the infrastructure intersects regular migration routes towards their breeding ground (ponds, lakes or rivers). Some species show a high degree of synchronisation, both when migrating to these areas and during the subsequent dispersal of the young towards terrestrial environments, generating a mass movement of individuals in the same direction for several days. Crossings should preferably be installed on sections of road that intersect these routes year after year with a view to preventing amphibians from accessing the road and generating a major roadkill hotspot.

- Problem sections must be permeabilised by installing several amphibian crossings and an appropriate fence structure to funnel them towards these crossings.

Dimensions

- The crossing width is recommended to increase with its length.

Crossing length (m)	<20	20-30	30-40	40-50
Width x Height (m)	1 x 0.75	1.50 x 1	1.75 x 1.25	2 x 1.50

- Maximum distance between crossings: 60 m, or up to 100 m if the guide fence has a slight funnel shape to facilitate movement towards the crossing.

- Minimum height of the guide fence: 0.4m or 0.6 m if agile frog (*Rana dalmatina*) is in the area.

Construction types

- Pipe structures can be adapted, but boxes are preferable since their vertical walls facilitate amphibian movement in the right direction.

Adaptation

Crossings

- Structures must have no steps or obstacles at the entrance or inside the crossing. Gently sloping ramps must be included if there are any steps between the exterior and interior of the crossing.

- Crossings must be well drained to prevent flooding. Amphibians require moisture, but not structures that are totally covered by water. A depressed sector where permanent water can run is a positive improvement as this maintains the necessary moisture level.

Fencing - guide structures

- Guide structures consist of a 40 cm high fence in concrete, treated wood or some other opaque material. Standard mesh fencing, even with the smallest diameter, is unsuitable as some species try to climb them instead of moving along the fence toward the crossing.

- The base of the fence must hug the ground perfectly, with no gaps. The interface with the crossing entrance must not have any discontinuities, edges or protrusions that might hinder the movement of animals. Even the smallest gap on the ground or at the crossing entrance will allows amphibian to climb onto the road, and the crossing will lose its effectiveness.

● Completely vertical fence are preferable. Those with rounded angles hinder mowing and do not help the fauna to move forward. The guiding fence should be installed at the base of —and as close as possible to— the road embankment, without hindering mowing along the verge. The crossing itself must be as short as possible.

● At intersections with tracks, transversal gratings should be installed across the entire width of the track to block amphibian access. They must be more than 40 cm wide to prevent amphibians from jumping across them, with a separation of at least 6 cm between elements to prevent animals from being trapped. Animals that fall through the gaps in the grid should be able to escape laterally and move along guide structures back to the crossing points. The maximum angle of these escape ramps is 45 ° (see File 20).

● The outer surface of the ground adjacent to the guiding fence must be well shaped and have no steps or vegetation in order to avoid any hindrance to the amphibians' movements. However, vegetation cover is useful in the surroundings as a refuge for migrating individuals.

● The ends of the fence should be curved towards the exterior of the track in order to guide the animals back to the natural environment in case they move in the opposite direction to the crossings.

Possible variations to the basic proposal

● Some experts suggest that day-light for crossings encourages their use and thus recommend that the crossings should be covered with gratings. However, there are no conclusive results to confirm the influence of this aspect on the crossing's effectiveness.

● One-way crossings are another suitable design for amphibians, although they pose many problems that must be assessed prior to their construction. They involve the construction of ditches parallel to the road. Amphibians fall into them and are forced to use crossings whose entrances are inside the ditches. These crossings are sloped towards the opposite end to encourage the amphibians to move in that direction. Problems identified with these types of crossings include the risk of the catch ditches acting as traps for small animals, particularly invertebrates. If such systems are chosen, it is also necessary to install safety barriers along the edges of the roads in the same section.

Temporary barriers and manual transfer of amphibians during migration periods

● The seasonal variation of the problems associated with amphibians means that a temporary system aimed at preventing roadkill can be employed in areas where migratory routes intersect with roads. This systems consists of a fence made of smooth, opaque material which prevents amphibians from accessing the road and guides them towards buckets where they can stay for some time before being collected and transferred manually across the road. These systems require the collaboration of a large number of people, and they are often only feasible when volunteer groups offer to participate.

● Temporary fences that prevent amphibians from crossing roadways and lead them towards the buckets should be made of completely smooth, opaque material (plastic or canvas) with a minimum height of 40 cm to prevent amphibians from climbing or jumping over them. They should be staked on the road side, not on the side where the animals move.

● The collection buckets must be attached to these fences to ensure that the animals fall in. The buckets must be least 30-40 cm high, sunk into the ground roughly 10 metres apart, with the edge set at ground level. One must be installed at either end of the guidance structure to prevent amphibians from accessing the road at the end of the fenced section.

● One to three inspections for amphibians and transfers every 24 hours are necessary, although this period will be adjusted according to the migration intensity. At peak periods, checks at intervals of up to every half hour may be necessary.

Maintenance

● Proper installation and maintenance of guide fencing in permanent structures must be ensured, and any damage must be detected and repaired.

● Regular maintenance must be planned to remove debris, silt or any other material that may hinder the system's effectiveness.

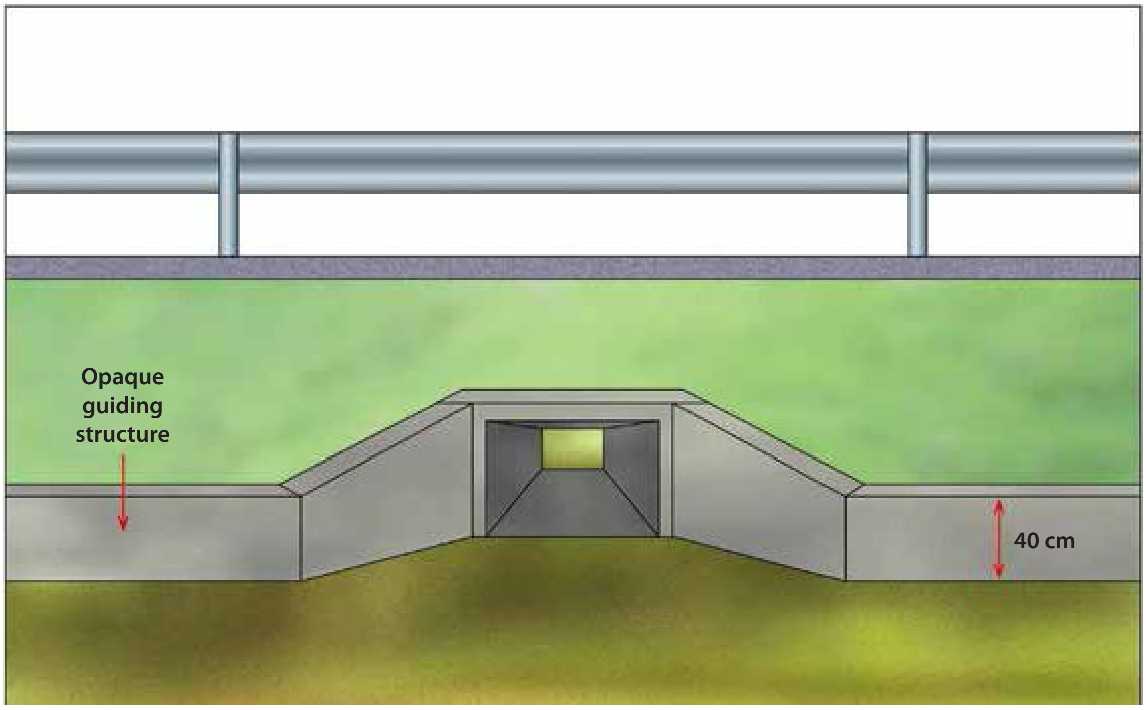


Figure 11.1. Diagram of an amphibian crossing.

Figure 11.2. Interior of an amphibian crossing with a semi-circular section. The vertical walls and the flat base facilitate amphibian movement. Photo: M. Puky.

Figure 11.3. Amphibian crossing with funnel-shaped guide structure. Photo: GIASA.

Figure 11.4. Amphibian crossing and prefab guide structure. Photo: M. Puky.

Figure 11.5. Opaque concrete fence, an optimum guide structure. Photo: C. Rosell.

Figure 11.6. Opaque metal structure applied to a fence to guide amphibians towards the crossings. Photo: CEDEX.

Figure 11.7. Fence leading amphibians towards a wildlife crossing under construction. Photo: Javier Cantero.

Figure 11.8. Temporary barrier combined with collection buckets. Photo: Environment Office, University of Vigo.

Figure 11.9. Amphibian collection bucket for manual transportation. Photo: Environment Office, University of Vigo.

Common bad practices and mistakes

Figure 11.10. Maladjustment between guide structure and amphibian crossing entrance. Photo: C. Rosell.

Figure 11.11. Discontinuity between different sections of the guide fences. Photo: F. Navàs.

Figure 11.12. Catch trenches for amphibians that lead to crossings entrances inside them act as traps for small animals. Photo: C. Rosell.

Figure 11.13. Galvanized wire mesh is not applicable because amphibians try to climb them. Photo: R. Campeny.

Target species and groups

- All groups.

Basic features and prescriptions

- To facilitate the use of wildlife crossings, it is important to ensure that their entrances are well connected to the adjacent surroundings and that animals are funnelled towards them. Fences are necessary in most cases to guide animals towards the crossing entrances.

- The structure surface also plays an important role in encouraging their use by invertebrates and small vertebrates that require shelter. Correctly designed revegetation on overpass surfaces also help to guide bird and bat flight paths across these structures.

- Land use and activities in the vicinity of the crossings must be compatible with wildlife movements. Mechanisms must therefore be designed to prevent the urban development of land, the loss or degradation of important habitats for target species and the installation of elements that may restrict wildlife movements such as farm fences.

Vegetation and wildlife refuges on crossings

- Vegetation must be planted near the entrances in hedgerow-like strips parallel to and outside the perimeter fence to guide animals into the structure entrance and to provide shelter and protection from traffic noise and lights (Figure 12.1).

- Vegetation must also be planted at an oblique angle or perpendicular to the infrastructure, linking the vegetation at the crossing entrances to the adjacent habitats.

- An area with a lower vegetation density —or only herbaceous species— must be planted facing the crossing to allow animals to clearly see the entrance and not hesitate before entering.

- Riparian vegetation along watercourses running through adapted culverts must be preserved or restored if it has been removed to ensure the continuity of the vegetation cover at the entrance to the structures. If it is a viaduct or another large structure, the continuity of the riparian vegetation must be maintained as far as possible under the structure as well.

Photo: C. Rosell.

- To encourage bats to use crossings, they must be properly integrated into the landscape matrix. For this purpose, the entrance revegetation must connect with the vegetation mosaic and the natural linear landscape structures in the surrounding area, as many species in this group use vegetation boundaries, ecotones, watercourses, etc. as guiding elements in their routes through the territorial matrix (see File 22).

- In the case of ecoducts (see File 1) and wildlife or multi-use overpasses (Files 2 and 3), these vegetation corridors at the entrance must form a continuity with rows of tall shrubs on both sides of the structure, on its surface and along its length to guide bat flight paths (Figures 12.5 and 2.1).

- Rows of branches, stumps, logs or rocks must be placed on all over- and underpasses, both wildlife and multi-use, to provide shelter for small animals and encourage their use of the structure as a crossing or a habitat (Figures 12.5 and 2.1).

- In landscapes with traditional dry stone walls, these may be used to guide animals towards the structure. In the case of ecoducts and other large crossings, the walls may also be continued along the edges of the structures. These elements also are optimal wildlife refuges (Figures 2.1 and 2.2).

- Native species from the local plant communities with low water and maintenance requirements must always be used. Shrubs with edible fruits can attract some species to the vicinity of the crossing.

Walls and fences

- The most appropriate type of wall or fence must be chosen for each target species of fauna (see Files 13 and 14).

- Animals are more likely to locate the entrance to a wildlife crossing if the fence is correctly installed, ensuring that it guides them towards the entrance to the structure that will take them across the road.

- The fence must be perfectly well connected with the edges of the wildlife crossing structure to ensure that no gaps are left where animals can access the road.

- On sections of busy roads set on embankments with wildlife underpasses, opaque screens should be installed along the shoulders to reduce disturbance by the traffic (Figures 6.1 and 7.1).

Earthworks

- The shape of the entrance must be adapted to the relief to facilitate the integration of the crossing with its surroundings and an optimal connection to the embankments and the adjacent land.

- All obstacles that hinder animal movement at crossing entrances (gratings, rubbish, stockpiled soil, etc.) must be removed.

- Continuity must be ensured between the surroundings and the lateral ledges or sectors containing animal crossings in adapted culverts (see File 9). At the downstream outlet of these structures, it may also be advisable to install stone beds to prevent water erosion.

- Entrance restoration and adaptation work must cover the entire zone in the public domain associated with the infrastructure. In some cases such as large ecoducts and wildlife crossings, expropriation of the higher ground should be envisaged, or alternatively, land stewardship agreements with the owners.

- Elements that hinder the circulation of motor vehicles such as large, randomly placed boulders may be installed near the entrance to exclusive wildlife crossings with a potential for uncontrolled vehicle access (Figure 1.11). Small ponds in the vicinity of the entrances are useful for attracting wildlife to the crossing (Figure 1.8). However, this is impractical in areas with a Mediterranean or continental climate with long drought periods.

Maintenance

- In the first years following tree and shrub plantations, regular watering must be planned to ensure that the vegetation takes root. Plants that are damaged or fail must be replaced.

- Regular mowing of the vegetation is required to maintain the initial design of the restored zone and prevent the spread of shrub and tree communities. Pruning is also necessary at the crossing entrances when there is a risk of excessive plant biomass, especially in drainage zones where the spread of brambles (*Rubus spp.*) or other such species can hinder the structure's use by wildlife.

- In infrastructure without perimeter fencing, shrubs and creepers that might connect the crossing entrances to the road verge must be cleared (Figure 12.8). This is to prevent these patches of vegetation from leading animals towards road sectors with a risk of road casualty. Layers of gravel or geotextile mesh on the verges prevent vegetation growth and reduce maintenance requirements.

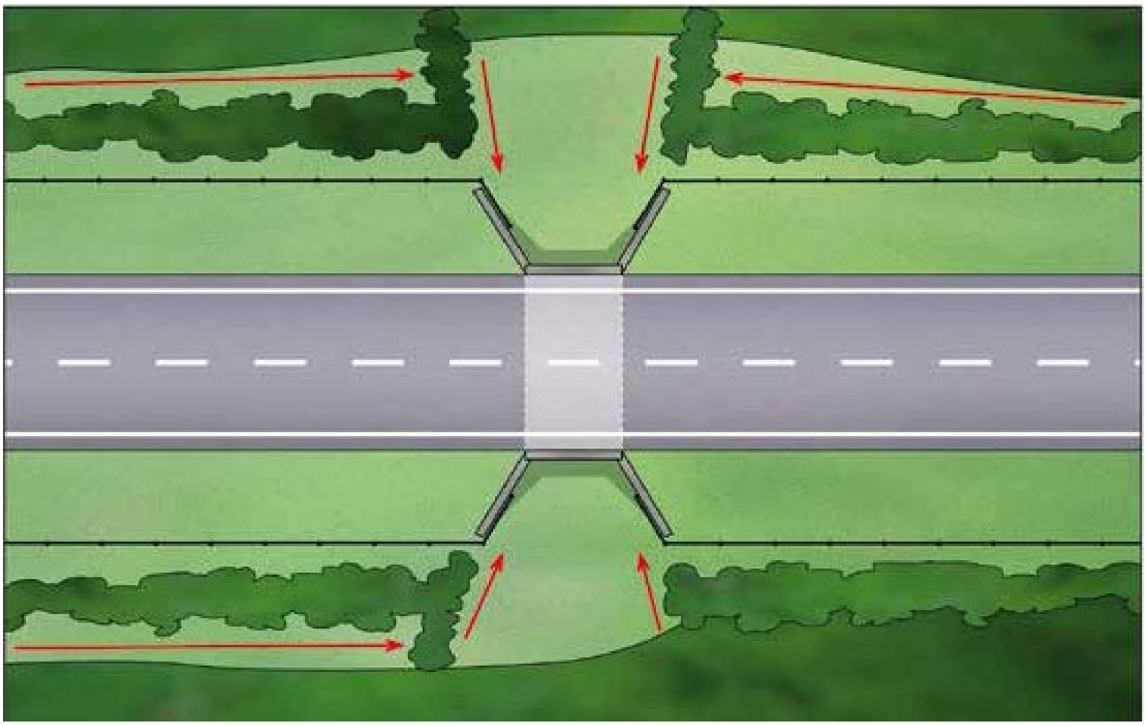


Figure 12.1. Diagram of vegetation distribution in approaches to wildlife crossings.

Figure 12.2. Adaptation of ecoduct entrances, combining patches of soil and rows of branches that provide shelter and lead the animals towards the structure. Ponds also attract wildlife. Photo: H. Bekker.

Figure 12.3. Vegetation at the entrance of a multi-use crossing that provides shelter for animals. Photo: Minuartia.

Figure 12.4. Continuous natural vegetation to the entrance of a modified culvert crossing helps to guide animals and increases the use of the structure. Photo: M. Fernández Bou.

Figure 12.5 Rows of branches and revegetation helps to guide wildlife into the structure. Photo: P. Robles.

Figure 12.6. Correctly installed perimeter fencing. Photo: M. Fernández-Bou.

Common bad practices and mistakes

Figure 12.7. Incorrect installation of a perimeter fence, which does not guide animals towards the crossing entrance. Photo: M. Fernández-Bou.

Figure 12.8. Strips of vegetation connect the banks of a watercourse to a road, facilitating animal entrance and increasing the likelihood of WVC. Photo: F. Navàs.

Target species and groups

- Ungulates and large carnivores. If the fence is installed properly and is sufficiently dense at the base, it also prevents breaches by medium-sized carnivores such as foxes and badgers (*Meles meles*).

- Reinforcement is needed for smaller species, and also to ensure the effectiveness of the fence when the target groups are species of major conservation importance such as otters (see File 14).

Photo: Roads Department, Government of Madrid.

Basic features and prescriptions

- The installation of a fence can reduce wildlife roadkill and also increase road safety by reducing the risk of accidents caused by WVC. However, fences must be combined with wildlife crossings since otherwise, it intensifies the barrier effect of the infrastructure.

- Fences play a dual role: they prevent animals from entering roads and also guide them towards wildlife crossings. This guidance is enhanced because when many species encounter a fence, they follow it until they find a crossing point (Figure 13.3).

- In general, it is recommend the installation of a continuous fence along all roads that carry more than 25,000 vehicles/day, although the final decision on the installation of a fence requires a specific analysis of each situation and the land uses in the area around the road.

- Exceptional circumstances may require the installation of devices to allow wildlife to escape from fenced sections that they have breached. However road designers should consider the risk of creating entry points for animals due to the use of inappropriate escape devices or poor maintenance (see File 15).

Discontinuous fences

- Fencing is only recommended on roads that carry less than 25,000 vehicles/day when there are sections with WVC hotspots. However, to prevent discontinuous fencing from generating a roadkill or collision hotspot at the end of the fenced section, it should lead animals towards wildlife crossings or safe crossing points (viaducts, tunnels, under or overpasses, etc.). It is particularly important to ensure that the ends of fenced sections lead directly to one of these structures.

- If the previous prescription is not viable, the fence must enclose the entire length of the hotspot, with a minimum of 500 m on each side, ending in straight sections of road with optimum visibility for drivers, accompanied by reinforced warning signs (see File 17). Bear in mind that this may generate an ungulate-vehicle collision hotspot at the end of the fenced section.

Fence mesh types and installation

- Fences should preferably be made of rectangular woven galvanized wire mesh with a graduated density or chain-link mesh. Galvanized steel fence posts are essential.

- The fencing mesh must hug the ground perfectly, with no gaps or points where animals might enter the road. Preferably, the base of the fence should be buried, an essential step to ensure its effectiveness in areas with high wild boar abundance.

- At the interface between the fence and wildlife crossing entrances, viaducts, etc., the fence posts must tie in perfectly with the wings or abutments of the structure (Figures 12.1 and 12.6).

- Intersection between fences and perimeter ditches are particularly difficult to resolve. One option is to install a supplementary section of fencing that hugs the base of the culvert or include crossbars that stop animals from entering but do not hinder the water flow (Figure 13.9).

Dimensions

● The recommended height and distance between fence posts depends on the target species, as set out below:

Species present in the area	Wild boar	Roe deer Fallow deer	Red deer
Minimum height above ground level (m)	1.60-1.80	1.60-1.80	2.20
Spacing between fence posts (m)	2-4	4-6	4-6

● 2 m high fences are generally recommended, with 1.8 m above ground level and the bottom 20 cm buried. This type of fence is suitable for wild boar, a species with a broad distribution area and dense populations in many regions. The distance between the vertical wires of the woven metal mesh should be 15 cm, and the distance between the horizontal wires should gradually increase from 5 to 15 cm at the bottom to 15-20 cm at the top.

● Two galvanized steel wires can be place at the top to raise the height of the fence, especially in areas with populations of fallow deer (*Dama dama*), or red deer.

In such cases, the strainer post should form an angle facing away from the road in order to hinder attempts to breach the fence by some species.

Recommendations for certain species

Reinforcements for wild boar

● In sectors where fence mesh has been lifted, the problem can be corrected by installing reinforcements at the base. If wild boar cause the problem, the reinforcement can take the form of 5 cm wide x 30 cm high stiff welded rectangular mesh, partly buried or attached to the ground with barbs formed by the vertical components of the mesh, rising 40-50 cm above ground level (Figures 13.5 and 13.6)

● Reinforcements must be installed outside and anchored to the existing fence.

Reinforcement for bears

● Conventional fences for large mammals may not suffice to contain bears. Specific bear fences should be installed in sections where they may be present. One type of mesh which has proved effective is 8 x 10 cm triple chain-link mesh with 2.7 mm wire, a height of 3 m and a 80 cm outrigger on a 45º angle pointing away from the road. The bottom of the fence must be reinforced with a 1.5 m wide horizontal mesh skirt, buried on the outer side of the fence to prevent bears from digging underneath (Figure 13.7). The fence posts (60 mm in diameter and 4 mm thick) must also be reinforced.

Specific fencing for Iberian lynx

● The Iberian lynx is an extraordinarily good climber and jumper. Chain-link or electrowelded fencing rising 2-2.5 m above ground level is recommended for this species. The base must be buried, with the terminal end forming a 45 ° angle facing away from the road, as in the case of bears (Figure 13.8).

Maintenance

● Regular inspection of fences is essential in order to detect and repair defects. The most common failures are caused by animals lifting the bottom of the fence when they try to pass underneath, incorrect adjustments between the base of the fence and the ground (in cases where the base is not buried) or incorrect adjustments between the fence and the edges of crossing structures (culverts, overpasses and underpasses, viaducts, etc.). These aspects should be included in regular fence inspections, every three months for the first year after installation and at least once every six months thereafter, although the frequency should be adapted to the local situation.

● In order to facilitate inspection and maintenance, a corridor immediately outside the fence should be cleared of brush. This also prevents the growth of shrubs or trees which can damage the fence and facilitate access by animals that are good climbers.

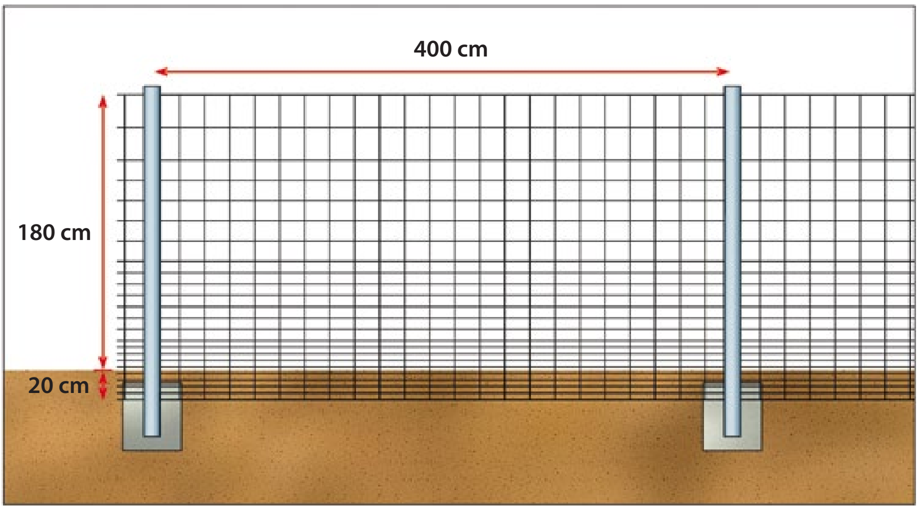


Figure 13.1. Diagram of a fence for large mammals.

Figure 13.2. Fence set at the base of an embankment. Photo: F. Navàs.

Figure 13.3. Fences lead animals towards crossing points. Photo: C. Rosell.

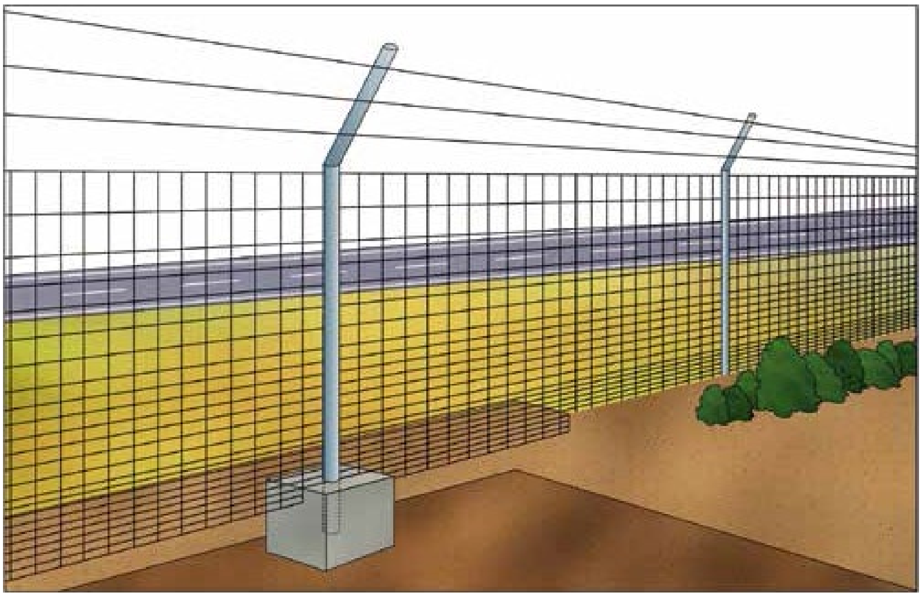


Figure 13.4. A fence can be extended upwards using outrigger poles angled away from the road, topped with galvanized barbed wire. The base of the fence should be buried.

Figure 13.5. Wild boar reinforcement in a particularly troublesome section. Photo: Túnels Barcelona-Cadi.

Figure 13.6. Detail of welded wire mesh reinforcement. Photo: C. Rosell.

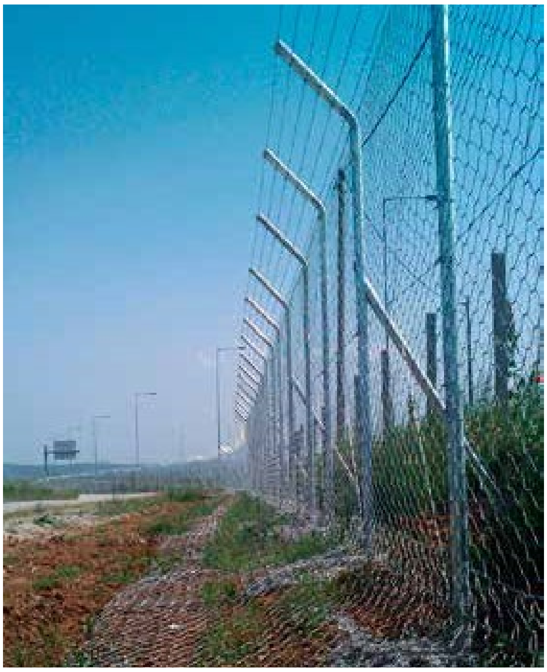


Figure 13.7. Specific fence for bears, with an outrigger at the top and skirting at the bottom (prior to burial). Photo: L. Georgiadis.

Figure 13.8. Specific fence for Iberian lynx. Photo: Public Works Agency. Government of Andalusia.

Figure 13.9. Two alternative systems to prevent animal passage at the interface between fences and roadside drains. Photos: Minuartia.

Bad practices and common mistakes

Figure 13.10. The fence should lead to the crossing, leaving no gaps that permit entrance to the embankment. Photo: C. Rosell.

Figure 13.11. Unburied mesh that has been raised by animals. Photo: F. Navàs.

Figure 13.12. Lack of maintenance facilitates wildlife entrance to a road. Photo: F. Navàs.

Figure 13.13. Bad adjustment between a fence and an overpass abutment. Photo: F. Navàs.

Target species and groups

- Small and medium-sized mammals, e.g., hedgehogs (*Erinaceus europaeus*), mustelids, etc. and some reptiles, especially tortoises.

- Not suitable for amphibians, which require another specific type of fence (see File 11).

Basic features and prescriptions

- Rectangular woven mesh fences used for large mammals (see File 13) do not block the passage of smaller species, which require smaller diameter mesh. Moreover, some species are able to climb these fences or dig under them, making it necessary to build specific fences that prevent or hinder this activity.

- This type of fencing is especially recommended in sections with a documented -or envisaged- high road mortality of a particular species.

- Fences for small vertebrates are usually installed as a reinforcement for the base of structures intended for large mammals. They must be placed outside and anchored to the conventional mesh (Figure 14.1).

- Fence installation must always be combined with appropriate wildlife crossings for the target species.

Mesh types and fence installation

- Fences should preferably be made of stiff welded wire mesh and galvanized steel posts. Chain-link fencing can also be used for some species such as otters, although this is less desirable as it easier to bend.

- The bottom 20 cm of the fence should be buried.

- It is advisable to install an outrigger on a 45 ° angle at the top 5 cm of the fence, pointing away from the road to prevent animals from climbing over.

- At the interface between the fence and the entrance to wildlife crossings, viaducts, etc., fence posts must tie in perfectly with the structure wings or abutments (Figures 12.1 and 12.6).

- Interfaces between fences and perimeter ditches are particularly difficult to resolve. One option is to install a supplementary section of fencing that is tied in with the base of the culvert, another is to install crossbars that stop animals from entering but do not hinder the water flow (Figure 13.9).

Photo: C. Rosell.

- If the fence runs through areas of major importance for steppe birds such as bustards (*Otis tarda*), highly visible marks should be placed at the top to prevent bird mortality (see File 19).

Dimensions

- The standard height for these fences is 60 cm above ground level, adaptable to the target species: 40 cm is sufficient for tortoises, for example.

- The bottom 20 cm must be buried in the ground. To prevent breaches by species that are good diggers, 50 cm of the base should be buried in an L shape (20 cm vertically and the bottom 30 cm bent outwards horizontally).

- The standard 2 x 2 cm mesh size can be adapted on the basis of expert advice, depending on the target species. 1 x 1 cm is recommended for tortoises, 4 x 4 cm is suitable for otters.

Specific recommendations for taxonomic groups

- Some animals are particularly difficult to contain with fences. This is the case with the European mink, an endangered species and a high conservation priority. Other species such as rabbits (*Oryctolagus cuniculus*) and chameleons pose special difficulties.

● It is therefore important to receive expert advice on the ecology of these species in order to adapt the general recommendations to each particular situation. It is also important to remember that the fences described in this document should funnel the animals towards wildlife under- and overpasses, viaducts and tunnels that cross the road.

● The problem with the European mink is that it can climb over 2 m high fences. For this species, 2 x 2 cm welded mesh fences are recommended with a height of 1 m and the top set at a 45 ° angle facing away from the road to prevent breaches. The base of the fence should also be buried to prevent gaps on the ground through which animals can enter the road.

● For otters 1 m high reinforced woven welded wire mesh fencing or 4 x 4 cm hexagonal triple chain-link fences with 20 cm buried at the base are effective. In sections where otters repeatedly breach the fence, a taller fence may be necessary with reinforcement at the top in the form of a 30 cm outrigger on a 45 ° angle pointing away from the road.

● Rabbits are a particularly difficult species due to their extraordinary digging ability. 60 cm high 3 x 3 cm triple chain-link fencing is recommended. It is especially important to bury 40 cm of the base in an L shape (20 cm vertically and the bottom 20 cm bent outwards horizontally).

● To mitigate the risk of bat roadkill -or railkill-, a particular type of fence could be required to guide their flight paths towards safe crossing points: tunnels, viaducts, overpasses, underpasses and even culverts if they have the appropriate features (see File 22). For narrow alignments such as railways and two-lane roads, 5 m high screens made of 5.5 x 5.5 cm chain-link mesh have proven effective —although they do not prevent all breaches— when erected on both verges (Figure 14.4). For wider roads such as dual-lane carriageways, a tunnel-type mesh structure with a closed top is recommended (Figure 14.5), since low-flying bats have been found to rise above and breach large mammal fences (up to 2.20 m tall in the case of deer, see File 13) and cross roads at a dangerous height. The results of existing installations are not conclusive, and tests are still underway with different fence dimensions and characteristics.

● The chameleon, a reptile with a highly localized distribution, also has a remarkable ability to breach fences by climbing and burrowing. Chameleons require a 60 cm high fence with perfectly smooth facing as they can climb mesh and rough surfaces. Shrubs and trees on adjacent land must not make contact with fences to prevent chameleons from climbing them and reaching the top of the fence. The reinforcement installed for this species must also be buried 20 cm below ground level to prevent breaches by digging.

Maintenance

● Regular inspection of the fence is essential to detect and repair defects. The most common failures are caused by animals raising the base of the fence when they attempt to pass underneath, a lack of adjustment between the base of the fence and the ground (in cases where the base is not buried) and between the fence and the edges of crossing structures (culverts, overpasses and underpasses, viaducts, etc.). These aspects should be included in regular fence checks. An inspection every three months is recommended for the first year after installation, and at least once every six months thereafter, although the frequency should be adapted to the local situation.

● In order to facilitate inspection and maintenance, a corridor immediately outside the fence should be cleared of brush. This also prevents the growth of shrubs or trees which can damage the fence and facilitate access by animals that are able to climb the vegetation.

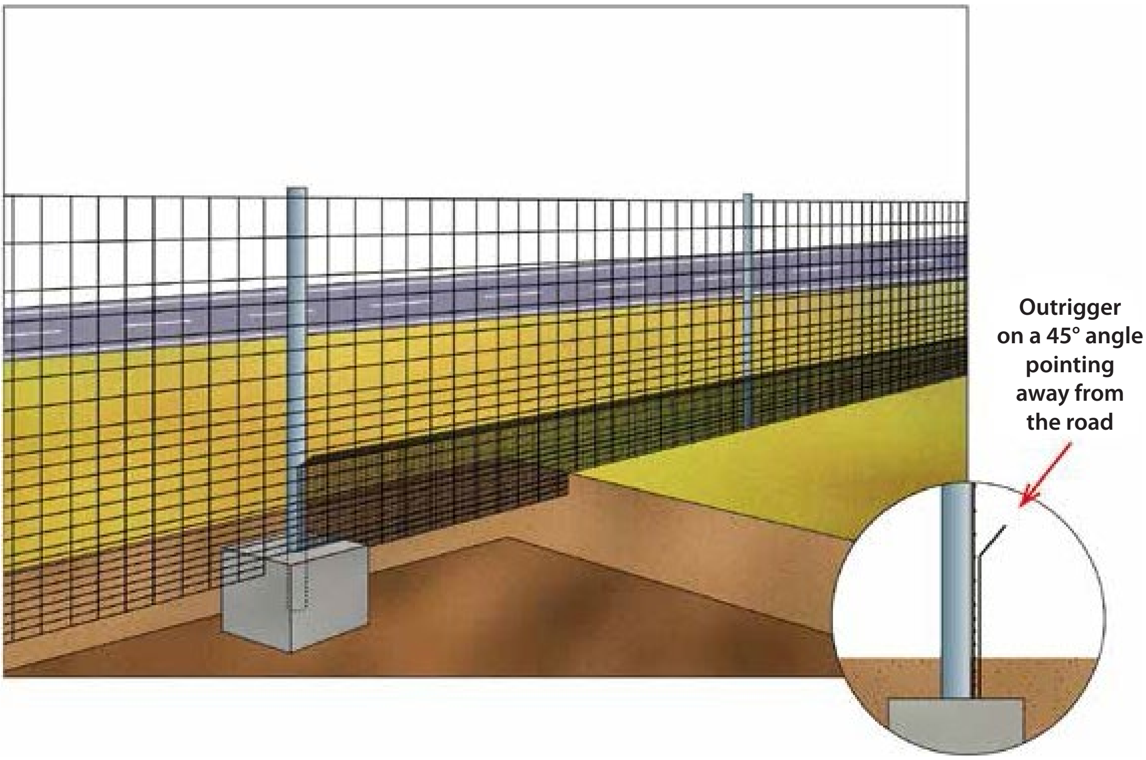


Figure 14.1. Diagram of reinforcement mesh, attached to the base of a fence for large mammals in order to prevent breaches by small vertebrates.

Figure 14.2. Reinforcement on the non-road side of conventional mesh. Photo: C. Rosell.

Figure 14.3. Fence combined with an outrigger to prevent deer from jumping over and base reinforcement for small vertebrates. Photo: M. Fernández Bou.

Figure 14.4. Fencing 5 m high and simple chain-link to avoid bat collisions on a high-speed railway line. Photo: ADIF.

Figure 14.5. Polyamide net structure in a funnel shape to prevent bat collisions on a highway, with hitherto inconclusive results. Photo: M. Fernández Bou.

Target species and groups

- Ungulates, carnivores and other taxa.

Escape systems

- On fenced road sections where for some reason there is a high risk of wildlife entering the road and becoming trapped, road designers should consider the installation of systems that allow these animals to exit the fenced road. However it must be guaranteed that the escape systems do not become additional entrance points due to inadequate design or maintenance. Their optimised location is a critical factor.

- The most recommended systems are compact earth ramps, which consist of building up mounds of earth against the roadway side of the fence to form a ramp up to the height of the fence top. Animals that are trapped in the road precinct can climb the ramps and jump back into the natural environment. The size of these ramps is determined by the nature of the road, particularly its shoulder width, and the target species.

- Figures 15.1, 15.2 and 15.5 show examples of more complex ramp systems, built on the basis of treated timber formwork that is filled with earth and revegetated. These systems are usually installed for ungulates in Central Europe, and require major maintenance expenditure.

- Another method used to enable animals to escape back to the wild are tilting and other types of gates on springs, which differ with the target species. Spring-loaded gates open when an animal exerts slight pressure from the road side (Figure 15.4). These systems are used in Central European countries to help badgers trapped in fenced sections. In recent years, Spain has seen a proliferation of several variations of these devices. Their effectiveness has not been proven, and they often do not work due to poor maintenance.

- In general, complex metal devices (tilting gates and escape hatches, recommended in some manuals) are strongly discouraged because they often rust and become useless, or remain open and become new entrance points into fenced-off road sections (Figures 15.10 and 15.11), making the fence ineffective.

Photo: H. Bekker.

Preventing animals from entering a road via an access track

- In fenced road sections, animals can sometimes enter causeways through access roads. Cattle grids are one solution (Figures 15.6 and 15.7). These structures, normally used to prevent livestock from escaping from fields, consist of a 30 cm deep trench across the road, covered with grating, pipes or metal bars, preferably mobile. The length of the trench varies with the ungulate species in the area, from the general recommendation of a minimum of 2 m up to 3 m in the case of red deer. There should be no gaps between the end of the fence and the cattle grid where animals can escape. To allow small animals that fall into the trenches to escape, the lateral walls must have a 30-45° angle, a rough surface finish or lateral openings (Figure 15.8).

- Gates are an alternative to cattle grids on private farm access tracks with little traffic, provided that they are properly installed, the continuity of the fence is ensured, and they have the same height.

- When the track is paved, another containment device that does not interfere with vehicle movement consists of electrified mats embedded crosswise in the roadway asphalt (Figure 15.9). These mats consist of electrified metal mesh, powered by solar panels. When an animal steps on the mat, it receives a electric shock that forces it to retreat. These devices have proved effective for bears and deer in the United States.

Figure 15.1. Ramps designed to allow roe deer to escape from inside a fenced section. Photo: C. Rosell.

Figure 15.2. Another view of the ramp showing its alignment with the fence. Photo: C. Rosell.

Figure 15.3. Escape system consisting of an vegetated soil ramp, seen from road side. Photo: H. Bekker.

Figure 15.4. Badger escape gate. Photo: Minuartia.

Figure 15.5. Escape ramp. On the left, viewed from the road side during the construction process, and right, viewed from the outside, once completed. Note that the fencing mesh has been removed at the top of the ramp to make it easier for animals to jump across. Photo: Public Works Agency. Government of Andalusia.

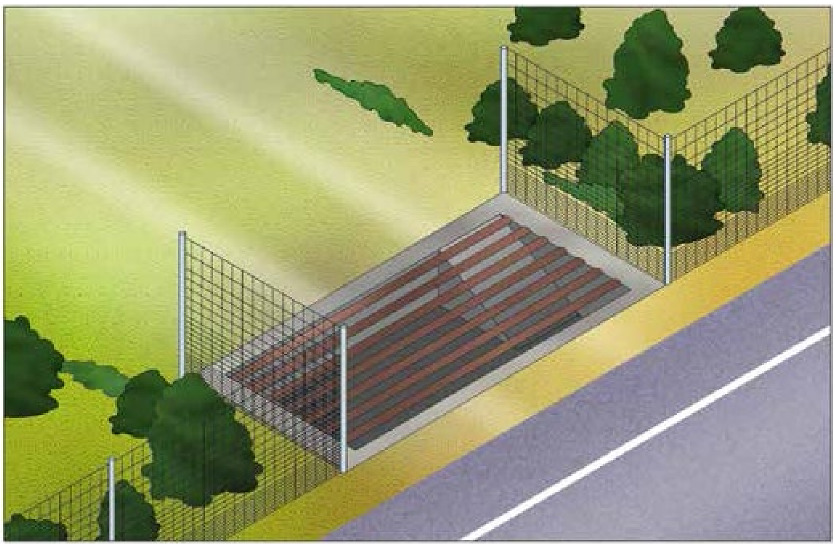


Figure 15.6 Diagram of a cattle grid for ungulates, with an interior escape ramp for animals that might accidentally fall into the trench beneath.

Figure 15.7. Cattle grid. When large deer species are present, wider sections may be installed to prevent them from jumping across. Photo: C. Rosell.

Figure 15.8.Cattle grid with a lateral escape aperture for small animals that might fall into the trench. Photo: Ministry of Public Works.

Figure 15.9. Electrified mat preventing animal entrance to a fenced main road via a paved access track. Photo: C. Rosell.

Common bad practices and mistakes

Figure 15.10. This ungulate escape gate can remain fully open, permitting free entrance by animals (and people) into the fenced area. Photos: F. Navàs.

Figure 15.11. Swinging escape hatches for medium-sized carnivores, permanently open because its hinges have rusted, allowing animals to enter the fenced area. Photos: F. Navàs.

Target species and groups

- Primarily various mammal groups and birds.

Basic features and prescriptions

- Verges and median strip management initiatives vary with the target species and the features of the surrounding landscape. Expert advice is therefore required for their design, although in all cases one of the criteria for verges management and revegetation should be the mitigation of WVC and accidents.

- Road verges and median strips can become an attractive habitat for birds and small mammals such as rodents and rabbits, and their proximity to roadways can increase the likelihood of roadkill. Road casualty hazard may be increased when carnivores arrive to consume the carcasses and predators use the road verge as a hunting ground. This has been come up observed in the case of endangered raptors and carnivores such as polecats and the Iberian lynx. Special attention to verge management is therefore essential in order to avoid the creation of refuges and the plantation of vegetation that can act as a food source for wildlife.

- To reduce the risk of WVC with large mammals such as deer and wild boar, it is also advisable to ensure good driver visibility of any animals on the road verge and thus facilitate collision avoidance. This also allows animals see approaching vehicles more easily and react by not crossing the road.

- A strip at least 3 m wide alongside conventional unfenced roads and railway lines should be cleared unless detailed studies recommend other measures. Tree felling may also be necessary, particularly in the distribution areas of carnivores that can climb trees easily, although clearance of the shrub layer is often enough. This is indispensable along road sections with a high incidence of roadkill for certain species and on roads that pass through the distribution areas of endangered species.

- A corridor with no shrub or arboreal vegetation should be maintained cleared immediately outside the fence to prevent animals that can climb such vegetation (including some endangered species such as the Iberian lynx) from using it to breach the fence. It also facilitates inspection and maintenance work.

- This work must be planned on the basis of the affected species, and may overlap with routine road maintenance tasks. In ungulate-vehicle collision hotspots the work must be done at the start of high-risk periods: September-October in the case of wild boar and some deer, and April in the case of roe deer. The seasonal nature of this phenomenon makes it advisable to combine the measure with temporary intensified signposting in the months with the highest risk of collision (see File 17).

Photo: R. Campeny.

- When this measure is applied in natural zones or in areas that host plant communities or species of major interest, expert advice needs to be sought on how to clear or mow without affecting this vegetation.

- Rabbits and voles are amongst the species that proliferate on embankments and median strips, and can also compromise the stability of the infrastructure when their burrows spread. In such cases reinforced fencing (see File 14) along with unattractive habitats along the verges is recomended.

- Species with a low risk of ignition should be chosen for roadside plantations in Mediterranean areas with a high forest fire risk. Pruning must also prevent the continuity of the tree tops from one side of the road to the other. This reduces the fire hazard and the propagation of fires along roads.

- Herbicides should not be used along roads and railway easements in application of the precautionary principle and indications in European Parliament and EC Directive 2009/128/EC and Spanish Royal Decree 1311/2012 of 14 September, which sets the framework for the sustainable use of pesticides. Verges and median strips usually facilitate runoff, which increases the risk of contaminated surface and groundwater and hence the reduction of biodiversity. Recommended alternatives are mechanical methods or others that are known not to involve the use of potentially toxic chemical products for wildlife.

Figure 16.1. Clearance to improve driver visibility and reduce refuges for animals at a WVC hotspot involving wild boar and deer. Photo: C. Rosell.

Figure 16.2. Unvegetated lane separation median strips. This may be appropriate on road sections where the proliferation of voles and other prey attract raptors and carnivores, increasing the roadkilling hazard. Photo: C. Rosell.

Figure 16.3. Verges mown to reduce refuge zones for animals alongside a roadway. Photo: F. Navàs.

Basic features and prescriptions

● This measure is designed to warn drivers of the likely presence of wildlife on the road and the need to reduce speed. It is applicable to conventional unfenced roads. To prevent WVC on motorways and other road with high traffic intensity, effective fencing and wildlife crossing must be applied instead of wildlife warning signs.

● In Spain, standard wildlife warning signs alerting drivers to the likely presence of wildlife on the road (P-24) has a low effectiveness due to their overuse on many roads. It is more recommendable to install special signs to highlight the message. All signs must conform to the official standards on road sign design, in particular in Spain, the Highway Instructions and General Road Rules 8.1-IC on vertical signs. Prior authorization by the respective authorities for non-standard designs must be obtained.

● On sections with WVC hotspots, warnings can be reinforced by additional signs with a yellow fluorescent retroreflective background and luminous signs, preferably flashing.

● In order to accurately identify the sections where enhanced signposting is justified, WVC locations, dates and species involved must be studied. These data are then used to identify and profile the hotspots and determine where enhanced signposting is appropriate.

● The signs to be placed at the ends of the problem sections should include a supplementary bottom strip (S-810 in Spain) showing the length of road with the highest WVC risk. This type of sign reinforcement is only justified in the case of very specific hotspots. Consequently, to prevent habituation by drivers, these warning signs should not be used on sections that are more than 1 km long.

● A recommended or compulsory speed limit of less than 70 km/h along problem sections should be considered, bearing in mind the road type. Vehicle speed is a variable that increases the risk of WVC, although speed restrictions are not always appropriate in some sections as they may have a negative effect on traffic flow.

● One of the objections to enhanced warning signs is that they are installed permanently, when in fact high risks of WVC are confined to specific periods. To increase their effectiveness, such signs should only be operative during the critical periods for the respective species (Figure 17.2). In the case of ungulates-vehicle collision, reinforced warning signs should be operational from early September until the end of January. If roe deer and fallow deer are involved, the section should also be signposted in April. Standard warning signs are sufficient for the rest of the year along these sections.

Photo: M. Fernández Bou.

● Flashing signs between dusk and dawn, the peak WVC period, can be used as a reinforcement in sections with a high rate of WVC.

● In extreme cases with an extremely high risk of WVC, warnings on variable message panels may be considered (Figure 17.4). However, there are few such elements on conventional roads, while roads with heavy traffic which do have them are usually equipped with perimeter fences which, if properly installed and maintained, ensure the absence of animals.

Signs with wildlife detection sensors

● Animal Detection System (ADS) (Figure 17.3) involve signs that emit flashing warnings, activated by fauna detection sensors. They have a higher cost and many technical difficulties.

● These sensors detect the movement of approaching large animals (deer, bears, etc.) at distances of up to 200 m, or the thermal difference between the animal's body and its surroundings. They require the removal of all visual obstructions and are thus not suitable in areas with a dense tree or shrub cover. A non-flashing sign is taken by drivers to mean that no large animals are present, making it essential to avoid detection failure.

- The effectiveness of these signs is mainly based on warnings of a real danger, not a potential risk. To increase their effectiveness, information panels at the ends of the sections should inform road users about the meaning of these flashing signs.
- These devices require frequent maintenance, regular inspection and connection to a power source. Photovoltaic panels are normally used, making them vulnerable to vandalism.

Figure 17.1. Warning message highlighted by a panel with a fluorescent yellow background. Photo: Ministry of Development and the Environment, Government of Castilla y León.

Figure 17.2. Reinforced seasonal warning signs during the peak WVC risk periods for ungulates. Photo: Territory and Sustainability Department. Government of Catalonia.

Figure 17.3. Flashing warning sign activated by animal detection sensors (ADS). Photo: C. Rosell.

Figure 17.4. Variable information panel warning about the possible presence of bears. Photo: L. Georgiadis.

Figure 17.5. Sign encouraging drivers to slow down due to the presence of highly vulnerable animals. Photo: Aiguamolls de l'Empordà Natural Park.

Figure 17.6. Warning sign indicating potential crossing by an endangered species. Photo: J.M. Martín López.

Target species and groups

- Ungulates.

Basic features and prescriptions

- This file describes three systems used to prevent ungulate-vehicle collisions based on noise, smell or visual stimuli designed to dissuade animals from crossing roads or to do so with caution.

- Monitoring has shown that animal habituation makes them all lose their effectiveness over time to a greater or lesser extent.

- These measures are therefore only applicable on a temporary basis at best, until other solutions with guaranteed long-term effectiveness are implemented.

Olfactory deterrents

- These systems, known as 'smell barriers', consist of synthetic resin impregnated with substances that releases a simulated human or ungulate predator scent, installed on both sides of the road. This is intended to alert animals to the fact that they are near the road edge and thus facilitate their detection of oncoming vehicles.

- The resin strips can be attacked to a row of poles spaced roughly 5 m apart, or to the roadside vegetation. Two rows of impregnated resin strips are necessary, one near the road and another parallel strip 10 m away.

- This measure has a high maintenance cost, since the product must be replaced manually at least every three or four months, depending on the weather. The maintenance of these poles often enters into conflict with verge mowing and farming work. The second row can be damaged if placed in a crop field beside the road.

- Monitoring in Spain has found that the number of accidents is reduced after the first few installations of these products. Over time, however, animals become habituated to these devices and their effectiveness drops after several replacements.

- Nevertheless, they can still be considered for temporary installation during critical periods at WVC hotspots along short sections of roads.

Photo: F. Navàs.

Audio devices

- Noise emission devices designed to scare away the target species: deer and wild boar.

- Experiments have been conducted with different types of sounds, ultrasounds and noise generators, in some cases attached to poles on the roadside and in others, installed on vehicles.

- This measure is not recommended. Monitoring in some countries, particularly in France, has shown that it is ineffective in the medium term. Nevertheless, research is ongoing and devices with a more advanced design, combining sound and visual stimuli, are yielding better results, although conclusive evidence of their effectiveness is yet to be published, particularly with respect to the speed of habituation by animals.

Reflectors

- Reflectors or mirrors installed on poles or kerb guardrails bounce the light from vehicle headlights into the habitats around the road. This is intended to warn animals in these areas and prevent them from approaching the road. Obviously this measure is only active at twilight and at night, the peak WVC danger period, when the vehicle headlights are on.

- Reflectors are used widely due to their low cost and ease of installation. However, widespread monitoring in several countries has found that animals get used to their presence and they lose their effectiveness in the medium term.

- In addition, reflectors require frequent maintenance and pose problems for mowing operations along the road verges.

Figure 18.1. Pole with synthetic resin impregnated with concentrated smell. Two rows of poles along a roadside. Maintenance of these poles can hinder verge mowing and farmwork, and they only have short-term effectiveness. Photos: F. Navàs.

Figure 18.2. Various models of reflectors are available to project headlight beams into the natural surroundings of roads. These systems require frequent maintenance and have short-term effectiveness. Photos: C. Rosell.

Target species and groups

- Birds.

Basic features and prescriptions

- This file describes several measures aimed at preventing bird strikes with screens and fences through the use of elements that increase the visibility of these screens and force birds to change their flight paths, usually by rising.

Transparent screens

- Transparent road noise abatement screens cause mortal bird collisions. Opaque screens are therefore preferable wherever feasible.

- This danger is most frequent in the case of screens on bridges and viaducts, as many bird flight paths follow the watercourse.

- To avoid this problem, transparent screens should be marked with a colour that contrasts strongly with the colour of the surrounding landscape, especially at sunset and dusk, the main periods of bird movement. The most highly recommended colours in natural environments are the same shades of white and orange used for warnings on equipment. One or the other should be chosen, depending on which one provides the best contrast with the surroundings (Figure 19.1).

- In landscapes of importance for birds in brown or ochre shades for a large part of the year (wetlands, steppes, etc.), these marks should be in a light colour, preferably white. This colour also increases the visibility of the screens at dusk and dawn, the peak periods for bird movements.

- In other contexts with a predominance of green landscapes, orange marks can be used. Another option is a combination of orange and white marks (Figures 19.1 B1 and B2).

- Vertical stripes are the most effective markings. They must be at least 0.5 cm wide (up to 2 cm if there is little contrast with the background) with a maximum spacing of 10 cm. These strips must cover at least 15% of the screen surface.

Photo: F. Navàs.

- Adhesive markings that mitigate bird mortality are easy to attach to previously installed screens.

- Adhesive silhouettes of birds of prey are not recommended. They are not effective because birds do not identify them as predators (their intended purpose), although some cases of effectiveness have been reported where these adhesives cover a large part of the screen.

- Adhesive products are available that are invisible to the human eye but reflect ultraviolet light and are thus visible to birds. The effectiveness of these systems has not been verified to date.

Fence marking

- Fences cause mortal bird strikes, especially in the case of steppe species such as the Great Bustard, the Little Bustard (*Tetrax tetrax*) and others with slow, low flight patterns. Fences must therefore be equipped with signs that increase their visibility. Fences with strands of barbed wire are particularly dangerous and should therefore be avoided.

- In the case of road or rail cuttings with fences above the transport platform, white 30 x 15 cm plates are attached to the tops of some screens with a horizontal separation of 2 m, arranged in two alternate rows at different heights to prevent bird strikes. Metal plates are preferably since they are less susceptible to deterioration than plastic material. The effectiveness of this measure has not been verified to date.

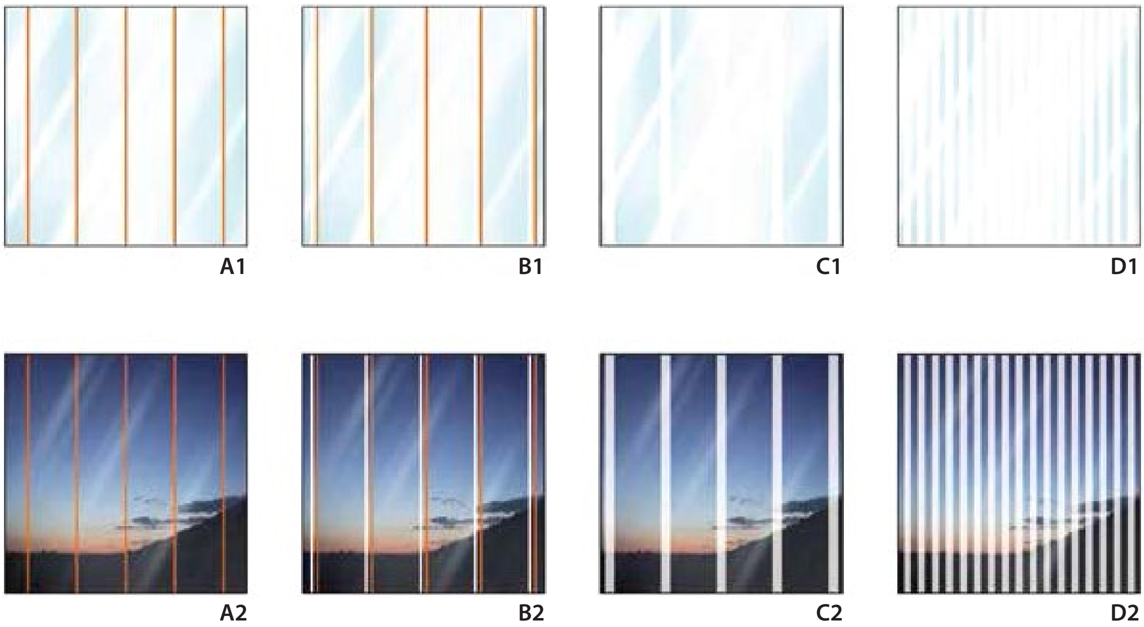


Figure 19.1. Diagram showing various types of vertical stripes for roadside screens. The colours must ensure maximum contrast with the background during the peak periods of bird movement. The combination of orange and white (B1 and B2) yields the best results for different situations.

Common bad practices and mistakes

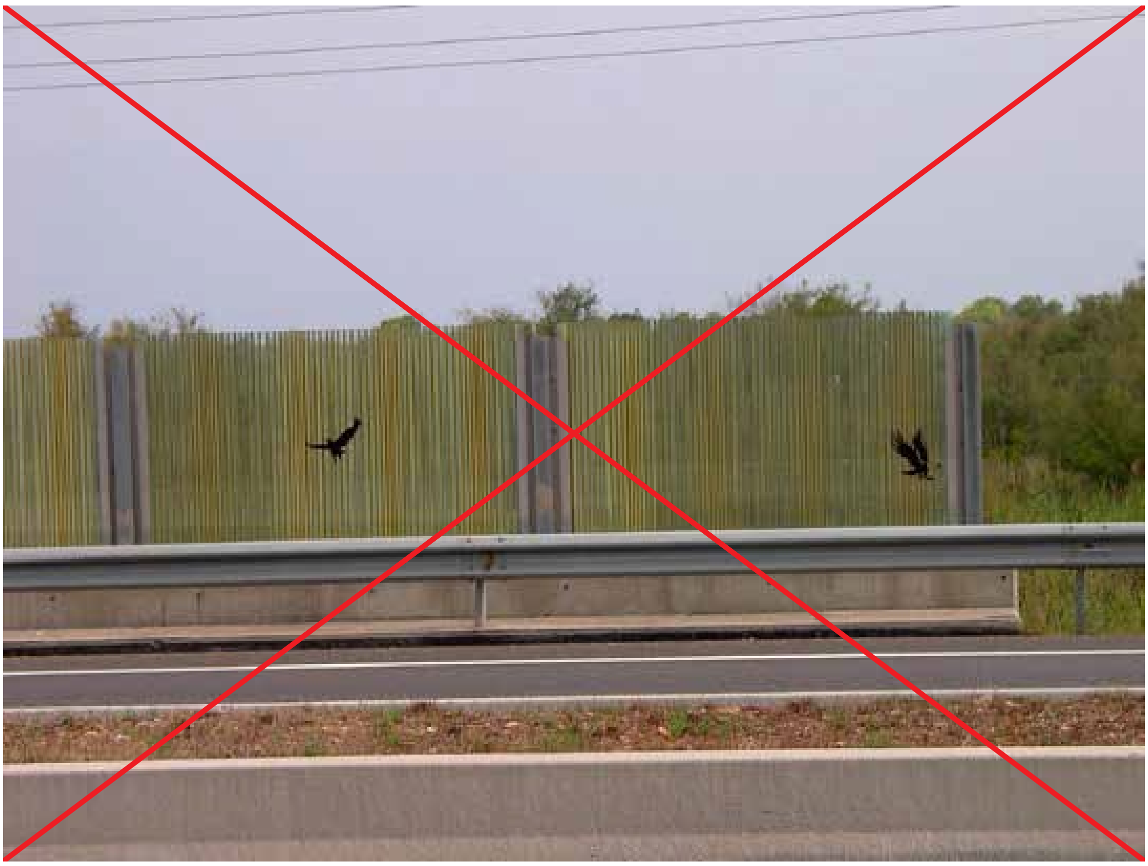


Figure 19.2. Transparent screen with silhouettes of birds of prey. This is ineffective for the prevention of bird collisions. Moreover, the vertical stripes do not stand out as they are the same colour as the surrounding vegetation. Photo: F. Navàs.

Target species and groups

- Small mammals, reptiles and amphibians.

Basic features and prescriptions

- This file describes several infrastructure adaptations that have been reported to cause mortalities in small animals.

Manholes

- Manholes or gullies and other structures associated with perimeter and transversal drainage hinder the movement of small species. Animals that fall through gratings can be trapped, drown or die from starvation. To minimize this impact, ramps on one or more sides of these elements must be installed to help animals to escape (Figure 20.1).

- The optimum angle for these ramps is 30 º. The maximum is 45 º.

- The ramp surface should be roughened to help animals to climb.

- Stone riprap is particularly suitable for surfacing drainage elements such as stepped drains to prevent embankment erosion (Figure 9.7).

Ditches and kerbs

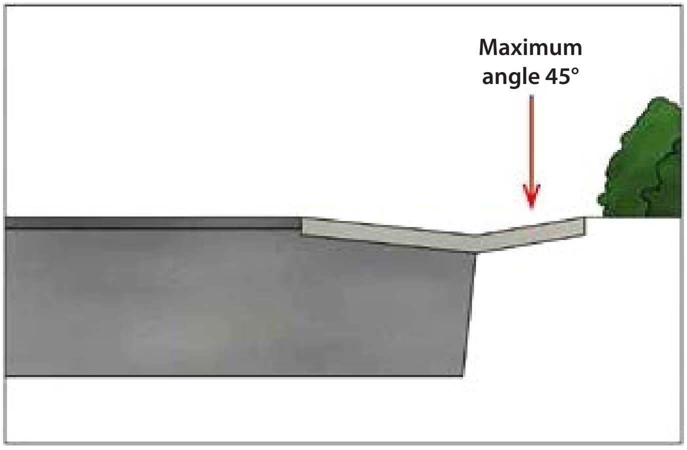
- Longitudinal ditches with vertical or steeply angled outer walls prevent small animals that

Photo: F. Navàs.

have entered the road from returning to the wild. Longitudinal ditches must therefore maintain a continuity with the surroundings, with an outer wall on an angle of less than 45 ° (Figure 20.1). This ameliorates the barrier effect otherwise exerted on small animals by ditches.

- Roadside kerbs, usually vertical, are also a death trap for many animals. Exit ramps on an angle of less than 45 º must be installed at intervals of 25 m at the most, or alternatively, ramped kerbs can be built (Figures 20.1 and 20.2).

- These measures are especially important on roads that traverse natural environments with a high fauna diversity or where conflict with a particular species is envisaged.



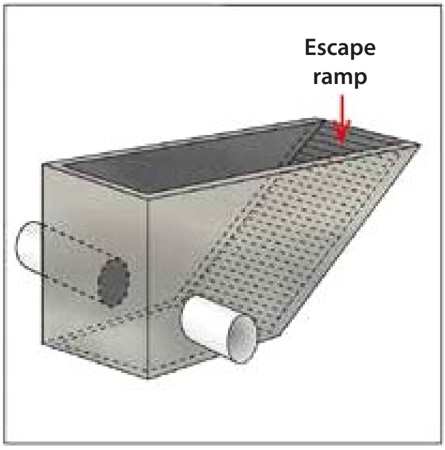


Figure 20.1. Diagram of an angled kerb and an exit ramp from a manhole or similar drainage infrastructure.

Figure 20.2. Kerb with easy access to the natural environment for animals after crossing a road. Photo: F. Navàs.

Figure 20.3. Gradual road-environment transition. Photo: C. Rosell.

Common bad practices and mistakes

Figure 20.4. Vertical kerb wall: a barrier for small animals that fall onto the road and cannot escape. Photo: C. Rosell.

Figure 20.5. Manhole and drain gratings must be dense to prevent small animals from falling inside. The walls of these structures should also be adapted to help animals to escape. Photo: C. Rosell.

Introduction

- Tortoises, including Hermann's tortoise (*Testudo hermanni*), classified as 'Endangered' in the Spanish Catalogue of Endangered Species (EAEC), and the Spur-thighed tortoise (*Testudo graeca*), have a high value for biodiversity conservation. Both species are listed in Annex IV of the Habitats Directive, which covers species of Community interest that require strict protection.

- This group is particularly sensitivity to the effects of roads and railway lines. The main conservation threats include habitat fragmentation and destruction and roadkill.

Suitable crossing structures for tortoises

- Wildlife crossings and also multi-use crossings, both over- and under-road (Files 1 to 9), are suitable for tortoises. Fencing is indispensable to funnel tortoises towards the crossing entrances.

- The main impediment for these species is their limited ability to overcome obstacles. Any such obstacles at entrance points compromises their utility as crossings.

- Ecoducts and viaducts (Files 1 and 5) with fully restored habitats for these species are the most suitable structures to ensure connectivity between populations of these species.

- Small vertebrate underpasses are suitable for tortoises. If the 2 m minimum height for other

Photo: R. Campeny.

small vertebrate species is impossible for technical reasons, structures at least 60 cm high can be adapted for use by tortoises, as there is evidence that they use them.

- Due to the restricted movements of tortoises, the complete integration of the crossing with its surroundings must be guaranteed, along with the continuity of higher quality habitats in adjacent areas. For this purpose, habitats in areas outside the public domain of the road must also be restored in some cases.

Fencing reinforcement for tortoises

- Standard fencing for small vertebrates also prevents tortoises from entering roads (see File 14). The base must be buried as tortoises are good diggers.

Introduction

● Bats have a high value for biodiversity conservation. Several species are rated as 'Vulnerable' and one, the long-fingered bat (*Myotis capaccinii*), is listed as 'Endangered' in the Spanish Catalogue of Endangered Species (EAEC). All bat species figure in Annex IV of the Habitats Directive, which lists species of Community interest that require strict protection. The special sensitivity of bats to the effects of transport routes is now fully acknowledged.

● Bats were previously considered to have a low risk of road mortality due to their low frequency in roadkill studies. However, sampling methods focusing on the location of small carcasses that degrade quickly on roads and thus go unnoticed have shown that bat mortality may in fact be much higher than previously estimated.

● Body size, wing shape, feeding ecology and type of echolocation emissions shape the flight paths of different species. Studies of flight patterns have also shown differences in preferred crossing types between groups of species.

Photo: X. Fernandez.

Suitable crossing structures for bats

● Wildlife crossings and also multi-use crossings, both over- and under-road, are suitable for bats. Revegetation of the crossing approach zone and adaptation of the overpass surface and the underpass interior are important adaptations that encourage their use.

● Bats cross roads by flying above overpasses such as ecoducts (File 1) and wildlife or multi-use overpasses (Files 2 and 3). However, their flight paths need to be funnelled towards these structures by designing the restoration process in such a way that rows of vegetation grow along the full length of the structure surface and between the two entrance points. Screens installed on both sides of the structure can partly enhance the function of these vegetation corridors (see File 12).

● Viaducts (File 5) and wildlife and multi-use underpasses (Files 6-9) are also suitable for bats. The most appropriate dimensions depend on the target species. For large bat species that tend to hunt in open spaces and others that use vegetation fringes and ecotones to guide their movements, e.g., *Eptesicus spp*. and *Nyctalus spp*., large mammal crossings and multi-use crossings (Files 6 and 7), measuring 7 x 3.5 m are suitable, as some studies have found that bats require structures that are at least 6 m wide. Small bat species, which have low, agile flight patterns, usually through vegetation, e.g., *Rhinolophus spp*., *Myotis spp*. and *Plecotus spp*., can use smaller structures such as small vertebrate underpasses (File 8) and modified culverts (File 9) —both with a minimum section of 2 x 2 m—, as they are perfectly able to fly within confined spaces.

● Bat gantries are used in some countries, although they are not considered to be effective. These structures consist of several taut parallel wires that span the road above the maximum clearance height, anchored to two poles on either side. They are supposed to guide bats and encourage them to cross above the vehicles, thus avoiding collisions. However, several monitoring projects have found that they are not effective. Their use is therefore not recommended.

Bat mortality reduction screens

● Fences normally used to prevent wildlife from accessing roadways are not suitable for bats (Files 13 and 14).

● Therefore, if particularly conditions such as the proximity of havens for large bat colonies or roads that intersect frequent bat flight paths make it necessary to install fencing for bats in order to reduce the risk of roadkill or railkill, a particular type of fence must be employed (see File 14).

Other aspects to consider

- The correct location of bat crossing structures requires prior studies to identify the main flight and migration routes of the species in the landscape intersected by the road.

- To encourage the use of crossings by bats, they must be well integrated into the local landscape matrix. To achieve this goal, the entrance revegetation process must create vegetation corridors connected to the surrounding natural mosaic, as many species in this group use natural linear structures to guide their flight paths through the territorial matrix.

- The effectiveness of viaducts and modified culverts with a running watercourse is improved if the watercourses and the associated riparian vegetation act as a natural funnel for the flight of some bat species, including Daubenton's bat (*Myotis dauben-tonii*) and the long-fingered bat (*Myotis capaccini*).

- Underpasses, including viaducts, wildlife and multi-use underpasses and modified culverts, can all assist the conservation of some bat species that use cracks and fissures in their walls as shelter. Some studies show that these cracks should be 1.5 - 2 cm wide to provide optimum shelter for these species. Shelters (which can also be artificial boxes) can attract bats into the structures, while at the same time enhancing their funnelling function for movements.

- Boxes and other types of bat shelters, new or restored feeding areas such as ponds, and forest clearings near the crossing entrances can all assist the conservation of bat populations and mitigate the impacts of the road.

- Road lighting near bat crossing structures and their entrance points must be avoided, as lighting deters most bat species from using them. Moreover, mercury lamps attract insects and consequently bats which feed on them, leading to a greater risk of roadkill for species such as *Pipistrellus spp.* that tend to feed near artificial light.

Introduction

- Semi-aquatic mustelids have a high value for biodiversity conservation, particularly the globally endangered European mink and the otter, both included in Annex IV of the Habitats Directive, which lists species of Community interest that require strict protection. The polecat (*Mustela putorius*), a species in decline in some parts of Spain, is also included in this group.

- Semi-aquatic mustelids are particularly sensitive to the effects of roads, and roadkill is the major anthropic cause of mortality, causing an estimated 60–90% of non-natural European mink deaths, depending on the region.

- These mustelids are associated with aquatic environments, rivers and riparian ecosystems. Roadkill hotspots are often points where roads intersect watercourses and drainage infrastructure (rivers, streams, canals, irrigation ditches, etc.). This is because individuals travel along riparian vegetation, and instead of trying to swim across the watercourse when they reach a completely flooded culvert, they usually go onto the road.

- In order to mitigate this source of mortality, culverts must be adapted by incorporating ledges for these animals above the water level and the revegetation at the entrance must be redesigned to guide them towards the mouth.

Suitable crossing structures for semi-aquatic mustelids

- Modified viaducts are optimal on road sections that cross rivers and larger watercourses, as they allow the aquatic and riparian habitats to be preserved (see File 5). It is important to maintain the shape of the banks, the continuity of the riparian vegetation and dry strips on both sides, even during floods.

- Culvert adaptation (see File 9) can be a solution with optimum cost-effectiveness in other situations. Drains with a section of at least 2 x 2 m must be used when adapting culverts for wildlife passage. In the case of habitat defragmentation projects for roads in service, the adaptation of drains less than 2 m wide can be considered only if they are intended for mustelids (badger, otter, etc.).

- This adaptation basically consists of installing ledges on each side of the structure interior with a minimum width of 0.5 m that will remain dry, even in periods of peak flow, and creating suitable connections with the surrounding natural environment. These ledges can be concrete platforms, walkways (see File 9) or raised platforms anchored to the wall or the top of the structure (Figures 9.5 and 9.6).

Photo: A. Gómez.

- In areas where watercourses are flooded for long periods, the lateral ledges must be stepped in order to ensure their effectiveness and adaptation to changing water levels (Figure 9.2).

- In the case of habitat defragmentation projects for roads in service involving culverts that may be completely flooded, two dry pipes with a small diameter (up to 40 cm) can be installed inside the structure at the top on both sides (Figure 9.2).

- The dry lateral ledges must be connected to the natural surroundings around both ends of the crossing. If they are on different levels from the ground, access ramps should be built to connect the crossing interior to the banks of the watercourse. Continuous strips of riparian vegetation must also be maintained to ensure that the animals are led directly to the modified culvert entrance (Figures 9.3 and 12.4).

Measures to prevent road encroachment by semi-aquatic mustelids

- The fence types normally used to prevent small vertebrates from entering roads may not be suitable for semi-aquatic mustelids. Specific fences for European mink or otter, depending on the requirements, should be installed at envisaged hotspots (see File14).

- Shrubs and creepers that might connect the wildlife crossing entrances to the roadside must be removed from unfenced road verges (see File 12 and Figure 12.8) in order to prevent these patches of vegetation from leading animals towards sections with high roadkill risk.

Introduction

● The brown bear is listed as 'Endangered' in the Spanish Catalogue of Endangered Species (EAEC), and it is included in Annex IV of the Habitats Directive, which covers species of Community interest in need of strict protection.

● Habitat fragmentation and the barrier effect generated by transport infrastructures are amongst the major threats to the conservation of this species in Spain.

● Most of the empirical data on the use of crossings by bears are from studies conducted in North America, and the recommendations on optimum crossing characteristics and sizes are designed for the American black and grizzly bears. Although the American grizzly bear and the European brown bears are the same species, there are important differences in the ecoethology of the two subspecies and, above all, the availability and size of habitats without anthropic disturbances. Consequently, this File contains recommendations based on European experiences, mainly in Greece, Bulgaria, Romania and, to a lesser extent, the Cantabrian mountain range in Spain.

● A decisive factor in the use of wildlife crossings by bears is the quality of the habitat in the vicinity of the structures and its interconnection with other suitable habitats. The importance of this aspect has been proven in studies in both North America and Europe.

● The correct location of the crossings is a decisive aspect for their optimised use by bears, especially in areas where habitats are heavily fragmented and humanized.

Suitable crossing structures for brown bear

● Ecoducts and viaducts are the best types in ecological corridors of strategic interest for connectivity between populations and along routes used regularly by the species, as they permit full connection between habitats (see Files 1 and 5).

Photo: Oso Pardo Foundation.

Wildlife crossings can also be appropriate at these points, especially if they have the optimum dimensions for large mammals (see recommendations in Files 2 and 6).

● Multi-use under- and overpasses can be used to enhance the permeability of the infrastructure in heavily humanised sections. This is because the behaviour of brown bears is adaptable, and the use of such structures has been recorded in Greece and Spain, albeit on an infrequent basis. In this case, crossings must have at least the minimum dimensions recommended for large mammals (see Files 3 and 7), although the sporadic use of smaller crossings has been detected.

● Plantations and fencing must be installed to guide the bears towards the crossing entrance points (File 12). Restoration work around the entrances should be designed to facilitate connections between appropriate habitats in the surroundings and the crossing entrances.

Specific fencing for bears

● Conventional fences for large mammals (File 13) may not prevent bears from entering roads. Bears can usually breach fences by pushing down the top of the mesh, or getting through gaps between the fence and the wings of the crossing structures.

● Specific bear fences can be installed on road sections expected to be roadkill hotspots (see File 13).

Introduction

● The Iberian lynx is an endemic species on the Iberian Peninsula. It is ranked as 'Endangered' worldwide and figures in Annex IV of the Habitats Directive, which covers species of Community interest in need of strict protection.

● This lynx is particularly vulnerable to the effects of roads and railway lines. Road casualties are one of the major threats to its conservation and the main anthropogenic cause of Iberian lynx mortality.

Photo: LIFE + Iberlince

Suitable crossings structures for the Iberian lynx

● Ecoducts and viaducts are the best structures in the case of ecological corridors of strategic importance for connectivity between populations and corridors used regularly by the species, as they facilitate a complete connection between habitats (see Files 1 and 5). Wildlife crossings can also be appropriate at these points, especially if they have the optimum dimensions for large mammals (See Files 2 and 6).

● Multi-use under- and overpasses can be used to enhance the permeability of the infrastructure in heavily humanised sections. In this case, the structures should have the dimensions recommended for large mammals (see Files 3 and 7). In the case of defragmentation projects for roads already in service, the adaptation or construction of smaller structures down to a minimum of 4 x 2 m can be considered.

● The use of modified culverts (see File 9) by this species has also been detected. These structures may thus also be appropriate if they are suitably adapted.

● Plantations and fencing must be installed to funnel lynxes towards the crossing entrance points (File 12). Revegetation of structure entrances should be designed to provide refuge and connections with suitable habitats in the area.

● The complete integration of the crossing with its surroundings must be ensured, along with the continuity of higher quality habitats in adjacent areas.The restoration of habitats in areas outside the public domain of the road may therefore also be necessary as strategic components of "green infrastructure".

Prevention of lynx access to roads

● Conventional fences for large mammals may not prevent lynxes from entering roads, given their extraordinary jumping and climbing ability. Specific lynx fences should therefore be erected at envisaged roadkill hotspots (see File 13).

● Measures aimed at reducing the proliferation of rabbits on road verges should be implemented throughout the species' distribution area, especially in areas that are occupied or are important for connectivity, as they are a powerful attraction point for lynxes and thus increase the risk of road mortality. See recommendations for verge management in File 16.

● Intensified shrub and tree removal along the roadside should be considered at lynx roadkill hotspots, with a view to creating 10-15 m wide strips devoid of refuge and stalking points between the woodland and the road.

4 Annex

1 Presentation

2 General aspects and frame of reference

3 Catalogue of technical measures and prescriptions

4 Annex

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For more information, see:

Ministry of Agriculture, Food and the Environment website: www.magrama.gob.es/es/.

Australasian Network on Ecology and Transportation website: www.ecologyandtransport.com

Infra Eco Network Europe (distribution of products manufactured under the Cost 341 Action) website: www.iene.info.

International Conference on Ecology & Transportation website: www.icoet.net/

Websites dealing with applications related to wildlife crossings and connectivity such as:
www.fs.fed.us/wildlifecrossings/index.php
www.conefor.org/
www.stream.fs.fed.us/fishxing

Other documents in this series
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2
PRESCRIPCIONES TÉCNICAS PARA EL SEGUIMIENTO Y EVALUACIÓN
DE LA EFECTIVIDAD DE LAS MEDIDAS CORRECTORAS DEL EFECTO
BARRERA DE INFRAESTRUCTURAS DE TRANSPORTE
*(Technical prescriptions for monitoring and evaluating the effectiveness
of corrective measures to mitigate the barrier effect of transport infrastructure)*

3
PRESCRIPCIONES TÉCNICAS PARA LA REDUCCIÓN DE LA FRAGMENTACIÓN
DE HÁBITATS EN LAS FASES DE PLANIFICACIÓN Y TRAZADO
*(Technical prescriptions for the reduction of habitat fragmentation
at the planning and routing)*

4
INDICADORES DE FRAGMENTACIÓN DE HÁBITATS CAUSADA
POR INFRAESTRUCTURAS LINEALES DE TRANSPORTE
*(Indicators of habitat fragmentation caused by
linear transport infrastructure)*

5
DESFRAGMENTACIÓN DE HÁBITATS. ORIENTACIONES PARA REDUCIR
LOS EFECTOS DE LAS CARRETERAS Y FERROCARRILES EN FUNCIONAMIENTO
*(Habitat defragmentation. Guidelines for mitigating the
effects of roads and railways in operation)*

6
IDENTIFICACIÓN DE ÁREAS A DESFRAGMENTAR PARA REDUCIR LOS IMPACTOS
DE LAS INFRAESTRUCTURAS LINEALES DE TRANSPORTE EN LA BIODIVERSIDAD
*(Identification of areas to be defragmented in order to mitigate the impact
of linear transport infrastructure on biodiversity)*

The second edition of TECHNICAL PRESCRIPTIONS FOR WILDLIFE CROSSING AND FENCE DESIGN is an update and expansion of the contents of the first issue (only in spanish) in the series of *Documents for reducing fragmentation of habitats caused by transport infrastructure,* drafted by the Working Group on the same topic composed of representatives from the Transportation and Environment Departments of Spain's Regional and National Governments. This Group is supervised by the National Committee on the Natural Heritage and Biodiversity. It is coordinated by the Natural Environment Sub-Directorate General, under the supervision of the Directorate General for Environmental Quality and Assessment and the Natural Environment and the Ministry of Agriculture, Food and the Environment.

The first edition was drafted on the basis of the European handbook FAUNA AND TRAFFIC, part of the COST 341 Action project. It specified the technical prescriptions for the design of wildlife crossings and fences, including the minimum standards necessary to ensure the effectiveness of these measures and recommendations for the optimisation of their function.

In this edition, the contents have been modified to reflect current knowledge and the best practice on the subject. It aims to provide a new impetus to the implementation of the most effective ways to mitigate the barrier effect and wildlife mortality associated with transport infrastructure, and also to help building safer roads with a lower risk of accidents caused by animals.

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