Wildlife & Traffic

A European Handbook for Identifying Conflicts and Designing Solutions

7 Solutions to reduce transport infrastructure impacts on wildlife

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Contents

7.4 Reducing barrier effect: wildlife passages

Preserving ecological networks (core natural areas and corridors connecting them) is a key biodiversity conservation action. Rapid infrastructure development and events linked to climate change require more than ever that native species are guaranteed the ability to move across the landscape. Conservation of wildlife populations can only be ensured in the long term by avoiding new barriers to movement and by restoring ecological connectivity, which includes defragmentation actions.

The barrier effect of transport infrastructure on wildlife is one of the most important factors associated with habitat fragmentation. Its magnitude varies with infrastructure characteristics (i.e. traffic intensity, infrastructure width, presence and type of fencing) and differs between species depending on their mobility, their behaviour towards traffic, and their capacity to inhabit or move across human-modified habitats. The barrier effect is not as tangible as animal-vehicle collisions, but the results can be equally lethal for the local survival of populations.

Wildlife passages (also known as 'fauna passages' and 'wildlife crossings') are structures designed and purpose built or adapted to enable wildlife to safely cross over or under linear transport infrastructure. Those movements are crucial for dispersal of individuals to find mating opportunities between different subpopulations, which increases genetic variability, or to find habitats that suit seasonal needs. Adaptation to the effects of climate change also requires that wildlife can overcome barriers. So, wildlife passages contribute to preserving ecological connectivity and are valuable elements of the Green Infrastructure.

Thousands of wildlife passages have been constructed and monitored over the last decades and the wide knowledge produced is summarized in this section. It includes requirements for different target species as well as recommendations on how to design and maintain these structures. It also describes how to install fencing to guide animals to the passage and to provide suitable landscaping and integration into the surrounding landscape.

This section includes Section 7.4.1 – General recommendations, description of four types of overpasses (Section 7.4.2 – Overpasses), seven types of underpasses (Section 7.4.3 – Underpasses) and at grade fauna passages (Section 7.4.4 – At grade fauna passages).

7.4.1 General recommendations

▸ **Access to Rationale. Requirements of target species to enhance wildlife passage use**

Wildlife passages as part of a general landscape permeability concept

Wildlife passages should never be considered as an isolated feature. They should be an integrated part of a general permeability plan to maintain connectivity within and between animal populations and/or ecosystems. A permeability plan emphasises connectivity between habitats at regional or larger scale and considers not only the transport infrastructure but also the distribution of habitats and ecological corridors as well as other potential barriers such as built-up or fenced areas. Wildlife passages can then be regarded as critical elements to connect habitats and enhance the mobility of animals across transport infrastructure.

A permeability plan should be designed for each transport infrastructure project. All connecting elements, such as tunnels, viaducts, underpasses, overpasses, stream and river crossings and culverts designed or adapted to facilitate wildlife movement should be integrated into an assessment of connectivity. Again, the primary objective must be to maintain permeability for wildlife across transport infrastructure and to ensure the connectivity of the habitats within the landscape.

Wildlife passages are necessary if transport infrastructure:

- bisects important patches of habitat or creates a barrier to traditional migration routes (see Chapter 3 – Effects of Infrastructure on Nature and Chapter 4 – Developing Integrated Solutions);
- causes a significant barrier which affects ecological networks, migration corridors or other particularly vulnerable habitats, such as wetlands or other bodies of water;
- threatens any wildlife species and particularly those most sensitive to barrier effect and traffic mortality;
- results in significant damage or loss of special ecosystems, communities or species which require frequent connections between habitats on both sides of the infrastructure;
- Impairs significantly the general permeability of the landscape, i.e. the connectivity between habitats in the wider countryside;
- is fenced at some sections or for the entire length.

Types of wildlife passages

The naming of structures differs between countries. Most commonly used names in Europe are provided in this chapter.

Wildlife passages can be divided in two groups: overpasses, crossings over the transport infrastructure, and underpasses, crossings under the infrastructure. Four types of overpasses and seven types of underpasses are listed and described below (Table 7.4.1. and Table 7.4.2.):

- Overpasses

    – Landscape overpass (Ecoduct, Green Bridge)

    – Wildlife overpass (Fauna overpass)

    – Multiuse overpass

    – Tree-top overpass (Canopy bridge)

- Underpasses

– Adapted viaduct (Landscape underpass)

– Wildlife underpass (Fauna underpass)

– Multiuse underpass

– Small fauna underpass

– Adapted culvert

– Fish passage

– Amphibian passage

Additionally, 'bat crossing' and 'at grade fauna passage' are also described even if further studies are required to establish the effectiveness.

Types of wildlife passages are defined in this handbook based on their ecological function, i.e. to provide links which connect ecosystems or to provide crossing opportunities for wildlife or particular target species. Names for these passages should not be confused with construction engineering terminology used in infrastructure design. E.g. a 'landscape overpass' is a type of wildlife passage that can be provided by a bridge, a cut-and-cover tunnel or even by an excavated tunnel (construction types).

Table 7.4.1 – Main types of wildlife passages – Overpasses. The names provided have been adapted from the originals in the first edition of the Wildlife and Traffic Handbook. Note that other specific names are used in guidelines of many European countries. Bat crossings and at grade passages, both under testing, are described in this chapter but are not included in the Table.

OVERPASSES
Name **Definition**
Landscape overpass; Ecoduct; Green bridge  **Large structure over transport infrastructure to provide continuity of habitats from both sides**. Due to their width, a diversity of habitat types (e.g. vegetation or soil types, stone rows or piles, ponds, etc.) could be included. Combined with perimeter fencing that funnels the animals to the structure and with light/noise screens to reduce disturbance by traffic when required. The main difference to wildlife overpasses is width and possibilities for vegetation cover and diversity of habitats being created which facilitate better ecosystem connection. Landscape overpasses can also be constructed over cut-and-cover or excavated tunnels.

Wildlife overpass; Fauna overpass

Structure built over transport infrastructure specifically to provide a safe crossing point for wildlife and to connect habitats from both sides.

The surface is covered with natural materials and soil allowing different species of vegetation growth. Other refuges for fauna such as stone or wood rows can also be installed.

Combined with perimeter fencing that funnels the animals to the structure and with light/noise barriers to reduce disturbance when required.

While similar to landscape overpasses, they are narrower, limiting the extent to which different habitats and vegetation can be included on the structure.

Multiuse overpass

Structure built over transport infrastructure with multiple functions including the movement of fauna. It combines wildlife and human uses such as small forestry roads, cattle passages or pedestrian paths.

Modifications are included to encourage use by wildlife such as addition of strips covered by natural materials and vegetation, and screens to reduce traffic disturbance when required.

Combined with perimeter fencing that funnels the animals to the structure.

Tree-top overpass; Canopy bridge

Rope, net or pole suspended above transport infrastructure from vertical poles or trees, for arboreal and scansorial species.

While fencing would improve rates of use, fence designs are yet to be developed due to the climbing ability of the target species.

Similar structures, have been proposed for bats, the success of which has yet to be demonstrated.

Table 7.4.2 Main types of wildlife passages – Underpasses. The names provided have been adapted from the originals in the first edition of the Wildlife and Traffic Handbook. Note that other specific names are used in guidelines of many European countries.

UNDERPASSES
Name Definition
Adapted viaduct; Landscape underpass

Large structure, usually supported by pillars or arches, which carries transport infrastructure and enables the preservation of valuable ecosystems and ecological corridors below the structure.

Preservation and restoration of continuous terrestrial, riparian and aquatic habitats below viaducts facilitate movement of multiple vertebrate and invertebrate species.

Land uses and activities under the structure must be compatible with fauna movements and preservation of ecological connectivity. Viaducts must not be considered as wildlife passages when human disturbance or infrastructure with high traffic volume is beneath.

Combined with perimeter fencing that funnels the animals to the structure and with light/noise screens to reduce disturbance when required.

Wildlife underpass; Fauna underpass

Structure built under transport infrastructure specifically to provide a safe crossing point for wildlife, typically large and medium-sized mammals, such as ungulates and large carnivores, but also for other vertebrates and invertebrates. Construction types are predominantly box, vault or beam platform structures.

The substrate is covered with natural materials and soil allowing different species of vegetation growth where there is enough light and humidity. Elements such as stone rows may provide wildlife refuges inside.

Combined with perimeter fencing that funnels the animals to the structure and with light/noise screens to reduce disturbance when required.

Depending on underpass dimensions, they may be suitable for different groups of animals.

Note: to be suitable for amphibians in migration, these structures may require specific fencing (see Section 7.4.3 – Amphibian passages)

Multiuse underpass

Structure built under transport infrastructure with multiple functions including the movement of fauna. It combines wildlife and human uses such as small forestry roads, cattle or pedestrian passages. A drainage function including streams or other small waterways inside the structure is also compatible and may even lead fauna through the passage.

These underpasses may include modifications to increase wildlife use such as fencing to funnel the animals, adaptation of vegetation at the entrances and measures to avoid excessive pooling of water.

Combined with perimeter fencing that funnels the animals to the structure and with screens to reduce light and noise disturbance from traffic when required

Small fauna underpass

Structure built under transport infrastructure designed specifically to provide a safe crossing point for small fauna such as reptiles, small mammals or invertebrates which are used to dark, humid habitats. Construction types are predominantly box or vault structures.

Combined with perimeter fencing that funnels the animals to the structure and with light/noise screens to reduce disturbance when required. Depending on underpass size, these are also suitable for larger animals.

Note: to be suitable for amphibians in migration, these structures may require specific fencing (see Section 7.4.3 – Amphibian passages)

Adapted culverts

Modified pipe or box culvert that allows a watercourse and/or drainage to flow underneath transport infrastructure and includes adaptations to facilitate aquatic and terrestrial wildlife crossing. These often include dry ledges or shelves to provide dry passage, which are connected to adjacent habitats.

The design and landscaping at the entrances is particularly adapted for the needs of wildlife, not only erosion control.

Fish passages

Modified pipe or box culvert that allows a watercourse and/or drainage to flow underneath transport infrastructure and includes adaptations to provide particular conditions that enable fish to swim through.

When possible, adaptations for use by wildlife may also include dry ledges or shelves to provide passage for other terrestrial species, and which are connected to adjacent habitats.

Amphibian passages

Small structures built under transport infrastructure designed specifically to provide a safe crossing point for amphibians. Often consisting of multiple underpasses in close proximity to each other.

Requires effective opaque fencing to intercept the amphibians and funnel them to the crossing structures.

Density and location of wildlife passages

The total number and distribution of wildlife passages required to effectively maintain habitat connectivity is a major decision when planning mitigation measures. The number and type of measures required will depend on the target species and the distribution of habitat types in each area (Table 7.4.3). In some cases, a single or a few large passages could be necessary to mitigate a local problem, whereas in other situations it may be more important to provide a large number of different types of wildlife passages suitable for a variety of target species and appropriate to connect different habitat types.

- Wildlife passages should be part of an overall permeability plan where the biggest structures which allow complete restoration of connectivity (such as landscape overpasses or adapted viaducts) must be located at strategic points of the ecological network, while other, possibly multiuse structures, play an important complementary role. When determining the permeability of an infrastructure, all crossing opportunities for animals should be considered, including multiuse structures that may not have been designed for wildlife but nevertheless can provide possibilities for passages.
- Landscape analyses to identify ecological networks and spatial distribution of habitats is one of the first, basic steps to determine the number and location of wildlife passages required. Different techniques, such as graph theory, least-cost path and others may provide useful tools to visualize possible movements and flows of wildlife and help to identify the most appropriate location for wildlife passages. For a given species, a maximum 'effective resistance' coefficient could be established between core areas ('nodes') that an infrastructure fragments in order to determine the correct number and location of wildlife crossings to provide appropriate permeability of the infrastructure. The more passages are built the smaller the 'effective resistance' is. This coefficient will depend on variables such as target species habitat preference, distance between the nodes or wildlife passage effectiveness.
- Habitat features, and particularly the location of ecological corridors and other valuable components of the Green Infrastructure are also crucial to assess the number and location of wildlife passages required. In general, the density of passages should be higher in natural areas, e.g. forests or wetlands, than in densely built-up or intensively-used agricultural areas. However, in areas where there are many artificial barriers resulting from transport infrastructure or built-up areas, wildlife passages can be essential for maintaining the general permeability of the landscape. Therefore, a good analysis and understanding of all landscape characteristics on different sectoral levels (other barriers, land uses, future developments and potential conflict areas) is critical to identify best locations for wildlife crossings. In such cases, solutions can be integrated with all remaining functional corridors, existing green infrastructure components or sites where restoration of connectivity is required.
- Identifying the species for which wildlife crossings are targeted is another basic step to decide on the number and location of the passages, as well as their dimensions and design (Table 7.4.4). Knowledge about the species' habitat dependency, scale of movement, behaviour, population size and dynamics is key. Larger species with wide ranges (ungulates, large carnivores) may require a few strategically placed passages of larger dimensions, while smaller species may require more passages, even if of small dimensions, located in specific habitats. Invertebrates must also be considered everywhere.
- The square-root of the home range ($HR^{0.5}$) may provide a useful measure to assess the scale of a species' mobility and help to decide how far apart wildlife passages should be located. As mobility may differ between populations, the recommendation is to use local, empirical data obtained in field studies using techniques such as camera traps or telemetry. However, focus on a single species will not ensure proper connectivity for all wildlife. To achieve a more permeable infrastructure, a multiple species approach is needed that balances species mobility, population size and behaviour. Here, the needs of smaller, abundant species may weigh less than the requirements of larger or rare species.
- Considering home range size and habitat type of target species, general recommendations are established in some European countries, e.g. in forested habitats, wetlands and agricultural landscapes there should be at least 1 wildlife passage / 1 km for large mammals and 1 wildlife passage / 500m for small vertebrates, while in areas heavily transformed by human activity the distances may be scaled-up to

1 wildlife passage / 3 km for large mammals and 1 wildlife passage / 1 km for small vertebrates.
- While the number and density of wildlife passages may be established on a wider scale relating to population sizes and dispersal, the specific location of the passages should be determined on a local scale based on local conditions. Different parameters such as wildlife-vehicle collision hotspots, known migratory and/or commuting routes and severance of habitats, are critical in the analyses to achieve the maximum benefit from wildlife passages for local biodiversity.

Choice of the appropriate wildlife passage

Types of wildlife passages

The selection of the most appropriate type of wildlife passage requires consideration of the landscape, habitats affected and target species requirements. The importance of the habitats and species should be evaluated at a local, regional, national and international scale as part of an EIA (see Chapter 5 – Planning Tools). Preserving ecological connectivity -or restoring it where required- should be the goal, meaning a multi-species approach is to be preferred. In general, the more species depend on habitat connectivity, the more complex should be the mitigation measures to ensure effectiveness (Figure 7.4.1). Therefore, when transport infrastructure unavoidably creates a barrier to an important ecological corridor for long distance dispersal, ecoducts or adapted viaducts may be the only measure that can help to maintain functional connectivity. In contrast, small adapted culverts or amphibian passages may be enough to maintain a migration corridor for a locally important population of small vertebrates (e.g., reptiles or amphibians). In practice, to effectively mitigate habitat fragmentation:

- A set of integrated measures for the whole infrastructure addressing problems at each specific site is required.
- The combination of diverse wildlife passage types combined with other measures, meeting the needs of a variety of target species or groups, will often be the best solution to reduce the barrier effect of transport infrastructure.

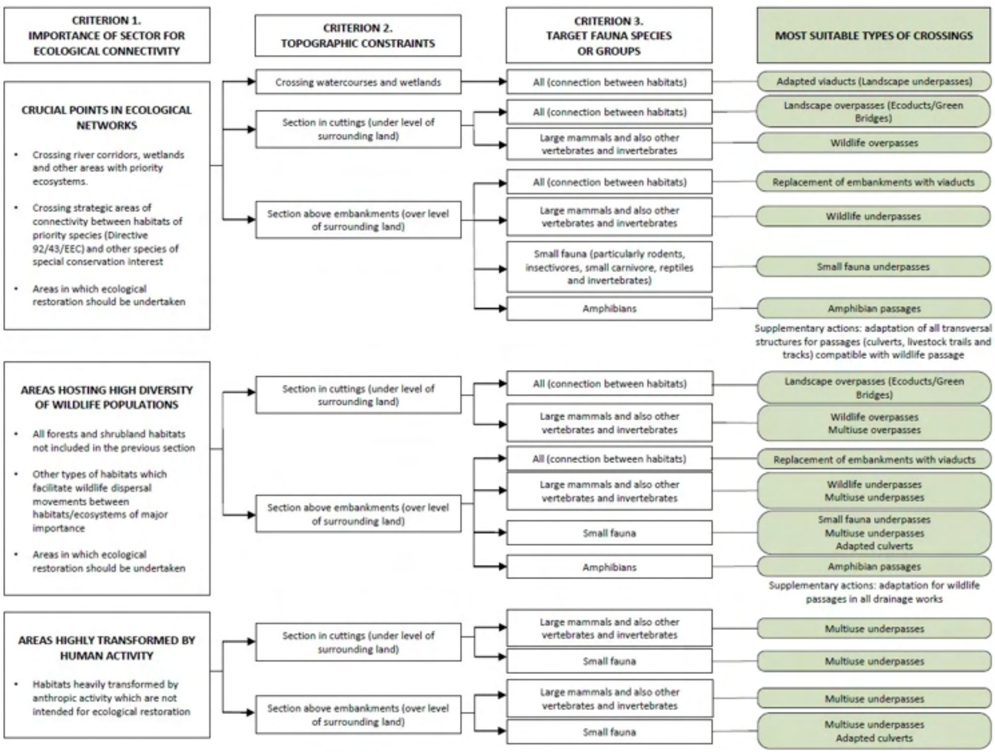


Figure 7.4.1 – The choice of wildlife passage type will depend on its importance for ecological connectivity and biodiversity conservation as well as on other criteria such as main target species and topographic constraints (Source: Adapted from Magrama, 2016). Different types of wildlife passages can be combined along a section of infrastructure section to achieve the best reduction in landscape habitat fragmentation.

Target species

Even if a multi-species approach is to be preferred when designing wildlife passages, it is essential to clearly identify the main target species (Figure 7.4.2 and Table 7.4.3). Large mammals, amphibians or some particularly endangered species among vertebrates and invertebrates will require rather different types of structures.

- While any wildlife species could be designated a target species for wildlife passages, including invertebrates, there is a need to avoid facilitating Invasive Alien Species (IAS) as they cause damage to local biodiversity.
- In practice, the expense of building wildlife passages means that priority will be given to reducing the barrier effect in areas crucial for conservation and restoration of ecological networks. Ideally, opportunities for all species in a territory to cross the infrastructure should be provided in its development. Identifying target species, their location and movement patterns are important steps in the process of planning the location and design of wildlife passages and planning monitoring procedures to evaluate the success of a passage (see Chapter 9 – Monitoring and Evaluation and Chapter 10 – Maintenance of ecological assets on transport linear infrastructure).
- Target species are often endangered species, but also abundant large mammals which are frequently involved in animal-vehicle collisions posing a big threat to infrastructure safety. Both influence the position and type of passage design. Hotspots of wildlife mortality should be considered in a global analysis combined with information about other factors such as local wildlife population density. Mitigation measures are required not only in hotspots of road mortality and even in areas not identified as hotspots, but where a seemingly low wildlife mortality could be critical for the long term conservation of low density target species or local endangered populations.
- Even if target species are important in deciding if and where wildlife passages are necessary, the design of passages must follow a multispecies approach not just catering for the needs of only one single target species. Usage can be maximized and effectiveness increased by including the needs of a wide spectrum of species. For example, an overpass across a motorway that is built to preserve a migration route for red deer must also form a habitat connection for populations of other vertebrates (not only mammals, but also birds, amphibians and reptiles) and invertebrates (e.g. insects). Nevertheless, experience has shown that some designs are better suited to some particular species than others. Table 7.4.3 gives some indications for appropriate passage type which may reduce mortality and provide safe crossing points for particular species or groups of species.

Figure 7.4.2 – Requirements of target species will determine the most suitable type of wildlife passage. Some examples of different species using wildlife passages: A: Otter (*Lutra lutra*); B: Wild boar (*Sus scrofa*); C: Brown bear (*Ursus arctos*); D: Pheasant (*Phasianus colchicus*); E: Mediterranean pond turtle (*Mauremys leprosa*); F: Little egret (*Egretta garzetta*); G: Roe deer (*Capreolus capreolus*); H: Ground beetle (*Carabus hortensis*) (Photos by: A, B, D, E, F: Minuartia; C: LIFE SAFE-CROSSING; G: E. Rondeau – VINCI Autoroutes; H: H. Reck).

Table 7.4.3 – Suitability of different types of wildlife passages for a selection of species or groups of species.

	Landscape overpass (Ecoduct, Green Bridge)	Wildlife overpass (Fauna overpass)	Multiuse overpass	Tree-top overpass (Canopy bridge)	Adapted viaduct (Landscape underpass)	Wildlife underpass (Fauna underpass)	Multiuse underpass	Small fauna underpass	Adapted culvert	Fish passage	Amphibian passage
Moose, Red deer	●	●	○	–	●	●	○	–	–	–	–
Roe deer, Chamois	●	●	○	–	●	●	○	–	–	–	–
Wild boar	●	●	○	–	●	●	○	–	○	–	–
Brown bear	●	●	○	–	●	●	○	–	–	–	–
European lynx	●	●	○	–	●	●	○	–	○	–	–
Wolf	●	●	●	–	●	●	●	–	–	–	–
Fox	●	●	●	–	●	●	●	●	●	–	–
Wildcat	●	●	●	?	●	●	○	●	●	–	–
Badger	●	●	●	–	●	●	●	●	●	–	–
Otter, European mink	○	○	○	–	●	●	●	●	●	–	–
Marten Stone marten	●	●	●	○	●	●	●	●	●	–	–
Other small mustelid	●	●	●	–	●	●	●	●	●	–	–
Genet	●	●	●	–	●	●	●	●	○	–	–
Hare	●	●	●	–	●	●	●	○	○	–	–
Rabbit	●	●	●	–	●	●	●	●	○	–	–
Hedgehogs	●	●	●		●	●	●	○	○	–	–
Shrews	●	●	●	–	●	●	●	●	○	–	○
Red squirrel	●	●	●	●	●	●	●	–	–	–	–
Dormice	●	●	○	●	●	?	?	–	–	–	–
Mice, voles	●	●	●	–	●	●	●	●	○	–	○
Beaver	○	○	○	–	●	●	●	●	●	–	–
Bats	●	●	●	–	●	○	○	○	○	–	–
Snakes, Lizards	●	●	●	–	●	○	○	○	○	–	–
Lizards	●	●	●	–	●	○	○	○	○	–	–
Tortoises	●	●	●	–	●	○	○	○	–	–	–
Amphibians	●	○[1]	○[1]	–	●[1]	○[1]	○[1]	○[1]	○[1]	–	●
Fish	–	–	–	–	–	–	–	–	–	●	–
Bird	●	●	●	–	●	○	○	–	○	–	–
Invertebrates - dry habitats	●	●	●	–	●	○	○	○	–	–	–
Invertebrates - forest, humid habitats	○	○	○	–	●	○	○	○	○	–	○

● optimum solution ○ can be used with some adaptation to local conditions – unsuitable
? unknown, more experience needed 1 If there is enough humidity and combined with opaque guiding fences

Overpasses versus underpasses

When a wildlife passage must be constructed in a particular site, there are several general considerations which determine the choice of either an overpass or an underpass, the most important being the local topography, landscape, target species requirements and budget available.

- In hilly terrain it is often feasible to construct either type and the choice depends on the infrastructure section being crossed. Over embankments an underpass is preferred, while between cuttings an overpass is recommended.
- In flat landscapes overpasses are the best option. To raise the level of the infrastructure by placing it on a viaduct is an alternative but the associated cost is considerably higher.
- Overpasses have the advantage that they allow a complete restoration of vegetation cover and microhabitats, providing a better connection between habitats on both sides of the infrastructure and consequently a wider range of species will use them. Underpasses can only be vegetated with difficulty due to lack of moisture and sunlight, unless the underpass is tall enough such as under a viaduct.
- The choice between an over- or underpass also depends on the adjacent habitats that are being connected.
- Underpasses are suitable when crossing streams which usually have a role as ecological corridors. An underpass is better suited to aquatic and semi-aquatic animals or those requiring wet conditions. Under certain circumstances, underpasses can also be more appropriate for small mammals and burrowing species.
- Both underpasses and overpasses are suitable for ungulates, nevertheless the choice could be adapted to the results of local monitoring. Some studies show that when both are available in the same area, moose and deer prefer to use overpasses, while other studies indicate ungulates prefer viaducts.

Specific structures for wildlife versus multiuse structures

A further distinction can be made between crossing structures depending on their primary purpose. Wildlife passages may either be designed solely for wildlife with no human access allowed or be intended to combine human and wildlife use. Many bridges, culverts, underpasses or overpasses built with other primary functions such as river crossing, drainage, facilitation of livestock or people, can be modified to be suitable for wildlife, increasing the permeability of the transport infrastructure for animals.

- Potentially, most crossing structures could be adapted to wildlife, with the exception of those with unsuitable features such as obstacles at the entrances, disturbance caused by human activities or high traffic intensity roads or railways passing thought.
- Any structure considered as a 'multiuse structure' and useful for wildlife should have appropriate landscaping, conditioning and maintenance to ensure its suitability for wildlife in the long term and according to local conditions and wildlife requirements.
- An appropriate combination of fauna-specific and multiuse structures could provide the most cost-effective solution to reduce barrier effect. When restoring connectivity across existing infrastructure is the goal, modifying existing culverts, under- or overpasses is often the most appropriate way to reduce the barrier effect. Many of such adaptations are not costly but can significantly increase the permeability of the infrastructure.

Dimensions

▸ **Access to Rationale. Wildlife passages dimensions**

Dimensions of the passages should be adapted to the target species' requirements and the overall objectives of the mitigation approach. Instructions provided in Table 7.4.4 are based on the results of monitoring and are to be adopted in new infrastructure projects. Even if individuals of a target species are known to use smaller structures, the adoption of the recommended dimensions will guarantee the best cost-benefit balance, provided other features of the structure are correct (appropriate location, good adaptation of entrances and surfaces, an appropriate maintenance programme, etc).

The way in which measurements are taken is relevant. Figure 7.4.3 provides instructions about recommended procedures for measuring the different types of structures.

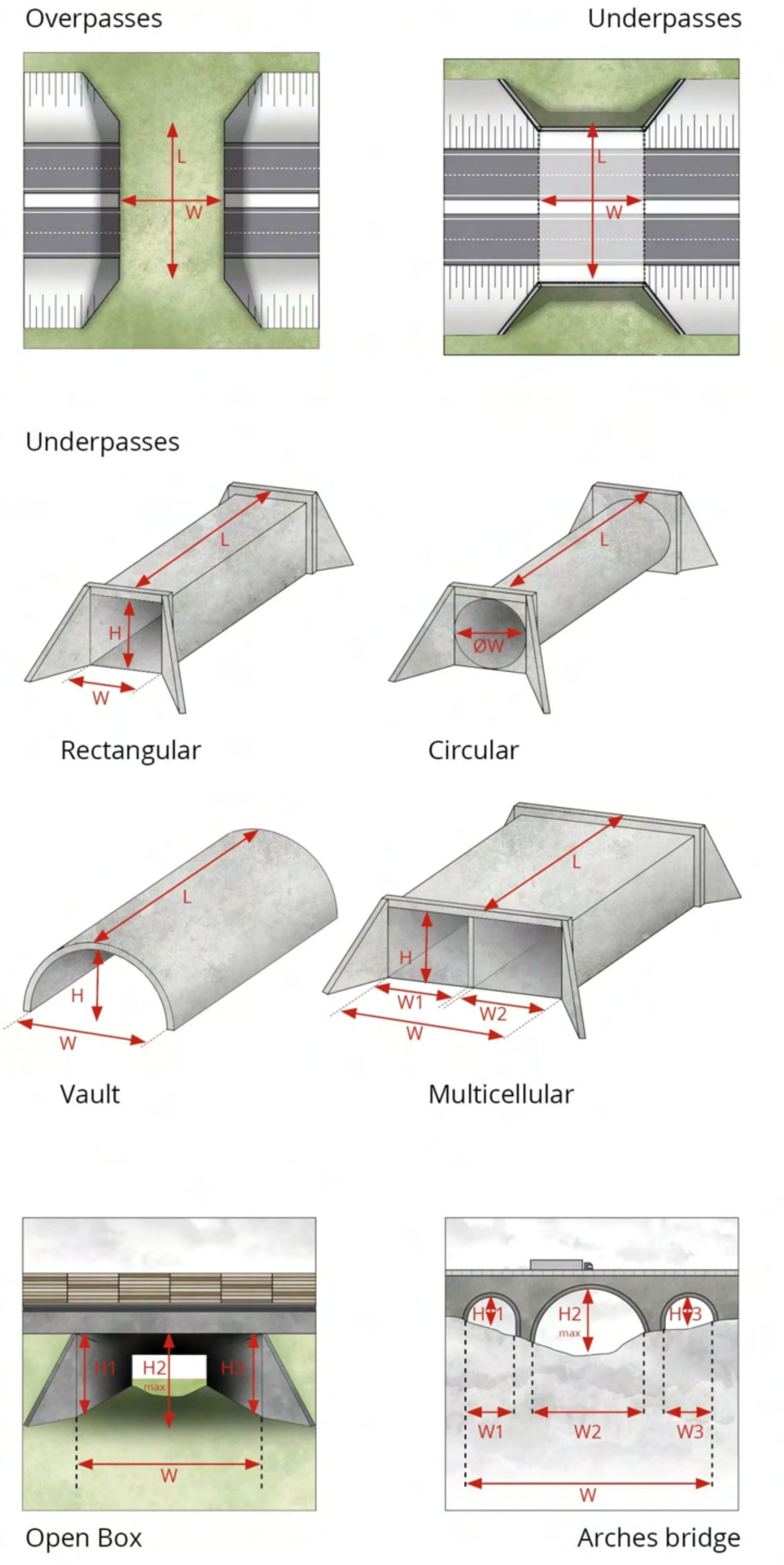


Figure 7.4.3 – Instructions to measure dimensions of different type of structures (Source: Spanish Ministry for Ecological Transition, 2020 – Adapted by: AT-Minuartia ***Authorisation to be asked to Spanish Ministry).

Table 7.4.4 – Recommended minimum dimensions for different types of wildlife passages. Ranges are based on guidelines which apply in different European countries derived from local monitoring.

Notes – H: Height L: length; OI: Openness Index ((W*H)/L). See Figure 7.4.3 instructions for obtaining dimensions. In multiuse over- and underpasses W: total width of the structure including the width of pedestrian, livestock or small road tracks. In viaducts H: distance from the soil to the viaduct platform.

	Type	Uses	Main target fauna groups	**Recommended minimum dimensions** (Total width of the structure; m) See Table Between brackets: figures in different EU countries, Wildlife and Traffic handbook, 2003 (WTH) and Carpathian Wildlife and Traffic handbook (Ca)
Overpasses	Landscape overpass (Ecoduct, Green bridge)	Wildlife and other uses (with appropriate landscaping)	Habitat continuity is provided. All terrestrial fauna including invertebrates and flying vertebrates (bats and birds).	W: 50 - 80 (WTH: 80; AT: 50; Ca: 80; CH: 80; ES: 80; FR: 40-60; NL: -; SE: 30) W/L > 0.4 - 0.8 (WTH: 0.8; AT: -; Ca: -; CH: -; ES: -; FR: 0.4; NL: -; SE: -)
	Wildlife overpass, (Fauna overpass)	Exclusively wildlife	Ungulates, Large carnivores, other terrestrial fauna including invertebrates and flying vertebrates (bats and birds).	W: 20 - 50 (WTH: 20; AT: 15-20; Ca: 20-40; CH: 20; ES: 20; FR: 20-40; NL: -; SE: 15) W/L > 0.4 - 0.8 (WTH: 0.8; AT: -; Ca: >0.8-1; CH: -; ES: >0.8; FR: >0.4; NL: -; SE: -)
	Multiuse overpass	Wildlife, livestock, pedestrian, etc.	Ungulates, Large carnivores, other terrestrial fauna including invertebrates and flying vertebrates (bats and birds).	W: 10 - 20 (WTH: -; AT: 15-20; Ca: 10; CH: -; ES: 10; FR: 25 NL: -; SE: 15+road width) W/L > 0.6 - 0.8 (WTH: -; AT: -; Ca: 0.6; CH: -; ES: 0.8; FR: 0.9; NL: -; SE: -) W is the total width of the structure including earthen/vegetated strips. Earthen/vegetated strips both side of trails/small roads: 1 - 2 m (WTH: 1; AT: up to 4 times the width of the road; CH: 2)
	Tree-top overpass (Canopy bridge)	Exclusively wildlife	Squirrels and other arboreal mammals	Rope diameter: 4 -10 cm Walkways W: 20 - 30 cm
Underpasses	Adapted viaduct (Landscape underpass)	Multi-use: wildlife, drainage and other	Habitat continuity is provided. All terrestrial fauna including invertebrates and flying vertebrates (bats and birds). Aquatic fauna if a watercourse runs under the structure.	H: 5; 10 in wooded areas (SE: H: 4.5; W: 30) When streams/rivers are crossed: 10 m riverbank on either side
	Wildlife underpass, (Fauna underpass)	Exclusively wildlife	Ungulates, Large carnivores, other terrestrial fauna including several species of bats and birds.	W: 15 - 30 (WTH: 15; AT: 25-30; Ca: -; CH: -; ES: -; FR: -; NL: -; SE: -) H: 3 - 4 (WTH: 3-4; AT: 4; Ca: -; CH: -; ES: -; FR: -; NL: -; SE: -) OI (W*H/L): 1.5 (WTH: 1.5; AT: -; Ca: -; CH: -; ES: -; FR: -; NL: -; SE: -) For particular target species: - Wild boar and Roe deer W: 5 - 10; H: 2 - 4; OI: 0.75 - 1 (Ca: W:10, H: 3.5, OI:1; CH: H:2.5-3.5; ES: W:7, H:3.5, OI: 0.75; FR: W:5, H:3.5; NL: W:5, H:4; SE:W:12,H:2,OI:1.4) - Red Deer/Large carnivore W:15 - 20; H: 3 – 4; OI: 1.5 - 2 (Ca: W:20, H: 3.5, OI:2; CH: H:4-5, OI:4.5; ES: W:12, H:3.5, OI:1.5; FR: W:10, H:4; NL: W:15, H:4) - Moose W: 12; H: 4.5; OI: 2.2 (Based on SE data)
Underpasses	Multiuse underpass	Wildlife, livestock, pedestrian, drainage, etc	Ungulates, Large carnivores, other terrestrial fauna including several species of bats and birds.	W: 10 - 20 (WTH: 10; AT: -; Ca: -; CH: -; ES: -; FR: -; NL: -; SE: -) H: 3 - 4 (WTH: -; AT: -; Ca: -; CH: 3.5; ES: -; FR: -; NL: -; SE: -) OI (W*H/L): 1.5 (WTH: -; AT: -; Ca: -; CH: -; ES: -; FR: -; NL: -; SE: -) For particular target species: - Wild boar and Roe deer W: 7 - 10; H: 2 - 3.5; OI: 0.75 - 1 (Ca: W:10, H: 3.5, OI:1; ES: W:7, H:3.5, OI:0.75; FR: W:25, H:3.5; SE: W:12+road, H:2, OI:1.4) - Red Deer/Large carnivore W:12 - 20; H: 3 - 4 OI: 1.5 - 2 (Ca: W:20, H: 3.5, OI:2; ES: W:12, H:3.5, OI:1.5; FR: W:25, H:3.5) - Moose W: 12; H:4.5; OI: 2.2 (Based on SE data; W 12+road width) Earthen/vegetated strips both side of trails/small roads: 1 - 2 m (WTH:1; CH: 2)
	Small fauna underpass	Exclusively wildlife	Small and medium size mammals, lagomorphs and other small fauna	W: 1 - 2 (WTH: 1-1.5; AT: -; Ca: 2; CH: -; ES: 2; FR: 1; NL: -; SE: -) H: 1 - 2 (WTH: 1-1.5; AT: -; Ca: 2; CH: -; ES: 2; FR: 0.7; NL: -; SE: -) Diameter: 0.5 - 2 (WTH: 1.5; AT: -; Ca: -; CH: 0.6; ES: -; FR: 0.4-2; NL: -; SE: 0.6) Minimum dimensions of 2x2 allow access for appropriate machinery to undertake maintenance tasks. Smaller structures are acceptable under specific conditions for particular target species (e.g. badger, otter).
	Adapted culvert	Wildlife, drainage	All terrestrial fauna (depending on dimensions and other features of the structure). Aquatic fauna if a watercourse runs under the structure	Small fauna - W: 1 - 2 (WTH: -; AT: -; Ca: 1; CH: -; ES: 2; FR: 2; NL: -; SE: 2) - H: 1 - 2 (WTH: -; AT: -; Ca: 1; CH: -; ES: 2; FR: 0.7; NL: -; SE: 4 and 0.2 above water) - Walkways (dry ledges) width: 0.5 (WTH: 0.5; ES 0.5; FR:0.5; NL 0.3) For large mammals: see Multiuse underpass
	Fish passage	Wildlife, drainage	Fish and other aquatic fauna	- (Remark: in some countries all culverts are required to be suitable for fish but also for terrestrial fauna; passages designed just for fish is not recommended)
	Amphibian passage	Exclusively wildlife	Amphibians	1x0.75 (<20m); 1.5x1(20-30m); 1.75x1.25 (30-40m); 2x1.5 (40-50). (WTH, Ca, CH, ES, FR; AT: 1x0.6)

7.4.2 Overpasses

Overpasses may provide safe wildlife crossing and habitat connections above transport infrastructure platforms and comprise four types of wildlife passages (see Table 7.4.1). Some overpasses are primarily constructed for forestry roads, cattle or pedestrian trails but can be adapted and maintained to provide a passage for wildlife also. This chapter describes how to design landscape overpasses (also known as 'ecoducts' and 'green bridges') and wildlife overpasses to provide habitat connection and passage for all terrestrial fauna including vertebrates and invertebrates (Section 7.4.2 – Landscape overpasses and wildlife overpasses). Recommendations are provided on how to adapt overpasses built for other purposes to enhance fauna passage opportunities (Section 7.4.2 – Multiuse overpasses) and to provide crossing structures for arboreal species (Section 7.4.2 – Tree-top overpasses). Crossings for bats (Section 7.4.2 – Bat crossings) are also described even if they are not included in Table 7.4.1 and Table 7.4.4 as their effectiveness is not clearly established and therefore their application is not encouraged.

Landscape overpasses (Ecoducts, Green bridges) and wildlife overpasses

General description and targets

Landscape and wildlife overpasses are purpose-built structures which enhance connectivity and provide a safe crossing point for a wide diversity of species. They are usually built over large transport infrastructure such as a highway with several lanes, high-speed railway lines or a combination of infrastructure types. They are a costly but effective means of enhancing ecological connectivity and minimising the fragmentation effects of transport infrastructure for terrestrial species and even aquatic species in certain cases. With regard to their goals, the main difference between a landscape overpass and a wildlife overpass is that the former aims to provide connections for a multitude of species at landscape and ecosystem level while the latter provides a crossing point for several target species at population/meta-population level. The main structural difference between these two types of wildlife passages are the dimensions, and particularly width, because the wider an overpass, the better the potential for ecological restoration and the more functions it encompasses (Figure 7.4.4). Because the two are distinguished by a convention defined by a recommended width (Table 7.4.4) any deviations below the recommended width should be justified. Landscape wildlife overpasses can be designed in various ways, for example as cut-and-cover tunnels or by adapting the design of bridges for traffic. Bored-out tunnels often have the same function as landscape bridges. They avoid habitat fragmentation by keeping the natural habitat intact. They are therefore not dealt with in this chapter (see Chapter 6 – Integration of Infrastructure into Landscape).

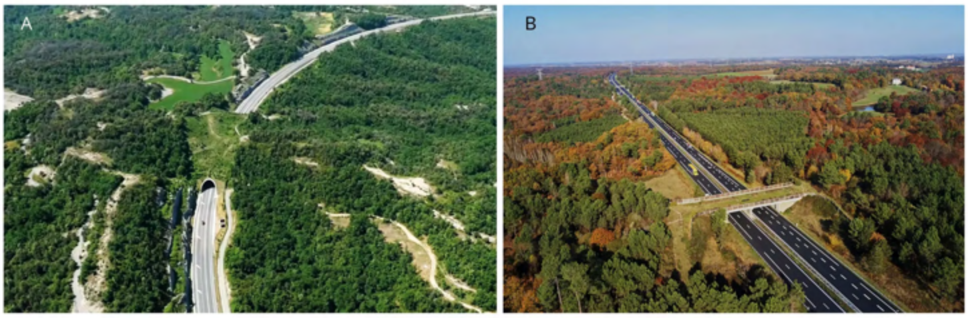


Figure 7.4.4 – A: Landscape overpass (ecoduct, green bridge) providing connection of ecosystems on both sides of the infrastructure (Photo by: Minuartia) and B: Wildlife overpass providing a safe crossing for a wide variety of species (Photo by: J. P. Moulet – VINCI Autoroutes). The biggest dimension for landscape overpasses permits a complete restoration of its surface, providing connection for grassland and forest habitats.

- Width, design and vegetation should be adapted to the conditions of the ecosystems and target species living in the surrounding areas, including ungulates, large carnivore and other mammals, as well as providing habitat connections for reptiles, amphibians and invertebrates. These structures also act as flight guides for birds, bats, butterflies and other flying insects, reducing mortality and enhancing the movement of these animals which may otherwise be reluctant to cross open infrastructure surfaces.
- Landscaping of the surfaces and entrances according to the goals for the overpass and its target species is critical to achieving maximum benefits. For small animals, the wildlife passage must include different types of habitat corridors providing refuges and food. For larger mammals, the width and location of an overpass as well as screening to reduce disturbance are critical to success.
- Costly constructions like wildlife overpasses and especially landscape overpasses should not be built just for one or very few target species, but to connect habitats at ecosystem level. This requires providing ecological restoration by including a diversity of habitat conditions similar to those existing on either side of the infrastructure, taking into account structure and composition of plant communities, and environmental factors such as soil type, humidity, temperature and light. Using an overpass to connect forests on either side of the infrastructure requires that similar habitat conditions are provided on the overpass, and where planting trees is not an option because of forest fire risks or potential damage from roots to the infrastructure, rows of bushes could provide an alternative.

Location

The location of overpasses must be tailored to the presence and behaviour of the target habitat and species (see also Section 7.4.1 – General recommendations), and to ecological network priority areas, which must be safeguarded for the long term.

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

Dimensions

Passage dimensions depend primarily on the target species and habitat conditions so can vary as shown in Table 7.4.4. In general, larger mammals require wider overpasses than small vertebrates. However, small vertebrates and particularly invertebrates rely more on the provision of special habitat features, which can only be provided on relatively wide passages with habitat restoration. To provide connections for a maximum number of target species, the choice of dimension must be based on the species which requires the largest size. The width of an overpass is given here from the perspective of the user of the overpass. Infrastructure designers and constructors usually call this the length, i.e. the stretch of the road/railway line that is covered by the overpass.

- Landscape overpasses

  The recommended minimum width for ecoducts in European standards ranges from 50 to 80 m (Table 7.4.4). This enables the establishment of different habitats to provide a connection at ecosystem level (Figure 7.4.4A). The optimal width depends on the diversity and conservation importance of the habitats that require connection. In areas which are highly important for ecological connectivity, a landscape bridge could need to be several hundred metres wide to preserve connectivity of all ecosystems in the landscape.

- Wildlife overpasses

  – The recommended minimum width for wildlife overpasses in European standards ranges from 20 to 50 m (Table 7.4.4) between the lateral fences or screens (Figure 7.4.4B). This permits the planting on the overpass of a diversity of vegetation that attracts multiple species. For small vertebrates and invertebrates, the vegetation and conditions must be designed to resemble as much as possible those adjacent to the overpass, forming a suitable habitat corridor.

  – A width below 20 m is not recommended. Experience with mammals has shown that while individuals familiar with the local situation may use narrower overpasses, the overall frequency of use is generally lower than on those that are wider. Some species specifically avoid using narrower overpasses. In some cases, a funnel-shaped structure with a minimum width below 20 m but an entrance width of c. 40 m may be used even by large mammals, particularly where the topography has a channelling effect leading the animals directly onto the crossing.

  – Length of the overpass should be minimized by angling the walls at the entrances to open into the surrounding landscape immediately after bridging the transport infrastructure (Figure 7.4.5).

  – Width of the structure should increase with the length of the overpass, i.e. an overpass across a six-lane motorway has to be wider than one over a small local road or railway. The recommended minimum width to length ratio in European standards ranges from 0.4 to 0.8 m (see Table 7.4.4).

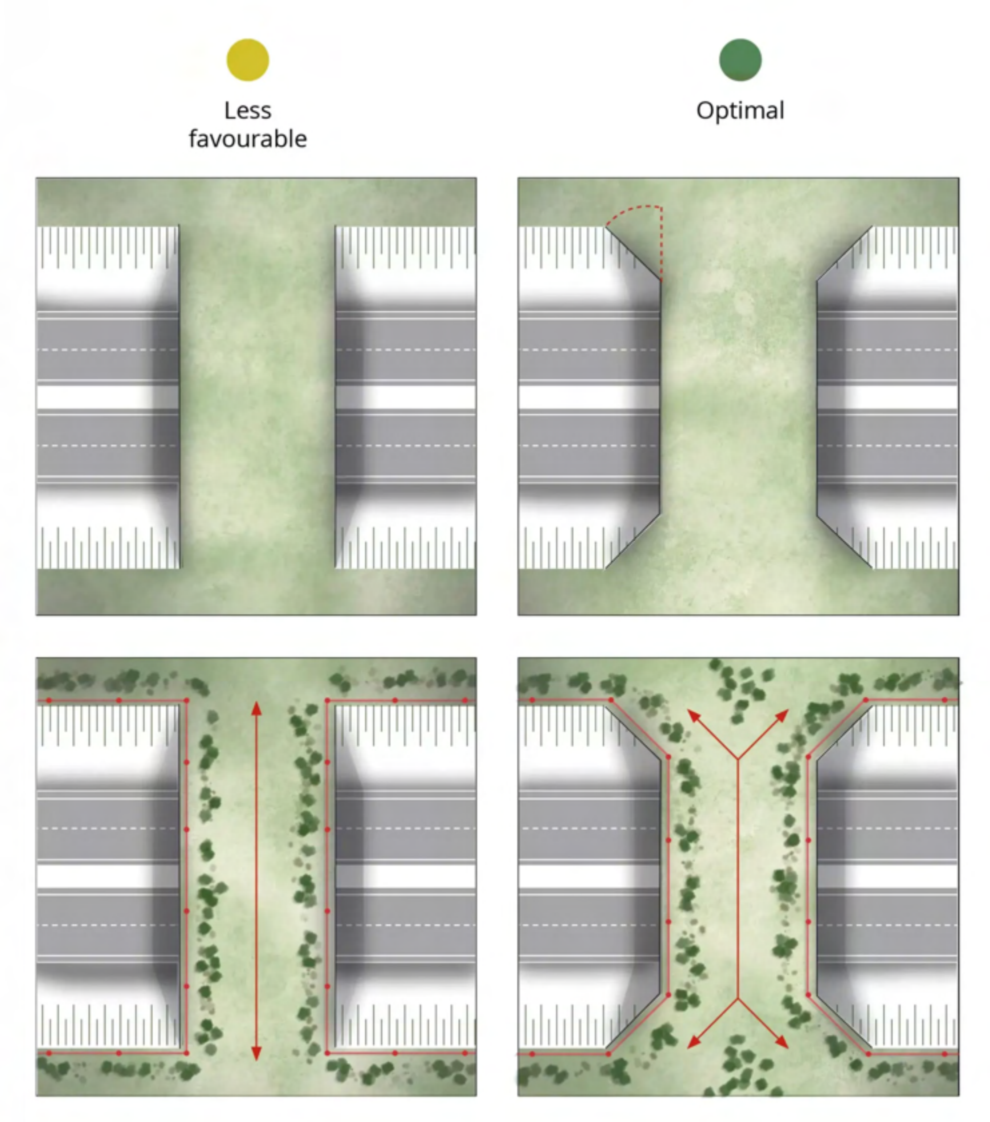


Figure 7.4.5 – Overpass design must minimise length. Long platforms with straight angles should be avoided. Opening the platform at an angle to minimise the length of the structure is recommended (Source: Cerema, 2021 – Adapted by: AT-Minuartia).

Vegetation

- The aim is not only to guide target species and the maximum variety of other animals across the overpass but to connect the target habitats and all ecosystems in the landscape.
- Vegetation on the overpass should reflect the habitats situated on either side of the infrastructure (Figure 7.4.6). Dense vegetation including bushes and/or trees must be located at both sides of the entrances to provide refuge and guide the animals though the passage. Nevertheless, vegetation should be kept low just in front of the entrance, so as not to deter ungulates.
- Only plant species native to the local area should be used in the restoration.
- Sowing grass/herb vegetation is not always necessary. Spontaneous establishment of plants can lead to good results (Figure 7.4.7).
- Instead of using expensive seed mixtures, the transfer of seed bank material (hay, topsoil) from areas adjacent to the overpass is recommended.
- Hedge-like installations along the edges of the structure provide refuges for small animals and a guiding line for larger mammal species. It also may offer cover and protection from light and noise from the road or railway.
- Tree roots can create maintenance problems on landscape bridges. The choice of suitable tree species or bushes should take maintenance and traffic safety into account.
- Planting a variety of local species that flourish at different periods of the year could feed target pollinator species. Breeding sites or refuges could also be provided to enhance

pollinator presence.
- Plant species which are preferred food sources can be used to attract herbivores and insects to the overpass.

Soil cover

- Soil is a prerequisite for vegetation and depth depends on the habitat types.
- Recommended topsoil depths are: Grass/herbs: 0.3 m; Bushes/shrubs: 0.6 m; Trees: 1.5 m (only landscape bridges). Depending on the type of vegetation to be favoured, soil depth can be varied, giving a varied micro-relief and lowering costs.
- Nutrient poor topsoil or special mixtures can be used.
- Fertilisation must be avoided.

Figure 7.4.6 – A landscape overpass (50 m wide) densely covered with bushes and small trees since it aims to connect the adjacent forests on the B31, Schwarzgraben, Germany (Photo by: V. Keller).

Figure 7.4.7 – Landscape overpass (80 m wide) where only bushes were planted while spontaneous growth of herbs and grasses was allowed, which may be later managed by mowing or grazing, on the B31, Weiherholz, Germany (Photo by: V. Keller).

Screening

Screening aims to reduce the disturbance to animals from light or noise (Figure 7.4.8). Artificial screens can be installed on relatively narrow overpasses. On landscape overpasses of 50 m upwards, hedges on either side, preferably on small earth mounds, are sufficient.

- The height of side screens should reach about 2 m. In that case, no fences are needed on lateral sides of the overpass.
- On overpasses less than 20 m wide (recommended only in special situations, see paragraph on width) high screens should be avoided as they may create an off-putting tunnel effect for animals.
- To maximise the width that can be used by animals, the screens are best placed at the outer edge of the structure.
- Screens should not only be limited to the sides of the overpass but extend at least 50 m on both sides along the perimeter of the infrastructure.
- Screens have to be properly connected to fencing along the road.
- Earth mounds at the outer edge of the overpass and extending along the transport infrastructure make good screens. They are particularly suitable for wide landscape bridges.
- Dense hedges used as screens are best placed on a low earth mound.

Figure 7.4.8 – Screening reduces disturbance from light and noise on the wildlife overpass. Materials should be durable and well-integrated. Systems to reduce vandalism could be installed, such as the upper metal barrier at the top of this screen on the A2 in Catalonia, Spain. (Photo by: Minuartia).

Fences

Fences are needed to guide animals to an appropriate wildlife passage. Design and specifications are given in detail in Section 7.2.1 – Fencing.

- Fences are essential on the outer edge of the passage if no screens are built.
- Fences on both sides of the passage need a seamless connection to fences alongside the infrastructure.

Design

There are many possible construction types. The choice depends mainly on topography, soil stability, cost, landscape, aesthetics and local design traditions. The following examples are chosen to provide ideas for the construction engineer and to highlight features which are important to ensure effectiveness for wildlife. *Construction principles relevant for wildlife are listed below,*

- Leading the infrastructure through a natural or artificial cutting allows an overpass to be built on the level of the adjacent land (see Chapter 6 – Integration of Infrastructure into Landscape).

- Where the level of the overpass is higher than that of the adjacent land, access ramps should not be too steep and should be well embedded in the adjacent landscape (Figure 7.4.9). So far there is little knowledge on the maximum gradient tolerated by different animals. In hilly areas steeper gradients may be more acceptable than in flat regions. Some existing overpasses that are used by animals have gradients from 16% (Hungary) to 25% (Switzerland) in flat landscapes to 30% or more in mountainous regions.
- Shape and materials should ensure that the necessary features (soil cover, vegetation) and the connection to the adjacent land can be achieved (Figure 7.4.10 and Figure 7.4.11).
- On existing roads, the use of prefabricated arches reduces construction time at the site (Figure 7.4.12 and Figure 7.4.13).
- In order to best guide the species towards the entrance to the passage and to limit the length of the crossing, building angled lateral walls to widen the entrance to the passage is recommended (Figure 7.4.5B).

Figure 7.4.9 – Wildlife overpass in France, where the passage is accessed by ramps (Photo by: R. Couteau – AREA).

Figure 7.4.10 – An hour-glass shape maximizes width at the passage entrance. Different landscape elements (a pond, open grasslands, bushes) maximize the number of species attracted to this ecoduct on the N69 in Borkel, The Netherlands (Photo by: Geo Dienst – Rijkswaterstaat).

Figure 7.4.11 – Shaping the surface of a landscape overpass with a topography similar to its surroundings allows a variety of slopes and orientations increasing diversity of habitat conditions provided to invertebrates and small vertebrates as shown by this overpass on the C37 in Catalonia, Spain (Photo by: Minuartia).

Figure 7.4.12 – Wildlife overpass in the Czech Republic with two prefabricated arches made of concrete (Photo by: H. Bekker).

Figure 7.4.13 – A: Corrugated steel elements were used for this wildlife overpass in Switzerland (40 m wide), which was constructed across an existing road during widening. This allowed traffic to flow along one lane during the whole of the construction phase (Photo by: O. Holzgang); B: The same overpass after completion (Photo by: V. Hlavác).

Innovative design alternatives can be applied to reduce costs. Even though the cost of a wildlife overpass usually makes up only a small part of the total for a road or railway development project, they are among the more expensive nature conservation measures in a planning scheme. The development of alternative, less expensive designs should therefore be encouraged.

- Utilising cut and cover structures reduces costs related to sourcing and transporting materials excavated when building infrastructure in hilly areas (Figure 7.4.14 and Figure

7.4.15).

- Repurposing decommissioned materials, i.e., bridge components, could be a good strategy to reduce costs if they are locally available or can be efficiently transported.
- Some designs, such as arched platforms, minimize the need for materials and, therefore reduce overall costs (Figure 7.4.16).
- Research on the application of innovative materials developed for other purposes should be explored as an option to minimize costs. Some options are geosynthetic reinforced soil buried bridges or ultra-high-performance fiber-reinforced concrete, resins and laminates.

Figure 7.4.14 – Landscape bridges (also known as 'ecoducts' and 'green bridges') provide optimal opportunities to restore ecological connectivity such as these structures on the C37 in Catalonia, Spain. They also provide a place to deposit material excavated from adjacent areas, reducing the needs to transport for disposal. (Photo by: Minuartia).

Figure 7.4.15 – Wildlife overpasses constructed by cut-and-cover tunnels providing links for pasture habitats. (Photo by: C. Rosell).

Figure 7.4.16 – Wildlife overpass designed as an arched platform without pillars, reducing the amount of materials used while ensuring an appropriate height to allow circulation of trucks on the A483 in Andalusia, Spain (Photo by: Agency of Public Works. Andalusian Government).

Points for special attention

- Passages are meant to be in use for a long time. Engineering works are developed for a period of 50 to 100 or more years. Safeguarding ecological corridors which allows access to the overpasses must endure for a similar time frame and should be part of spatial planning at local and regional level. In particular, no development (i.e: housing, local roads, industrial areas) should be permitted which would reduce the functioning of the overpass.
- A proper maintenance plan should be developed.
- Hunting in the vicinity of fauna passages should be restricted to an area designated according to the local conditions and the type of passage.
- Landscape and wildlife overpasses for exclusive use by wildlife are recommended as a general rule and especially if important daily or seasonal migrations of larger mammals have to be preserved or restored. Periodical inspections should guarantee that no inappropriate uses are occurring.
- In exceptional situations large landscape overpasses located in areas which are not in a priority area for biodiversity conservation could include trails used by pedestrians or small unpaved roads used by forestry or agricultural vehicles. In this case landscaping must be planned very careful to avoid any disturbance from human co-use to wildlife. Tracks must run along one of the outer edges of the structure to ensure a maximum width of vegetated and undisturbed area. Screens or earthen walls to separate the track and the vegetated area are required to reduce disturbance if traffic intensity is over 500 vehicles per day. Other recommendations for multiuse overpasses are described in Section 7.4.2 – Multiuse overpasses.
- Where access by walkers is a possibility, providing a narrow path to concentrate human movement is preferable to leaving the whole width of the passage open for use.
- Extra shelter on the landscape or wildlife overpass can be important for a wide variety of species. Tree-stumps, a heap of branches or stone piles can provide shelter for invertebrates and small vertebrates and are particularly important during the period in which the vegetation has not yet become well-established (Figure 7.4.17).
- Sand beds created to monitor tracks of animals can leave a long term gap in the continuity of the vegetation and may pose an obstacle for invertebrates. These should only be left for a limited period of time when the monitoring is taking place.
- Roads and forestry tracks which run parallel to the infrastructure may obstruct access to the overpass. They should be routed away from it.

Figure 7.4.17 – Wildlife overpass including stone rows to provide refuges for small fauna and guide animal movement over the passage, vegetation to benefit pollinators and boulders to block vehicle access on the A2 road in Catalonia, Spain (Photo by: Minuartia).

Multiuse overpasses

General description and targets

Multiuse overpasses are structures built over linear transport infrastructure which combine human and wildlife use. In order to classify a passage as a 'multiuse overpass' it must meet the structural requirements of the target species, be located in a suitable and accessible environment and be provided with appropriate, specific maintenance to guarantee its long term functionality. Many of the features and requirements mentioned in Section 7.4.2 – Landscape overpasses and wildlife overpasses are also applicable to multiuse overpasses.

Major linear transport infrastructures are typically crossed by many conventional overpasses for small forestry or agriculture roads, cattle passages or pedestrian paths. These structures are usually long and narrow, have paved tracks and are not designed for animals. However, such structures may be occasionally used by wildlife, and they may offer opportunities to be adapted to enhance this use by providing earthen strips with natural vegetation on both sides of the path or carriageway, screening to reduce disturbance from traffic and guiding fencing.

Due to their high numbers, they may contribute significantly to reducing the barrier effect of infrastructure on wildlife, but multiuse overpasses can never substitute for passages that are specifically designed for fauna and are free of human disturbance, having the potential to be used by a wider diversity of species.

Dimensions and landscaping determine the diversity of species that will use the structure. With joint use, particularly involving traffic, the potential for disturbance is higher, which could mean that species less tolerant of traffic noise and light will be deterred from using it.

When planning new infrastructure, any overpass located in a suitable area should be considered for adaptation to combine human uses with wildlife passage improving the global permeability of the infrastructure. Overpasses may all be equipped as standard with earth-covered strips, contributing greatly to mitigate the barrier effect at little additional cost. They must also be provided with appropriate landscaping, fencing and even made wider than required just for human use in all important areas for ecological connectivity. Cut-and-cover structures which are often built for aesthetic reasons to preserve the original aspect of the landscape or as a noise protection measure, can easily be adapted to be multiuse overpasses as well.

Existing overpasses may be retrofitted and upgraded to improve the permeability of infrastructure under operation The many pre-existing overpasses, if suitably adapted, could bring beneficial effects for ecological connectivity.

Design

- The recommended minimum width for multiuse overpasses in European standards ranges from 10 to 20 m (Table 7.4.4). A minimum of 10 m width may be sufficient when existing overpasses are being adapted to include wildlife use, with at least half of the section for natural soil and vegetation and the remainder for trails or small roads (Table 7.4.4). In passages located in important areas for ecological connectivity a minimum width of 20 m is recommended.
- Vegetation providing shelter near the entrances and leading to the passage, could improve its functionality for wildlife.
- Vegetated strips are recommended at both sides of any path or track on the overpass (Figure 7.4.19 and Figure 7.4.20). Strips of natural soil 1 to 2 m in width and allowing spontaneous vegetation growth could be enough to enhance movements of some target species particularly invertebrates or small vertebrates. Wider vegetated strips may facilitate the crossing of large mammals and also offer opportunities to provide refuges and habitats for small fauna i.e. rows of stones or wood. Rows of shrubbery may provide shelter and funnel bat flight.
- Measures to prevent the spread of alien invasive plant species should be applied. Seeding native species could prevent their growth.
- Soil cover must be adapted to the intended vegetation. A minimum depth of 0.3 m is enough to maintain grass and small shrubs.
- Screens to reduce noise and visual disturbance from traffic circulating under the structure must be installed on both sides of the overpass.
- Fencing to guide fauna to the entrances of the passage must be installed with fence ends appropriately connected to screens on both sides of the overpass. Design and specifications are given in detail in Section 7.2.1 – Fencing.
- Access for the animals onto the overpass must not be hindered by roads intersecting at the entrance (Figure 7.4.18).

Human co-use

- Adaptation of an overpass to enhance its use by wildlife is recommended only when traffic intensity is low; e.g. small roads with less than 500 vehicles per day, even if thresholds must be adapted considering local conditions. Unpaved dirt or gravel tracks are preferred as such surfaces may allow the movements of both small and large wildlife. A ban on vehicle circulation, temporary road closure or limited access to certain vehicle types (e.g., tractors, bicycles) are additional options to be considered.
- On large overpasses, tracks for vehicles must run along one of the outer edges of the structure to ensure a maximum width of vegetated and undisturbed area. Screens or earthen walls to separate the track and the vegetated area are not recommended in general, but could be included on large structures to reduce disturbance if traffic intensity is over 500 vehicles per day.
- Overpasses modified to enhance wildlife should be kept dark at night, avoiding artificial lighting.
- Information panels about wildlife use of the passage could be provided to promote an appropriate use by people and to reduce human disturbances.
- Access for people at night or during certain seasons critical to wildlife movements could be restricted.
- Where conflicts between human and animal use arise and the passage is in a critical location for ecological connectivity, the provision of a separate passage for pedestrians or vehicles is recommended.

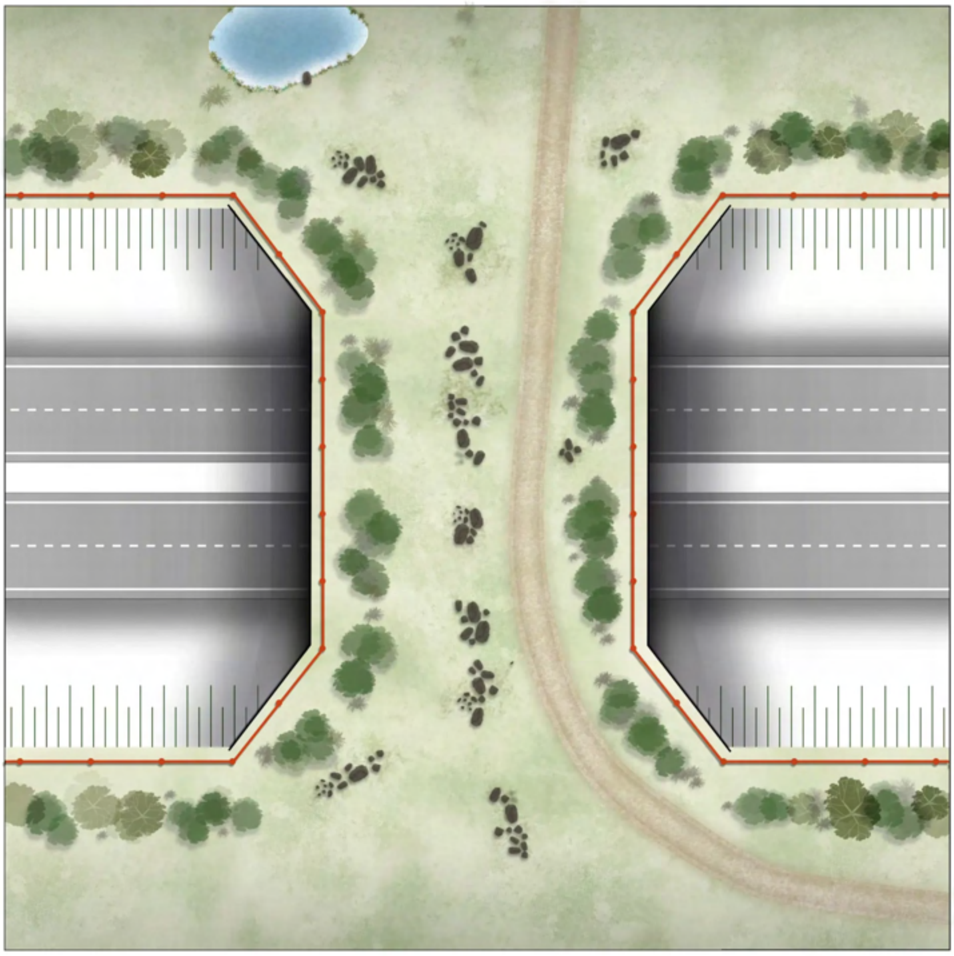


Figure 7.4.18 – Landscaping of the multiuse overpass surface is critical to increase the probability of use by a wide range of wildlife. Rows of stones or stumps provide refuges to invertebrates and small mammals; rows of tall shrubs help to funnel bats flight across the passage; paths for pedestrians or cycles should be on one side of the structure and non-paved (Source: Iuell et al., 2003 – Adapted by: AT-Minuartia).

Figure 7.4.19 – A strip of natural soil and vegetation covering a part of the overpass facilitates wildlife crossing, also for small animals. (Photo by: A. Righetti).

Figure 7.4.20 – Vegetated strips along both sides of a multiuse overpass including a forestry track with very low traffic intensity increase the permeability of infrastructure for wildlife as in this overpass in France. Screens to reduce noise and visual disturbance from traffic circulating under the structure are also installed (Photo by: Cerema).

Tree-top overpasses (Canopy bridges)

Access to Rationale. Tree-top overpasses

General description and targets

For climbing mammals, special types of passages may be needed. Squirrels or pine and stone martens readily cross roads and railway lines and fences are no obstacle to them, but where traffic is heavy, the risk of mortality is high. Edible and garden dormouse on the other hand rarely descend to the ground and prefer to cross roads at points where the branches of trees get close to each other.

Wildlife overpasses will be readily used by squirrels and martens, whereas they may only be suitable for dormice when there is adequate tree cover. However, passages designed or adapted to allow climbing animals to cross the infrastructure above the traffic may be a good alternative to reduce mortality risk for such particular target species. In a few countries these treetop overpasses have been constructed but currently research data on the topic in Europe is limited (see Rationale box. Tree-top overpasses). So far clear recommendations cannot yet be given. The first indications are, however, that these passages are indeed used by squirrels and dormice and in other parts of the world by monkeys or possums and other climbing species.

Location

Tree-top overpasses should be considered

- In wooded areas with important populations of dormice, red squirrels and pine martens where other suitable solutions, such as landscape or wildlife overpasses, cannot be constructed.
- Where mortality of target species due to collisions with traffic is concentrated.
- In large parks in towns and cities where a high road mortality of squirrels is registered and overpasses are not available.

Special requirements

- Taut enough for animals to pass along.
- Safe from predators.

- Places for small animals to hide.
- Good connections to trees and bushes on either side of the infrastructure.
- Safe in relation to road users.
- Tree top overpasses of flammable rope or wood should not be installed in areas where prevention of forest fire spread is a high priority. In these cases metal structures are preferred.

Design

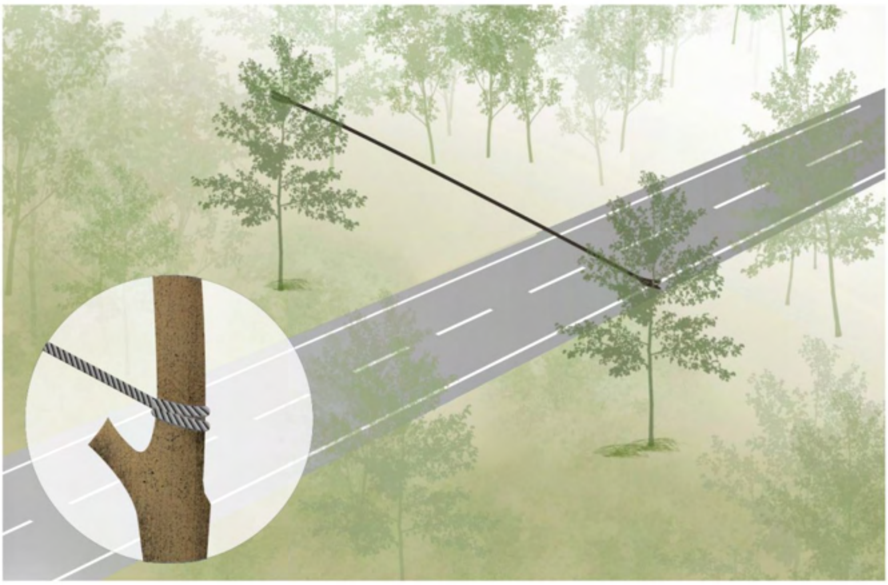
The design of tree-top overpasses depends on the type of road. On minor local roads the crowns of trees are often close enough together to enable climbing animals to move from tree to tree. When the distance is too big, a rope, rope ladder or other walkway can provide a connection (Figure 7.4.21A-B). On wider roads and in other situations where the distance between tree crowns is too great, the connection needs more stability (Figure 7.4.21C). Ropes and also constructions of steel cables with a small pathway in-between have been implemented. These structures have to be wide enough for animals to walk on.

- The bridges should be linked both side of the road on trees and with feeder ropes.
- Squirrels will use ropes with a diameter of 4-10 cm.
- Rope ladders with a width of 30 cm have been installed in some locations.
- Walkways of two steel cables with a net between (20-30 cm) have also been deployed.
- Planting of trees and shrubs and additional ropes and planks can facilitate animal access to the tree top overpass.
- On broad motorways, installations for traffic signs erected over the road can be adapted with a wooden walkway, shelters and hiding places.

Point for special attention

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

A



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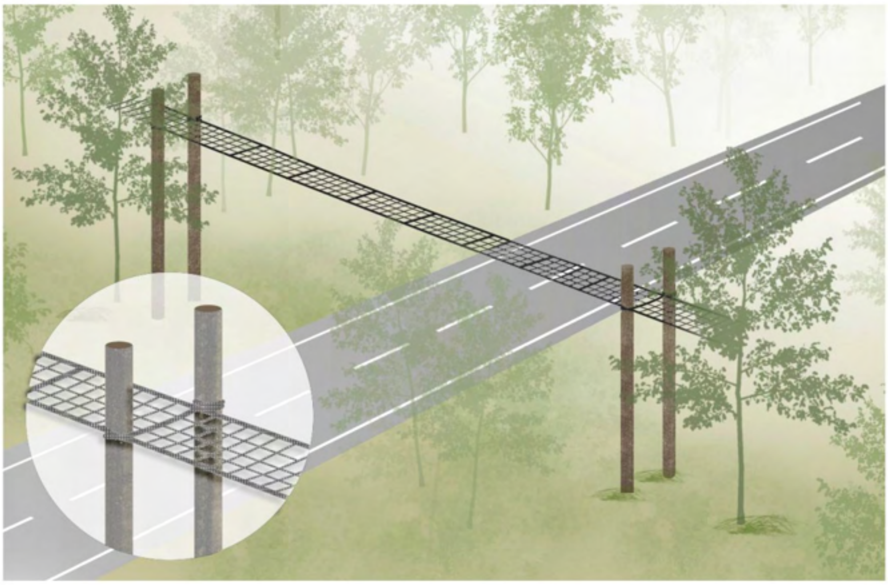

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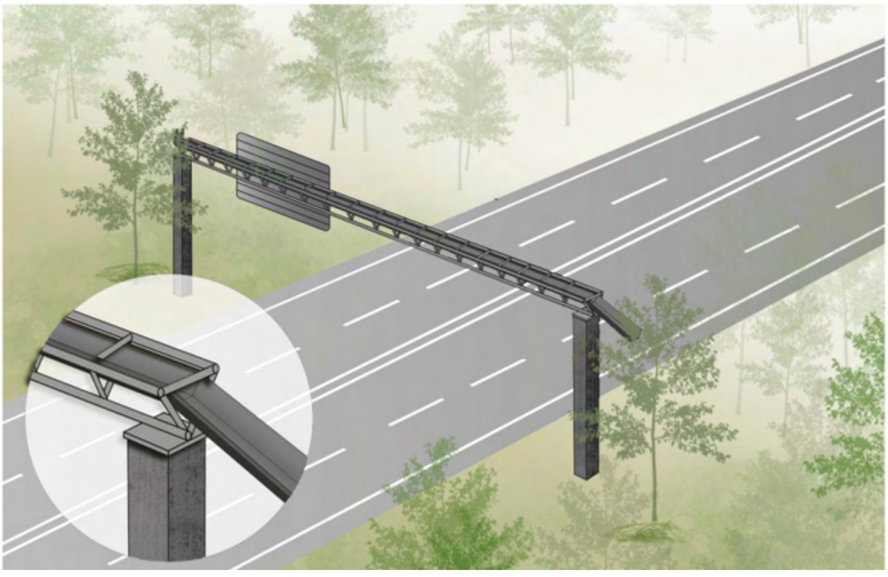

▸ Access to Rationale. Bat gantries

Figure 7.4.21 – Different types of tree-top overpasses. A: Cable or rope over a small road; B: Mesh bridge crossing. C: Walkway including a path for animals. Metal or other fire-resistant materials must be used in areas with high risk of forest fire spread. (Source: Magrama, 2016 – Adapted by: AT-Minuartia).

Bat crossings

General description and targets

Bat passages are devices specifically designed to provide safe crossing for bats over the infrastructure, in particular those bats which follow landscape features such as rows of trees. However, the effectiveness of these structures is not established. If they are provided because another type of wildlife passage cannot be installed, they must be considered an experimental measure and have appropriate monitoring and feedback regarding effectiveness.

These devices try to replicate a physical structure which guide bat flight over the infrastructure at a height sufficient to avoid any risk of collision with traffic below. They are dedicated specifically to bats and, because of their cost, they are limited to exceptional situations where there is no possibility of a combined use with other type of overpass, which would be a more effective solution.

There are several types of devices, all of which are considered experimental, including a system of wires stretched over the infrastructure, sometimes equipped with mirror balls to help bats perceive it better, gantries which are equipped with netting, and walkways or metal gantries (Figure 7.4.22).

Points for special attention

- This type of experimental mitigation measure must be placed right at the point of conflict between the transport infrastructure and the bats' flight route.
- Connection between the flight route and the gantry should be optimal.
- Some tree-top-overpasses have features similar to narrow bat bridges and could therefore combine the needs of several species-groups. However, these situations are found most often only on small infrastructures.

Figure 7.4.22 – Innovative experimental design for a bat passage on the A89 motorway in France. Further research is required to establish effectiveness of such type of devices and define additional landscaping measures to connect the device with bat flight routes (Photo by: D. Riou http://www.denisriou.com/autoroute-a89-chiropteroduc).

● To avoid; ● Less favourable; ● Optimal.

7.4.3 Underpasses

Underpasses may provide safe wildlife crossing and habitat connections below transport infrastructure platforms and comprise six types of wildlife passages (see Table 7.4.2). Many underpasses are primarily constructed for drainage, forestry roads, cattle or pedestrian trails but can be adapted and maintained to provide a passage for wildlife also.

This chapter describes how viaducts and river crossing structures can provide suitable connections for ecosystems and a passage for a multitude of species (Section 7.4.3 – Adapted viaducts). Further sections describe fauna-specific underpasses which comprise those suitable for all terrestrial fauna, including large mammals (Section 7.4.3 – Wildlife underpasses), and those suitable only for small vertebrates, i.e., voles, shrews, reptiles and some species of invertebrates (Section 7.4.3 – Small fauna underpasses). Other sections give recommendations on how to adapt underpasses and culverts built for other purposes to make them serve also as fauna passages (Section 7.4.3 – Multiuse underpasses; Section 7.4.3 – Adapted culverts).

Passages for fish (Section 7.4.3 – Fish passages) and for amphibians (Section 7.4.3 – Amphibian passages) are also described in separate sections.

Adapted viaducts (Landscape underpasses)

General description and targets

Viaducts are large structures usually supported by pillars or arches, which carry linear transport infrastructure and could be easily adapted to enable the preservation of particularly valuable ecosystems and ecological corridors associated with floodplains and river valleys. Movements for a multitude of species, both vertebrates and invertebrates, are facilitated by the preservation and restoration of continuous terrestrial, riparian and aquatic habitats below viaducts. These are also known as 'landscape underpasses' as ecosystems below the structure are preserved just as landscape overpasses preserve ecosystems above (see Section 7.4.2. – Landscape overpasses and wildlife overpasses)

Land uses and activities compatible with fauna movements and preservation of ecological connectivity are required under the adapted viaducts. They must not be considered as wildlife passages when there is human disturbance or infrastructure with high traffic volume beneath.

In hilly areas a viaduct is a good technical solution to traverse valleys (Figure 7.4.23) which are often important ecological corridors and preferred routes for many animals, particularly when there is a watercourse present. In these cases, measures for wildlife need only ensure that habitat connection is maintained or restored when the infrastructure is completed.

A low viaduct is ecologically preferable to a solid embankment when transport infrastructure crosses a valley or other area lying lower than the alignment (Figure 7.4.24). By spanning above habitats, viaducts preserve ecosystems (Figure 7.4.25), provide optimal crossing structures for large mammals and are also of particular benefit to invertebrates and small vertebrates which require suitable habitats provided under a viaduct and would hardly use dark, dry and unvegetated underpasses.

From an economic point of view, solid embankments are often a low cost solution to redeploy material excavated from other parts of the development. However, that a viaduct preserves particularly valuable ecosystems and ecological corridors outweighs any short term cost saving. This is because even low viaducts can provide better links and are suitable for a wider range of species than small underpasses built into an embankment.

Location

- Viaducts can be built wherever lower-lying ground has to be crossed by infrastructure. These structures are particularly recommended where a watercourse is present or becomes active under seasonal or extreme weather conditions.
- Wetlands (marshes) should be crossed by infrastructure only if construction is imperative and no alternative route can be found. In these cases, the infrastructure must utilise viaducts to span a wetland, avoiding the construction of any embankments.

Figure 7.4.23 – Some construction methods, such as successive cantilever or pushed slab techniques, permit the building of viaducts while preserving the original vegetation and habitat conditions of the landscape beneath the structure, such as in this viaduct on the C37 in Catalonia, Spain (Photo by: Minuartia).

Figure 7.4.24 – Instead of building an embankment, the A20 motorway in northern Germany was built on pillars. This viaduct preserves the floodplain and marshes below and is high enough to allow continuity of vegetation (Photo by: DEGES).

Figure 7.4.25 – Viaducts allow the definition of different zones under the structure, preserving riparian vegetation along rivers, agricultural lands or even small local road as on this C25 in Catalonia, Spain. Spatial planning has to ensure that those parts suitable for the passage of animals remain so in the long term (Photo by: C. Rosell).

Design

- Vegetation cover under the structure should be preserved or restored when possible maintaining the surrounding vegetation and ecological corridors. Where watercourses are present, the continuity of both terrestrial and aquatic habitats should be maintained.
- To allow continuous plant cover, a viaduct should have a minimum height of 5 m (distance from the soil to the viaduct platform). In wooded areas the minimum height should be 10 m.
- Viaduct length (distance between the crossing structure abutments) which could reach several hundred metres, must be maximized, preserving all landscape associated with the valley and avoiding the construction of embankments.
- Watercourses under the viaduct should be kept in a natural state, including the riverbed and riverbanks (Figure 7.4.26). Banks should allow the free movement of both semi-aquatic species such as otters or European mink, and terrestrial species moving along the riparian habitat.
- Where rivers are crossed, the viaduct length should stretch at least a further 10 m on both sides of the riverbank to allow the growth of riparian vegetation (Figure 7.4.27).
- Natural floodplains should be spanned completely by a viaduct.
- A lack of water and light may limit the growth of vegetation within underpasses. Depending on the target species or habitats the ground should be covered with earth and not with gravel or stones. If small roads or railways traverse under the viaduct, the use of tarmac should be avoided if possible. Open unobstructed ground should be provided (Figure 7.4.29; Figure 7.4.30).
- When a viaduct carries wide infrastructure such as a motorway, a median gap separating the two circulation platforms provides extra light and rainwater to the ground under the viaduct, enhancing vegetation growth. However, narrow median gaps should be avoided to prevent noise disturbances caused by passing vehicles that can deter animals, especially large carnivores, from crossing.
- Under wider viaducts, zoning use of the land is necessary. Any roads running under the viaduct with night traffic should be screened off from animal movement corridors to reduce the impact of vehicle lights and noise.
- Rows of tree stumps, heaps of twigs or large stones can provide cover for small fauna and act as a link between habitats on each side of the structure (Figure 7.4.28).
- Screens could be installed on both sides of the viaduct to reduce noise and light disturbance to the habitats beneath. These screens should extend long enough (at least 50 m) at both ends of the structure to better protect surrounding habitats from traffic disturbance. To reduce risk of bird collision, screens should be opaque or provided with marks visible to birds to avoid the risk of bird collision (see Section 7.3.2 – Noise screens).
- Perimeter fencing of the transport infrastructure, with the fence ends well fixed to the viaduct abutments helps funnel any crossing animals under the viaduct.

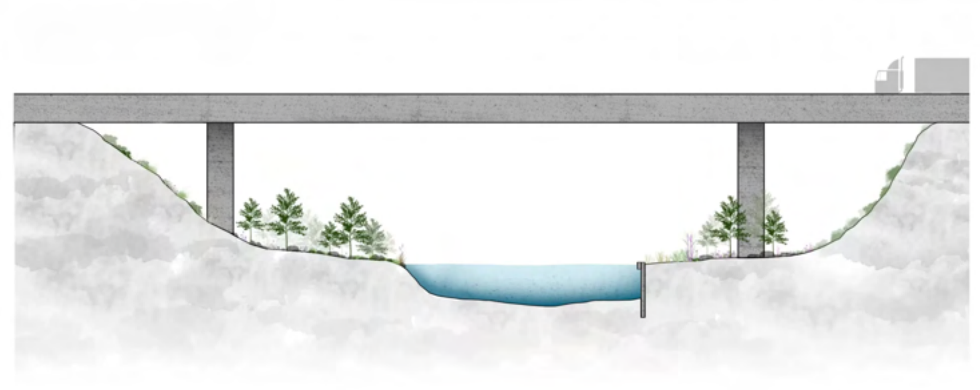

Figure 7.4.26 – Modified embankments beneath a viaduct which spans a river permits the restoration of vegetation on the riverbanks and around pillars (Source: Iuell et al., 2003 – Adapted by: AT-Minuartia).

Figure 7.4.27 – A river crossing which preserves the natural riverbed and also the riparian habitats under the viaduct allowing movements by both terrestrial and aquatic animals (Photo by: Minuartia).

Figure 7.4.28 – Tree stumps were used as shelter for animals under the Zandheuvel viaduct on the A27 in the Netherlands. The wooden screen separates a road under the viaduct from the wildlife passage to reduce traffic noise and light disturbance (Photo by: H. Bekker).

Points for special attention

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

Figure 7.4.29 – Unsuitable uses under the viaduct can prevent animal movement such as this example on the RN59 in France, where a fence and stored material block wildlife access (Photo by: J. Carsignol).

Figure 7.4.30 – Wildlife passages should be inspected periodically to avoid activities that can cause disturbance or damage to wildlife, such as this carnivore trap under a viaduct in Sweden. Photo by: J. O. Helldin.

Wildlife underpasses

General description and targets

Wildlife underpasses are structures specifically built to provide a safe crossing point for a wide range of species and are suitable particularly for hilly areas or where the infrastructure is situated on an embankment. Common target species are usually ungulates (such as deer and wild boar), and large carnivores (brown bear, lynx and wolf). However, they can be used by a wide range of species such as small mammals, bats, reptiles, walking birds (ducks or partridges) and also for amphibians if fencing and conditions are suitable. Underpasses are less appropriate for flying birds and many invertebrate species which require light to guide their movements. Due to limited dimensions, wildlife underpasses may often lack sufficient light and water to support vegetation, making them less suitable for connecting habitats than wildlife overpasses.

Location

- Wildlife underpasses should be located where the infrastructure crosses ecological corridors, routes used by target species or where local topography funnels animal

movements towards the passage. The identification of such paths is undertaken within environmental impact assessment procedures (see Chapter 5 – Planning Tools).
- If the structure cannot be located in the optimal place, surrounding land should be restored to connect the underpass entrance with the ecological corridors and provide a better integration into the landscape.
- Areas where human activity is causing disturbance should be avoided.

Dimensions

- The dimensions of an underpass are defined as height, width and length. The openness (Openness Index, OI = width*height/length) is also a useful parameter to provide (Figure 7.4.3) but it should never be used as the sole criteria to define suitability of the underpass for a target species. The recommended minimum dimensions for wildlife underpasses in European standards ranges from 15 to 30 m width; 3 to 4 m height; 1.5 Openness Index (Table 7.4.4). Other requirements for ungulates and large carnivores are provided in Table 7.4.4.
- Experience suggests that mammals may learn to use an underpass situated in their home ranges even if its dimensions (particularly height) are less than recommended. However, inexperienced animals, in particular young individuals in their dispersal phase or migratory individuals, may be more reluctant to do the same. There has been little research in this area, as monitoring programmes usually focus on the use by animals resident in the vicinity of an underpass. Constructing a correctly assessed underpass according to recommended dimensions may eliminate the risk that the structure is used by only a low number of resident individuals.

Vegetation and soil cover

- The ground inside an underpass should be natural, i.e. covered with soil.
- Due to limited light and water, vegetation will may grow only sparsely inside an underpass, but should be supported where possible.
- Vegetation at the underpass entrances should be attractive to the target species. Ungulates could be attracted to the passage by planting attractive palatable plants at both sides of the entrances. Bushes around the entrance may be planted both to guide animals towards the underpass and to provide screening against light and noise disturbance from the road or railway line. Nevertheless vegetation should not obstruct the entrance, and must allow a good view through the passage (Figure 7.4.32).

Fences and screens

- Stretches of road or railway where wildlife underpasses are built should be fenced off to lead the animals towards the structure and prevent attempts to cross the carriageway.
- Screens running across the top of the underpass reduce disturbance from traffic (Figure 7.4.31).

Figure 7.4.31 – Vegetation and stones at the entrance and inside an underpass provide refuges for animals. Screens reduce disturbance from traffic (Source: AT-Minuartia).

Figure 7.4.32 – Wildlife underpass in France with visual screens to reduce light disturbance from traffic. (Photo: C. Rosell).

Points for special attention

- Underpasses for exclusive use by wildlife are recommended as a general rule to maximise fauna use and particularly improve crossing by large carnivores and ungulates.
- A watercourse leading through the underpass may make it more acceptable to wildlife.
- Hunting in the vicinity of fauna passages needs to be restricted to an area designated according to the local situation and the type of passage.
- Underpasses must not be used for storage or parking.
- Access to the underpass should be levelled out and free of obstacles that hinder small animals.
- Design and materials must ensure that standing water does not accumulate in the underpass.
- Places to shelter inside the underpass encourage its use by smaller animals (e.g. logs, rocks, piles of dead wood) (Figure 7.4.33).
- In order to limit the length of the crossing and to open up access to the entrance of the passage as much as possible, walls of the structure and the sides of embankments may be constructed with an opening angle> 45° (Figure 7.4.34).
- The joint use of an underpass by animals and vehicles or walkers is possible where traffic is very light. Points for special attention for multiuse underpasses are listed in Section 7.4.3 – Multiuse underpasses.

Figure 7.4.33 – Wildlife underpass under the B100 in Austria where refuges for small fauna have been included in the surroundings and inside the underpass. Visual screens are provided to reduce disturbance by traffic lights. (Photo by: C. Boschi).

Figure 7.4.34 – Angled walls each side of the structure help to funnel animal movement to the entrance of the wildlife underpass under an irrigation channel (Photo by: Minuartia).

Multiuse underpasses

Multiuse underpasses are structures built below linear transport infrastructure which combine wildlife use with human use and/or drainage function. In order to classify a passage as a 'multiuse underpass' it must meet the structural requirements of the target species, be located in a suitable and accessible environment and be provided with appropriate, specific maintenance to guarantee its long term functionality. Many of the features and requirements mentioned in Section 7.4.3 – Wildlife underpasses are also applicable to multiuse underpasses.

Small forestry roads, cattle passages or pedestrian paths may be compatible with fauna use when appropriate landscaping is provided. A drainage function including streams or other small waterways inside the structure is also compatible and may even lead fauna through the passage.

Due to their high numbers, they may contribute significantly to reducing the barrier effect of infrastructure on wildlife, but multiuse underpasses can never substitute for passages that are specifically designed for fauna and are free of human disturbance, having the potential to be used by a wider diversity of species.

Dimensions and landscaping determine the diversity of species that will use the structure. With joint use, particularly involving traffic, the potential for disturbance is higher, which could mean that species less tolerant of traffic noise and light will be deterred from using it.

When planning new infrastructure, any underpass located in a suitable area should be considered for adaptation to combine drainage and human uses with wildlife passage improving the global permeability of the infrastructure. In all important areas for ecological connectivity underpasses could be provided with appropriate landscaping, fencing and even made wider than required just for drainage or human use.

Existing underpasses may be retrofitted and upgraded to improve the permeability of infrastructure under operation. The many pre-existing underpasses, if suitably adapted, could bring beneficial effects for ecological connectivity.

Design

- The recommended minimum dimensions for multiuse underpasses in European standards ranges from 10 to 20 m width; 3 to 4 m height; 1.5 Openness Index (Table 7.4.4). Other requirements for ungulates and large carnivores are provided in Table 7.4.4.

- A minimum width of 10 m is recommended when existing underpasses are being adapted for wildlife use, with at least half of the section for natural soil and vegetation and the remainder for trails or small roads (Table 7.4.4). In passages located in important areas for ecological connectivity a minimum width of 20 m is recommended.
- Underpasses that include streams are particularly suitable for improvement (Figure 7.4.37).
- If a natural stream is included in the underpass, continuity for both terrestrial and aquatic habitats should be provided and riverbanks restored. In long passages lack of light in the central parts of the underpass could limit terrestrial habitat restoration, therefore in important areas for ecological connectivity, viaducts provide the best alternative for restoring habitat continuity.
- Earth-covered strips must be provided at each side of the infrastructure to improve use by fauna.
- Providing shelter inside the underpass (tree stumps, stone rows, heaps of branches, etc.) is recommended for wide structures to offer refuges for small fauna. These elements can be placed on the strips at each side of the passage.
- Underpass entrances may have to be redesigned to facilitate the use of the passage and its integration in the surroundings. Vegetation on both sides of the structure lead animals to the entrance.
- Screens to reduce noise and visual disturbance from traffic circulating over the structure must be installed on both sides of the infrastructure above.
- Fencing to guide fauna to the entrances of the passage must be installed with fence ends appropriately connected to walls on both sides of the underpass (Figure 7.2.2). Design and specifications are given in detail in Section 7.2.1 – Fencing.

Human co-use

- Adaptation of an underpass to enhance its use by wildlife is recommended only when traffic intensity is low; e.g. small roads with less than 500 vehicles per day, even if thresholds must be adapted considering local conditions. Unpaved dirt or gravel tracks are preferred as such surfaces may allow the movements of both small and large wildlife. A ban on vehicle circulation, temporary road closure or limited access to certain vehicle types (e.g., tractors, bicycles) are additional options to be considered (Figure 7.4.35 and Figure 7.4.36).
- Underpasses modified to enhance wildlife should be kept dark at night, avoiding artificial lighting.
- Information panels about wildlife use of the passage could be provided to promote an appropriate use by people and to reduce human disturbance.
- Access for people at night or during certain seasons critical to wildlife movements could be restricted.
- Where conflicts between human and animal use arise and the passage is in a critical location for ecological connectivity, the provision of a separate passage for pedestrians or vehicles is recommended.

Figure 7.4.35 – Multiuse underpass in Denmark regularly used by wildlife (fox, badger, marten, stoat and polecat) as well as by humans and horses. The natural soil allows the growth of vegetation in some parts of the structure and reduces noise

inside the underpass (Photo by: B. Wandall).

Figure 7.4.36 – Multiuse underpass combining wildlife use and crossing of a low traffic intensity railway. Wide strips of natural soil and vegetation are provided to enhance its use by fauna (Photo by: V. Hlavac).

Figure 7.4.37 – Multiuse underpass that combines the crossing of a stream (drainage function) with wildlife use. Piles of stones and branches provide refuges for small fauna (Photo by: A. Righetti).

Small fauna underpasses

General description and targets

Underpasses for small fauna consist of pipes or rectangular structures which are built specifically for some target species. They often target small carnivores (e.g. fox, badger, otter, polecat), but are used by many other small mammals, reptiles, amphibians and invertebrates that can cope with the specific cave-like conditions (Figure 7.4.38). There is also a potential to combine fauna use with drainage which is described in Section 7.4.3 – Adapted culverts.

Provision of small fauna underpasses should be considered in sections where there are no culverts that could be adapted for wildlife use to increase the permeability of the infrastructure to small animals. Specific small fauna passages may be needed where animals regularly cross infrastructure and high mortality is registered. This is the case particularly for species such as badgers or otters that move along clearly defined paths.

Location

- Underpasses for small animals are appropriate where a road or railway line across a natural area is built on an embankment (Figure 7.4.39).
- They are particularly necessary in areas where hotspots of small fauna mortality are registered or there is a need to provide safe passages for small fauna movements, particularly threatened species.
- If the target species use clearly defined paths, the underpass should be placed as closely as possible to the site where the path crosses the infrastructure.

Dimensions

- The recommended minimum dimensions for small fauna underpasses in European standards ranges from 1 to 2 m width; 1 to 2 m height, or in the case of a pipe from 0.5 to 2 m diameter (Table 7.4.4).
- To allow appropriate maintenance of a culvert using machinery, a width and height of 2 m is recommended. Nevertheless, narrower structures could be used for a variety of species. Even a width of 0.3-0.5 m may be acceptable to badgers and otters, but such small passages are not suitable for a passage aimed also at other species.
- The diameter of a pipe has to be large enough to allow the bottom part to be filled in to provide a flat surface for animals to walk on.

Design

- Rectangular structures are preferable for amphibians, and possibly other species, because the vertical walls provide better guidance and a larger floor space. Such a shape profile is the preferred installation on new transport infrastructure.
- Pipes are often cheaper than rectangular constructions and are easier to install under existing roads. The base of the pipe should be filled to provide a flat surface to walk on.
- Corrugated steel is not recommended. Metal surfaces deter some species, e.g. rabbits and some carnivores.
- Design solutions should be adopted that prevent the passage from becoming waterlogged. To allow a free-draining tunnel, the minimum gradient is 1%. The maximum gradient should be 1:2. Internal surfaces where there is a gradient should be rough.
- The bottom of the structure should at all times be above the level of the ground water.
- The floor should be as natural as possible with sand, stones and rocks when possible. Tarmac or other non-natural materials are not as suitable.
- Underpass entrances should be kept free from human disturbance. Artificial light should be avoided.
- Entrances should be located in recesses along the fence line so that animals are guided to them. They also must be set up as high as possible in the embankment to shorten the length of the crossing but at the same time avoiding steep gradients.
- Entrances have to be placed outside any fences which run alongside the transport infrastructure.

Points for special attention

- Shelter and guidance for small animals (mice, invertebrates) could be provided with two strips of tree stumps, stones or other material.
- The underpass should be accessible for inspection.
- Access for animals has to be unobstructed.
- No roads or tracks that interrupt the habitat connectivity adjacent to the underpass should be built parallel to the infrastructure being crossed.
- The vegetation around the tunnel entrance needs to be appropriately maintained.

Figure 7.4.38 – Entrance to a small fauna underpass on the A8 in Switzerland (diameter 1 m). Stone walls, which in this mountain region are a common feature, guide animals to the passage. In such small structures maintenance tasks are difficult and could be often blocked by branches and other materials (Photo by: A. Righetti).

Figure 7.4.39 – Small fauna underpass constructed under an existing road to provide a safe crossing point for otters. Stones piles provide extra shelters. (Photo by: Minuartia).

Adapted culverts

Conventional culverts, usually pipes or rectangular structures (but also large arches in some particular locations), are designed to allow the flow of water and may contain rain water from perimeter drainage or small streams. Some culverts carry water all year round, others only temporarily, e.g. after heavy rainfall or during the period of snow melt. When culverts carry water permanently, adaptations to permit terrestrial animal passage are needed (Figure 7.4.40). If culverts are dry for long periods, this could be achieved with minor adaptations.

Modified culverts have been shown to be used by small fauna in particular, including the smaller carnivores but also by fish and other aquatic species. In situations where culverts are large and dry for much of the year (e.g. in Mediterranean areas) they may also be used by larger mammals (Figure 7.4.41). Where fish populations are present, culverts have to be designed to also enable fish passage (see requirements for fish in Section 7.4.3 – Fish passages).

Adaptation of culverts

- Where culverts are built to lead a stream, the design has to be such that not just the water is led through, but also dry areas on both sides of the watercourse are provided. The same principles apply as for river crossings (see Section 7.4.3 – Adapted viaducts).

- Lowering a part of the concrete base surface to channel water may provide also a guiding line for small animals.
- If the culvert frequently contains water, the base must be adapted to keep a part of it dry at all times (Figure 7.4.42). This can be achieved with a lateral embankment or ledges (i.e. a board of rot-proof material) at both sides of the structure with a minimum width of 50 cm (see Table 7.4.4). Height should be adapted to the hydraulic conditions to allow the ledge to remain above the water level. Floating systems in channels, for example a wooden board which can move depending on the water level, are also used successfully.
- Prefabricated rectangular culverts can be designed with an integrated ledge.
- In existing corrugated steel drainage structures, the base should be filled with concrete or other suitable material to provide a more attractive substrate for animal movement.

Culvert exits

Certain culverts may have stepped exits to reduce water erosion of embankments. These can be a trap for animals using the culvert as a passage and should be modified with structures to reduce the height of the steps. Different modifications can be made, e.g. to open the lateral walls of the stepped channel or substitute the steps with a ramp (Figure 7.4.43).

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

If new culverts are planned, it is crucial that the requirements of fauna are also taken into account. Depending on the target species and the length of the culvert, different dimensions apply.

Adapted culverts also need frequent maintenance (particularly after storms or other weather events) so access must be provided for people and machinery. This is why an adapted culvert has a recommended minimum width of 2 m.

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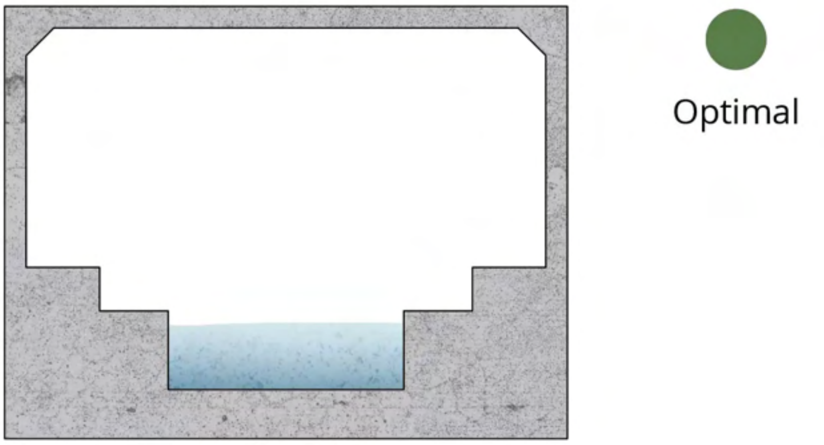

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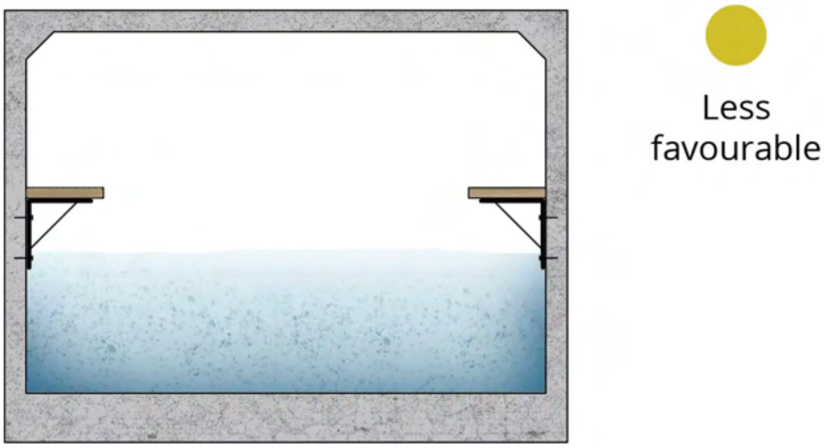

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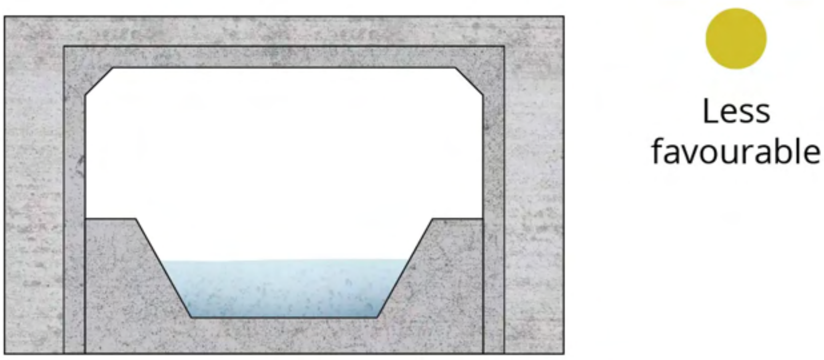

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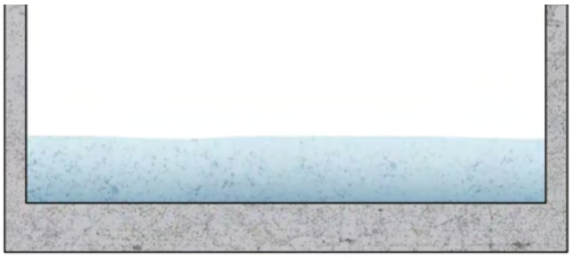

Figure 7.4.40 – Small terrestrial animals can use culverts if dry walkways are provided. A: Optimal solution for terrestrial animals; B: wooden board above the water level, fixed to both sides walls; C: prefabricated concrete walkways above the water level; D: not suitable for terrestrial animals (Source: Iuell et al., 2003 – Adapted by: AT-Minuartia).

Figure 7.4.41 – Culverts in Mediterranean areas may remain dry or with low water level for much of the year, but require large dimensions for drainage during periods of heavy rain. These structures are particularly suitable for adaptation to wildlife by providing dry ledges, appropriate landscaping at the entrances and guiding fencing (Photo by: Minuartia).

Figure 7.4.42 – Adapted culvert with two ledges to keep dry areas for fauna passage. The lower is part of the original concrete structure and the higher is a wooden ledge installed later to facilitate animal crossing when lower part is flooded. (Photo by: Minuartia).

Figure 7.4.43 – A stepped drainage exit with vertical walls can trap animals and must be avoided. Opening the lateral walls of the channel or substituting the steps for a ramp with a rough surface will allow fauna to reach the embankments and access areas adjacent to the infrastructure. (Photos by: Minuartia).

● To avoid; ● Less favourable; ● Optimal

Fish passages

▸ Access to Rationale. Fish passages

General description and targets

The ecologically best way to provide continuity for river and streams where crossing an infrastructure are viaducts or large adapted culverts (see Section 7.4.3 – Adapted viaduct and Section 7.4.3 – Adapted culverts) which allow to maintain both water course and riparian habitats on both sides. Smaller pipe or box structures than only transport water often pose a movement barrier to fish. This section focusses on how to adapt such small structures to enable fish to cross. However, adaptation of existing culverts in some situations could be so problematic that replacement with a new specially-designed structure is necessary.

Fish must be able to move freely both upstream and downstream. This is important not only for fish but other species, such as the larvae of freshwater mussels, transported in the gills of fish. Barriers created by infrastructure mainly restrict upstream movements, which are particularly important when fish migrate to their spawning grounds. This section provides general guidelines to facilitate fish crossing, but specialist consultation will be required as each species has many specific requirements and every site has its own specific conditions.

Location

Fish passages should be constructed where infrastructure crosses fish habitats such as rivers, streams and lakes. The design of the passage is determined by the requirements of the target species and constraints of the site, such as features of the structures already built. Important characteristics to be considered are:

- length
- slope
- width or diameter
- bottom substrate.

The design of a passage for aquatic species is different to that for terrestrial species and must take into account water flow fluctuation, velocity and volume, type of watercourse (natural stream, ditch or canal), continuity to be achieved and requirements of target species which will use the passage.

A ditch which has only a hydraulic function and does not allow fish to swim does not provide the same opportunities as a watercourse which is also an aquatic habitat. Where fish populations exist, additional assessment work is required and regulatory obligations need to be fulfilled in the design of the crossing structure.

Design

- An excessive drop at the entrance or exit of the passage must be avoided.
- If the foundation of the passage is positioned at a different slope to the original riverbed, the structure creates breaks in the natural slope. This results in water chutes downstream or steep slopes upstream which reduce depth and increase water velocity. Both problems create difficulties for fish movement (Figure 7.4.44).

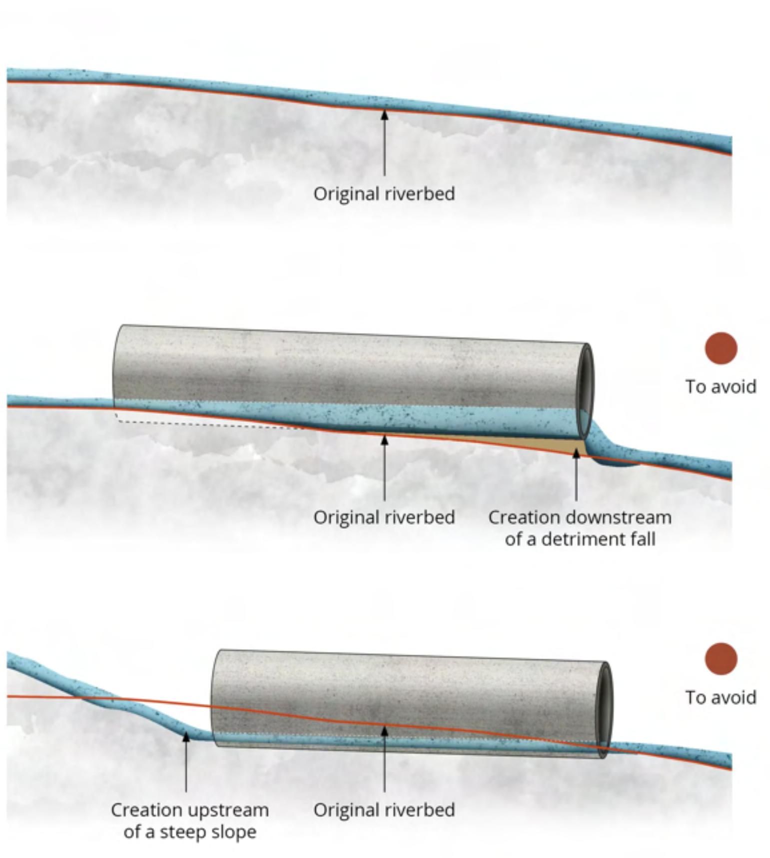

Figure 7.4.44 – Problems created by inappropriate longitudinal positioning of a structure (Source: Baudoin et al., 2014 – Adapted by: AT-Minuartia)

- Structural problems inside the passage, such as steps caused by inappropriate joints between parts of the structure, must be avoided as they can reduce the flow and make fish movement difficult.
- Inadequate water depth within the passage may pose problems for a variety of species. Different species have different demands at different stages of their life cycle and periods of the year, e.g. adult salmon require a water depth of at least 20 cm, while trout require a depth of 5 to 10 cm. A smooth base combined with an unsuitable slope may result in water depths making it difficult or even impossible for fish to swim through the structure during drier periods. Appropriate width of the structure, according to the watercourse minor bed is necessary for the required depth to be achieved. Too wide and the water may become too shallow to allow fish to move through it.
- Excessive water velocity within the passage hinders movement of fish. An insufficient width creates excessive water speed within the passage and creates a current in excess

of the swimming capabilities of the fish. A smooth base substrate and too high a current through the passage leave no resting zone for fish trying to use it.

- Hydraulic simulation (see section on design) is necessary to ensure the correct dimensions when designing culverts modified to allow fish passage. Flow velocities must be analysed under conditions of low and higher water in line with the expected operating range of the structure. The water velocity can also be reduced by installing thresholds, deflectors or macro-roughness treatments which raise the height of water and diversify its flow. In downstream and steep culverts, the riffle has to be high enough that the water line in the entire culvert is at the same level. This solution requires appropriate maintenance as sediments and debris will be deposited in the pools.
- Debris accumulation can create barriers to fish within the passage. This happens when structures are undersized in relation to the width of the watercourse, when there is a strong narrowing of the passage section, or if the air draft between the water line and the entrance of the passage is insufficient (Figure 7.4.45). Debris and bed material should be managed by collecting it upstream or allowing it to pass unhindered through the passage. Debris accumulation can also create a hydraulic swirl upstream which affects fish habitats and may render the passage non-functional (Figure 7.4.46).

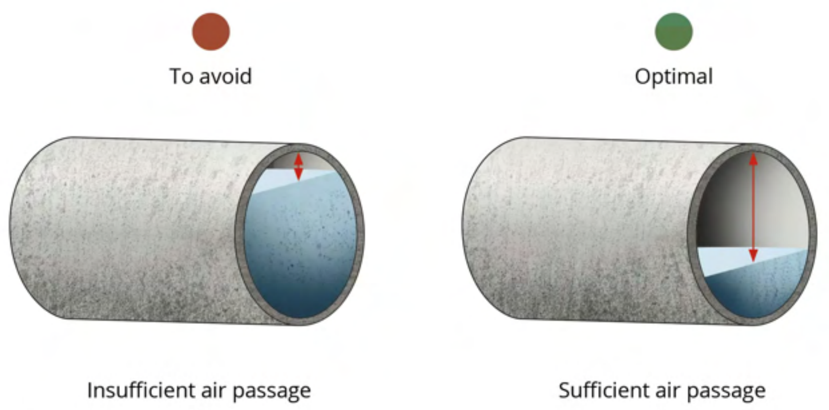

Figure 7.4.45 – Insufficient air passage facilitates the accumulation of debris which creates barriers to fish movement (Source: Baudoin et al., 2014 – Adapted by: AT-Minuartia).

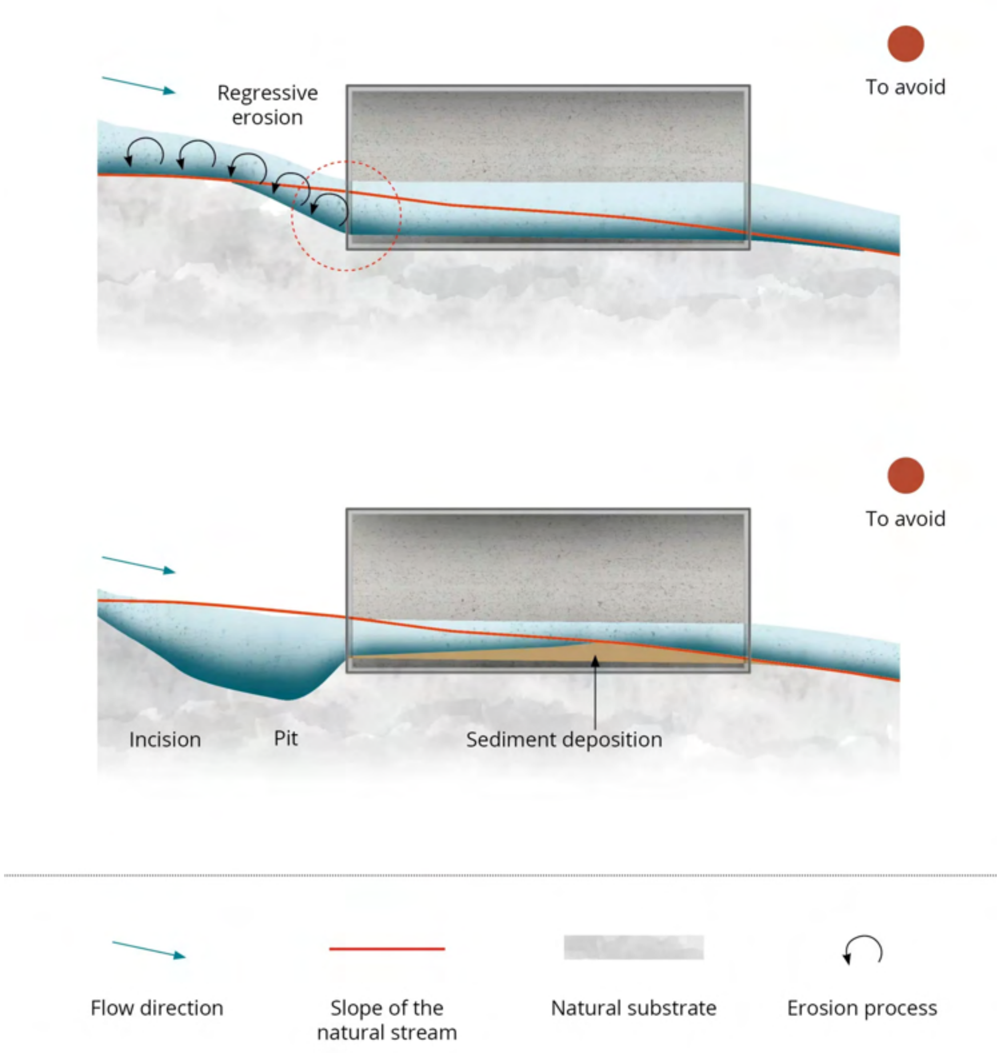

Figure 7.4.46 – Example of an erosion phenomena leading to an alteration of fish habitat. (Source: Sétra, 2013 – Adapted by: AT-Minuartia).

Choice of the structure type

For hydraulic structures, passages open to the ground (Figure 7.4.47A) without concrete on the base, must be installed unless technical issues make this impossible. The choice of structure depends on:

- technical and functional constraints of the infrastructure.
- the physical and biological components of the watercourse to be crossed, and in particular its ecological challenges.
- other functions and uses that the passage will restore (flood expansion zone, pedestrians, animals, etc.).
- cost considerations.

When the surroundings of infrastructure present unavoidable issues relating to watercourses and/or the local ecosystems, solutions to mitigate the impact on these is essential and it is strongly advised:

- to find an alternative to the pre-defined infrastructure route.
- where re-routing is not an option, installing open structures such as viaducts provides the greatest water connectivity and maintains the natural functions of the watercourse by preserving the minor bed, riverbanks, even in some cases the riparian forest and the watershed associated with the watercourse. Fish movement is maintained, avoiding the installation of heavy and expensive devices for bank protection and energy dissipation.

Verifying the correct conditions enabling fish to cross the structure.

Correctly sizing a structure which allows fish to cross entails a comparison between the swimming capacities of the fish and characteristics of the water flow within the structure, including water height, the presence of drops, water speed and distance to cross. The hydraulic design process is based on the maximum water current speed that the target fish species can withstand, depending on the length to be crossed. The longer the distance, the lower the maximum permissible speed.

Not every animal using a water passage to cross the infrastructure will swim through it. Eels for example may also crawl, however in this document, swimming is the main means of movement dealt with.

- The swimming ability of target species is a reference to consider in the design of the structure. The 'cruising speed', which corresponds to the speed an individual fish can maintain continuously for more than 3 hours, is used as the design reference because it is the speed that can be maintained over long distances.
- The speed of the current and water level in the structure determines the potential for a target species to cross the structure. Hydraulic simulation must be undertaken in order to check compliance with depth and flow speed required for the less capable target species. Issues to be considered are:

  – maximum passable distance for a target species, depending on the flow speed in the structure and is strongly associated with its shape, roughness and slope. Flow speed should be equal or inferior to the 'cruising swimming speed' of target species, for flows between 'low water' and up to 2.5 times the debit inter-annual average.

  – minimum water depth required by target species, which is in the range of 5 cm for small species (sculpins, studs, minnows, groupers) to over 20 cm for adult Atlantic salmon.

Positioning of structures

- Open structures: bridges and viaducts (Figure 7.4.47A). Foundations must be laid as far back as possible from the minor bed, the banks and the riparian forest in order to guarantee the stability of these environments and to restore ecological continuity. Well dimensioned, these works should not require the installation of any additional equipment. These design features should be prioritised in new infrastructure projects.
- Closed structures: culverts (Figure 7.4.47B). These must be positioned similar to the initial precise longitudinal profile of the watercourse which must be determined by a precise topographic survey. The objective is to reconstitute a natural background while avoiding the presence of steps or any other obstacle causing different water levels upstream and downstream from the structure and taking care not to create breaks that would give rise to erosion. Once slope angles are determined, the leading edge of the foundation should be installed at least 30 cm below the natural bed of the stream (Figure 7.4.48). Burying the foundation also makes it possible to correct small errors in the positioning of the structure during installation and recreate a favourable rough bottom surface.

It may arise that an existing structure must be modified to allow fish passage, but the conditions already listed cannot be achieved due to characteristics of the watercourse (hydrological regime, width or slope), the structure (dimensions or positioning) or the target species present in the catchment area. In this instance, devices for energy dissipation should be installed at the basis of the structure which would allow the substrate to be maintained and/or raise the water line (Figure 7.4.48).

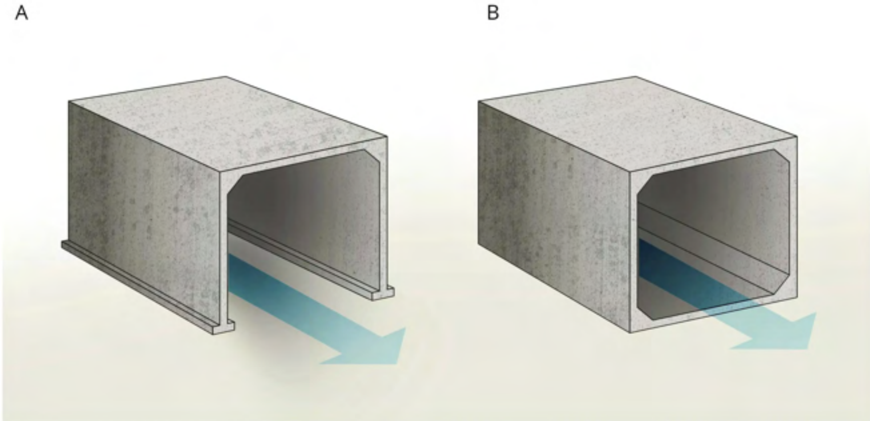

Figure 7.4.47 – A: Open structure; B: Closed structure (Source: Baudoin et al., 2014 – Adapted by: AT-Minuartia).

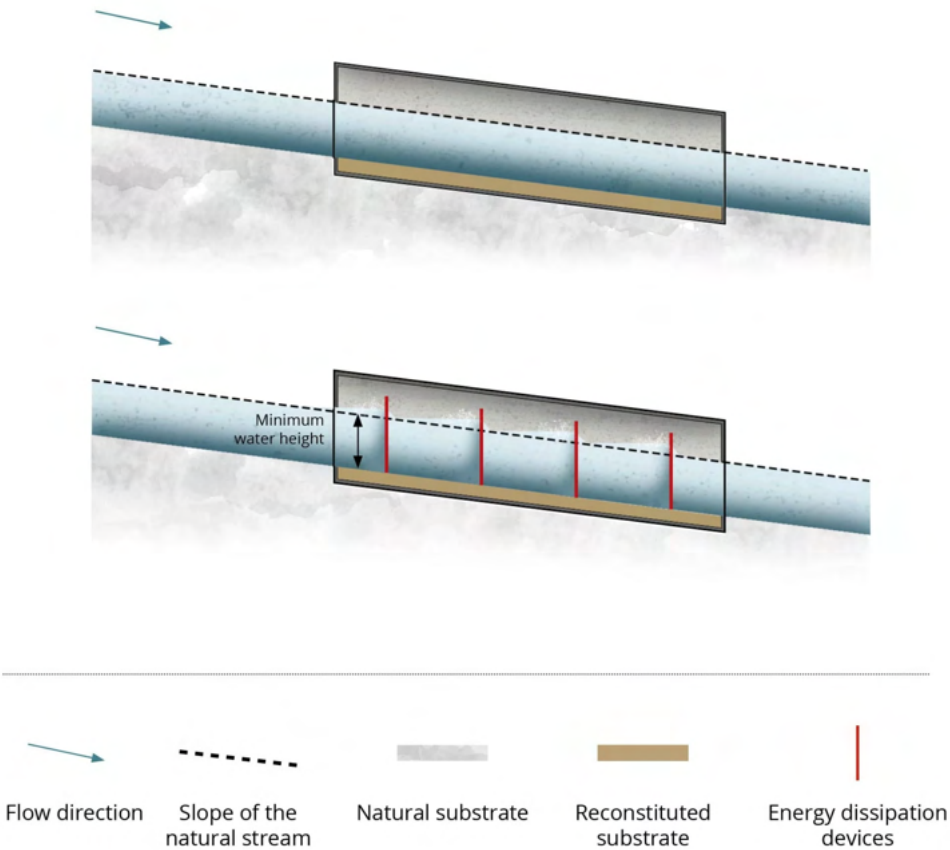

Figure 7.4.48 – Position of the structure must be adapted according to the slope of the water stream (Source: Sétra, 2013 – Adapted by: AT-Minuartia).

Openness Index

Studies have shown that the ability of fish to cross hydraulic structures is improved by an optimal Openness Index (ratio between section and length). The openness should increase as a function of the length of the cover (Table 7.4.5).

If length reaches or exceeds 60 m, it is necessary to consider modifying the structure (in the case of several consecutive structures, the cumulative length should be considered).

Reducing the length of structures, by constructing wing walls or vertical embankment retaining walls, are measures to be considered.

Table 7.4.5 – Modulation of the section / length ratio according to the length of cover (Source: Setra, 1993; River and stream continuity partnership, 2011).

Cover length (single or cumulative)	Section / length ratio
L < 30 m	0.25
30 m ≤ L ≤ 60 m	0.50
L > 60 m	0.75 (or use another type of structure: viaduct, bridge)

Substrate

A bed of substrate that mimics the natural watercourse as closely as possible must be laid on the base of the structure to a depth of at least 30 cm. The size of particles used in this substrate is very important to maintain the circulation of fish and the ecological capacity of the watercourse. The substrate must avoid any infiltration which would reduce the flow or even cause the structure to dry up.

Once the grain size has been decided, it is important to ensure that the substrate cannot be stripped by being lifted and carried away, especially when the flow rate is at its maximum speed in the structure. If this is a risk, a substrate stabilization threshold or deflectors will prevent periodic stripping (Figure 7.4.49).

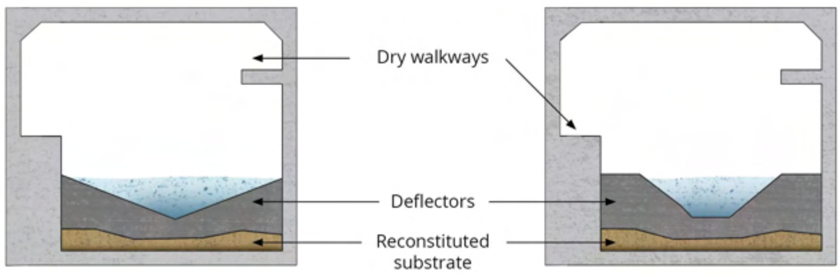

Figure 7.4.49 – The installation of weirs to stabilize the reconstituted substrate but also to concentrate low flows and provide resting areas for fish (Source: Sétra, 2013 – Adapted by: AT-Minuartia).

Energy dissipation devices

When the conditions that allow fish movement cannot be reached or maintained it will be necessary to add energy dissipation devices and / or water line enhancement.

Thresholds, deflectors (baffles) or macro-roughness such as blocks bonded to the bottom of the structure, positioned transversely or staggered, will decrease the speed of the current, stabilize the substrate and / or enhance the water line, which ensures conditions compatible with fish swimming abilities:

- Thresholds (Figure 7.4.50A) are triangular crest sills which have the advantage of creating heterogeneous flow conditions, the fish being able to choose the passage zone which suits them best according to the flow conditions.
- Deflectors (baffles; Figure 7.4.50B) are more difficult to install and more expensive given their inclination, their reduced spacing and, consequently, their number.
- Macro roughness substrate (Figure 7.4.50C): the reconstitution of a “natural” bottom makes it possible to restore a roughness to the raft. In addition, large diameter blocks, made of concrete or natural materials, can be positioned regularly and/or staggered. The latter create a heterogeneous flow within which the fish can find their preferred path.

The nature, quantity and spacing of these deflectors must be determined on the basis of a specific hydraulic study and according to the requirements of target fish species. Installing thresholds combined with macro-roughness substrate may also be considered.

Figure 7.4.50 – Solutions to adapt existing drainage structures to enhance opportunities for fish passage – not recommended for any new infrastructure where best options are wider structures which allow the restoration of the stream and natural embankments at each site. A: Installing weirs stabilises the reconstituted substrate but also concentrates low flows and provides resting areas for fish. Lateral dry passages also allow terrestrial mammals to use this passage (Source: Cerema, 2021); B: Installation of weirs in a passage that is only suitable for fish (Source: Cerema, 2021); C: Stones fixed into the substrate achieve the same objective as weirs but are not suitable for mammal crossing (Source: Sétra, 2013).

Amphibian passages

Access to Rationale. Amphibian passages

General description and targets

Amphibian passages (traditionally called amphibian tunnels) are a system of underpasses specifically designed to allow the movement of frogs, toads, newts and other species of amphibians. Passages are linked to opaque smooth guiding fences, to prevent animals from accessing the road and funnel them to the entrance. Multiple underpasses are placed in close proximity to each other (Figure 7.4.51). Temporary installations are also applied in some conditions, consisting of temporary fences and buckets to prevent amphibians from accessing the transport infrastructure. Amphibians caught in these buckets are taken to the other side of the transport infrastructure and released. Both types are described in this section.

The vast majority of amphibians have a bi-phasic biological cycle characterized by an aquatic phase (eggs and larvae) and a terrestrial phase (juveniles and adults). Generally once the juveniles leave the aquatic environment, they often do not return to the water until the time comes to reproduce, except those species which are more aquatic or during warm and dry weather.

Each year, the adults migrate to and from their terrestrial habitats and the aquatic breeding grounds and juveniles leave the aquatic habitats post metamorphosis. In addition to these reproduction migratory movements, other movements take place in searching for food, going to seasonal territories or dispersing to new territories. These different purposes bring different targets for mitigation measures when trying to maintain populations. Preserving as close to 100% of the migrant individuals during breeding is desirable, while a much smaller percentage of the total population could be sufficient during dispersal depending on the context.

The best placement of amphibian tunnels requires monitoring and study periods should be adapted according to the species, which varies significantly between regions and species. Frog and toad species mainly need to cross transport infrastructure in late winter and spring, while newt species do so in autumn.

When transport infrastructure intersects migration routes in particular, road mortality and habitat fragmentation can be substantial and thus specific risk minimization measures must be taken to ensure the safe crossing for breeding adults and dispersing juveniles reducing mortality risks. Numerous other negative impacts on populations include chemical pollution (e.g. from de-icing substances) noise and light pollution that should also be reduced wherever possible.

On existing roads or to isolate infrastructure works areas from migrating amphibians, the absence of crossing structures may be compensated for by the installation of temporary amphibian collection systems (typically by erecting temporary fences and pitfall bucket systems) during significant migratory movements. Due to the resulting personnel requirements to implement and monitor such systems, the creation of a permanent crossing will be more cost effective even if expensive to build and with ongoing maintenance. There are further arguments which offset the costs related to permanent passages, in that temporary measures may fail to predict the movement of juvenile amphibians, leaving them exposed to high mortality. Increasing traffic density also renders temporary measures insufficient to protect a population. Effective permanent amphibian passages, as well as other types of wildlife passages suitable for amphibians, e.g. viaducts, protect all migrators, including juveniles.

Permanent installations

These devices specifically designed for amphibians maintain or restore the functionality and safety of migratory movements on new or existing infrastructure. These passages are generally installed in areas of high amphibian mortality risk and are in addition to other wildlife passages such as adapted culverts, that could also ensure amphibian crossing together with other species.

Amphibian passages should also be placed at strategic sections where the infrastructure is intersecting a migration corridor guaranteeing overall population connectivity and dispersal. This is especially important for certain particularly endangered species (e.g.: newts) which show more diffuse migration areas, even if hotspots of high mortality are not observed on the infrastructure.

These specialized passages are made up of two components:

1. A guiding structure providing a barrier to prevent amphibians from accessing the road and guide them towards safe crossing devices.
2. A crossing structure comprising a series of tunnels under a road or a railway through which amphibians cross safely to the other side.

- Guiding structures

  – Metal, plastic or concrete are common materials used in different types of guiding fences, which should be durable (at least 10 years) and smooth to make it difficult for amphibians to climb.

  – Guiding fencing should be buried or well anchored at the base, leaving no holes, and perpendicular to the ground. A rounded fence shape does not provide adequate guiding.

  – The ends of the fences should be U-shaped to direct amphibians away from the road when they reach the ends of the barrier (Figure 7.4.52).

  – The height should be at least 40 cm over ground, even 60 cm if some target species are living in the area (e.g. agile frog *Rana dalmatina*).

  – The top part of the barrier must form a flap to prevent animals climbing over.

  – A movement surface free from vegetation is recommended right beside the barrier and vegetation adjacent to the movement corridor should provide cover.

  – The guiding structures should be placed as close to the road as possible to minimise the length of the crossing tunnel. A safety barrier prevents vehicles from becoming stuck in the guiding structures.

  – Corners and edges should be avoided especially where the guiding structure joins the entrance to the tunnel.

– Fences should be placed to reduce the risk of damage during mechanical verge vegetation cutting (Figure 7.4.53).

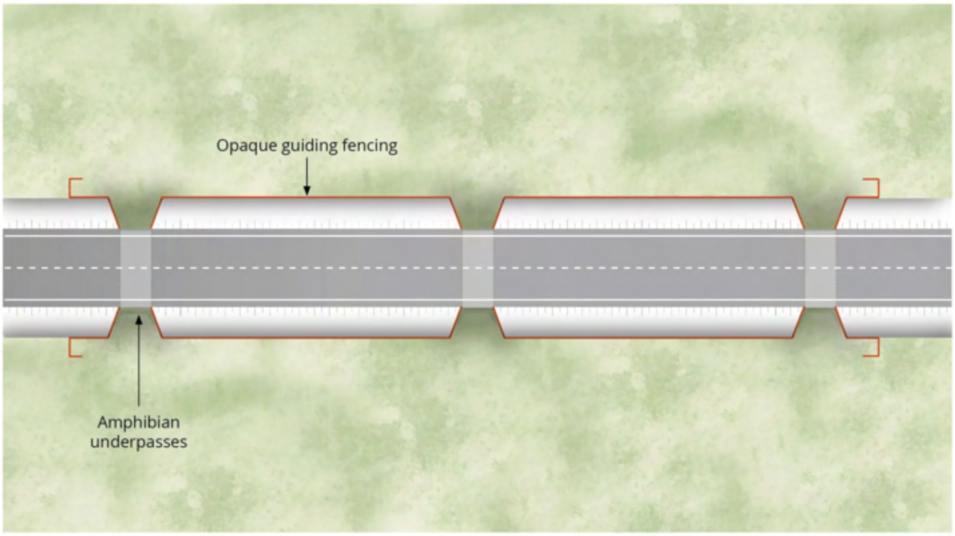

Figure 7.4.51 – Amphibian passages are composed of multiple rectangular or dome-shape underpasses located at maximum distances of 60m and with opaque guiding fencing (Source: Langton & Clevenger, 2021; Adapted by: AT-Minuartia).

Figure 7.4.52 –The end of the amphibian passage guiding structure should be U-shaped to direct animals away from roads or railways and helps avoid access to the infrastructure (Photo by: Minuartia).

Figure 7.4.53 – Fencing must facilitate vegetation maintenance tasks and should be completely anchored to the entrance of the tunnel. If open spaces are left below, amphibians may access the road (Photo by: Minuartia).

To avoid; Less favourable; Optimal

- Amphibian underpasses

  – Distances between tunnels must be as short as possible to maximise the chance for amphibians to find a tunnel entrance, to a maximum of 60 m.

  – Width of the structure must be as large as possible, with a minimum of 1 m in underpasses less than 20 m long. Ideally they must be as short and as wide as possible. Width should be adapted to the length of the tunnel. The dimensions recommended in Table 7.4.6 have been successfully tested and guarantee that the structures are also suitable for small mammals and some reptiles and maintenance is feasible. A smaller width (40-50 cm minimum) may be the best achievable when providing defragmentation measures on existing infrastructure where hotspots of amphibian mortality are detected. These passages can be expected to be used by amphibians, but may not be suitable for all species and could pose maintenance difficulties.

  – Tunnels allowing the animals to move in both directions (also known as 'two-way systems') are recommended (Figure 7.4.54) allowing free movement of amphibians if there is an appropriate width (see Table 7.4.4 and Table 7.4.6). A double-pipe system (one-way tunnels), with separate pipes for each direction of crossing is not recommended. There is little evidence it is effective and is more complicated to build and maintain. This type is not suitable for small mammals and may even trap amphibians if not properly installed and maintained.

  – Crossing structures must be rectangular or dome-shape. Circular structures are not recommended because some species attempt to climb the tunnel walls which then takes a long time to cross or could even trap them inside. Tunnels with rectangular cross-sections are also recommended because of the larger base compared to pipes of similar heights. It is also easier to fix guiding structures to the vertical tunnel entrance.

  – Structures without concrete on the base are preferable because they maintain contact with the natural, moist surface and allow soil to be added during installation.

– Concrete passage construction is preferable to steel, plastic or other materials because it is more durable and easier to maintain.

– Amphibians are susceptible to desiccation, especially young animals and this is particularly relevant because, in Europe, juveniles normally cross roads in late summer. Protecting the movement of these juveniles is vital to ensure population survival, so longer, drier tunnels are not as effective as those in combination with an aquatic element, such as a drainage channel or carrying a stream.

– Water should drain easily from the tunnels. Standing water in the tunnel is generally not recommended even if some species (e.g. salamanders and newts) are reported to use completely flooded passages.

Table 7.4.6 – Minimum size requirements according to length for each tunnel in an amphibian underpass system for new infrastructure. Circular tunnels are not recommended. Tunnels more than 40 m long are demonstrated to be less effective and should be avoided; in these cases other types of wildlife passages such as multiuse underpasses, viaducts or landscape bridges could be adapted to amphibian use.

	Minimum dimensions of each tunnel (m)				**Distance between tunnels** (m)
Length	<20	20 – 30	30 – 40	40 – 50	
Rectangular (width x height)	1.0 x 0.75	1.5 x 1.0	1.75 x 1.25	2.0 x 1.5	20 to 60 (as short as possible)
Dome-shaped (half circle)	1.0 x 0.70	1.4 x 0.7	1.60 x 1.1		20 to 60 (as short as possible)

Figure 7.4.54 – Examples of amphibian passages: A: dome-shaped underpass (Photo by: M. Puky) and B: top-grated underpass (Photo by: E. van der Grift). Open grid tunnels are not recommended in all situations as they can suffer pollution from water that drains into the tunnel or from salt in roads located in mountain cold-weather areas.

- Other types of wildlife passages suitable for amphibians

  – Other types of wildlife passages such as viaducts, adapted culverts, landscape bridges and wildlife overpasses are recommended instead of amphibian tunnels where the passage would be more than 40 m or where necessary humid conditions cannot be guaranteed. In all cases the installation of appropriate guiding amphibian fencing is recommended.

  – Viaducts and adapted culverts that connect aquatic habitats such as rivers and wetlands could be particularly useful for amphibian crossing. Small culverts which are permanently flooded are not suitable.

  – Landscape bridges and wildlife overpasses could also be used if they guarantee appropriate conditions (particularly humidity) for amphibians. Maintenance of small ponds at the entrances of the structures could be useful. This type of overpass is not suitable if located in dry areas where humidity of the soil is not guaranteed.

- In railway infrastructure trenches under the rail lines complimented with rejection devices (Figure 7.4.55), may offer safe crossing for amphibians in a less complex and cheaper way. While the effectiveness of these systems is still not established, the current recommendation is to install amphibian deflectors and trenches at a distance of least every 8 to 12 train sleepers. A final assessment of the functionality and application areas of these measures is still pending.

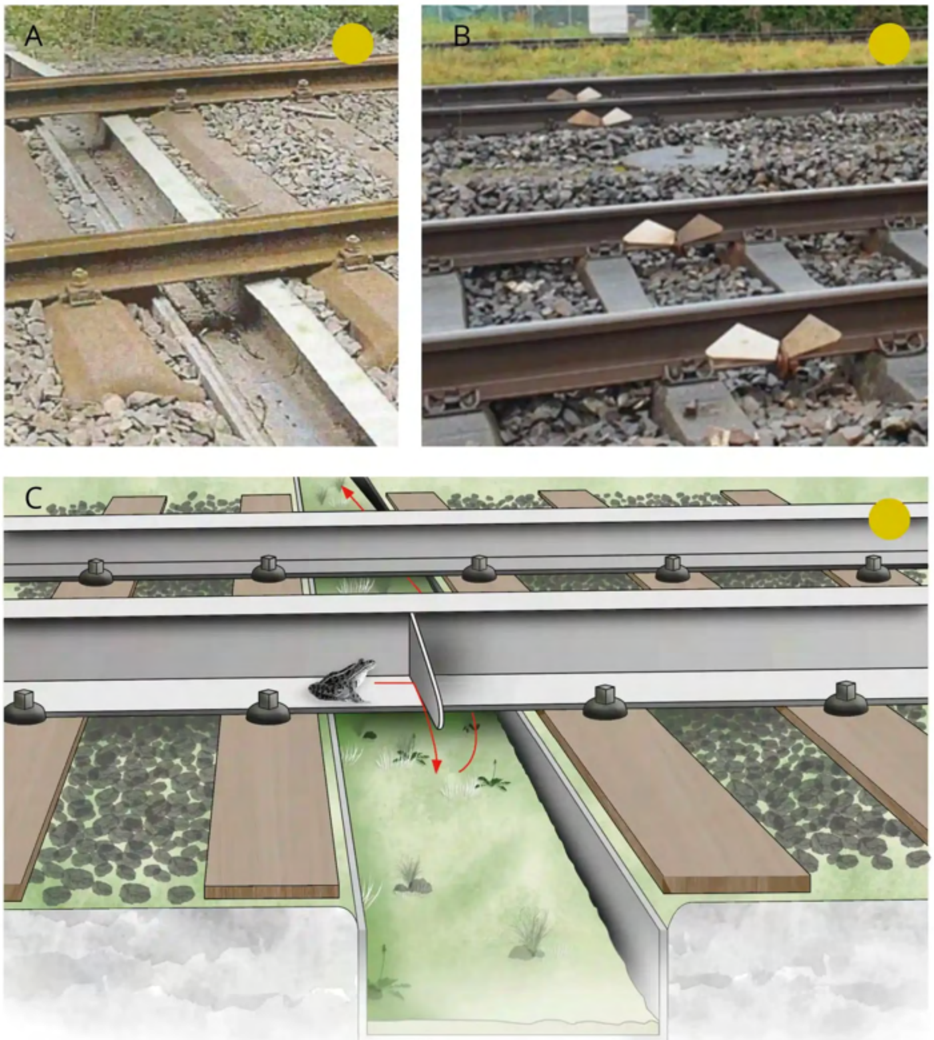

Figure 7.4.55 – Amphibian crossing devices for railways. A: Trench under the railway (Source: Müller and Berthoud, 1994); B: Rejection devices (Photo by: K. Hilfiker); C: Example of the combination of a transversal amphibian barrier in the rail which leads the animal to a trench below. Further research is required to determine the effectiveness of such devices (Source: Iuell et al., 2003 – Adapted by: AT Minuartia).

To avoid; Less favourable; Optimal.

Temporary installations

Where a crossing passage cannot be provided or when undergoing construction, a migration corridor for amphibians can be protected to a certain extent by building a barrier to block access to the road and guide the amphibians to collection buckets dug into the ground (Figure 7.4.56). The animals are then transported and released by volunteers on the other side of the road on a daily basis.

On existing roads, the system is usually installed only where volunteers are available to check the installations at least once a day and preferably twice (morning and evening) or more. In the majority of cases, this solution is mainly applied to protect amphibians migrating towards breeding sites, unlike return migrations of adults and the dispersal of juveniles which are not targeted. Therefore, this measure can probably sufficiently maintain the population only if there is light to moderate traffic.

- Buckets:

    – The buckets should be at least 30-40 cm deep.

– The bucket rim should be level with the ground.

– The recommended distance between the buckets is 10 to 15 m.

– During the peak migration period, buckets have to be checked frequently. The frequency depends on the number of animals present: at least one to three times per 24 hours and in areas with large numbers of amphibians, up to every half hour. If only one check can take place, it should be late at night or early in the morning.

– Care must be taken to prevent water from accumulating in the buckets and leading to the drowning of trapped animals. A perforation of the bottom of the bucket (3 mm holes) placed on a bed of pebbles to ensure filtration or emptying the bucket manually may be necessary.

– In some situation a broad bucket with straight walls is recommended to prevent newts, young frogs and toads or tree-frogs from climbing out.

– At locations where mice and shrews could get trapped in the buckets, a thin stick placed inside it may help them climb out.

– To avoid the risk of desiccation adding dead leaves and a damp sponge at the bottom of the bucket maintains a level of humidity.

- Barriers:

  – Barriers should be used to guide amphibians to the buckets.

  – The fence should be opaque and smooth. Wire mesh and particularly netting are not recommended because amphibians can climb over these (see Section 7.2.1 – Fencing and reinforcements for small vertebrates; Figure 7.2.16B).

  – No space should be left between the barriers and the buckets so amphibians won't miss the buckets.

  – Buckets should be placed at the ends of the fence.

  – The minimum height of the fence should be 40 cm. In presence of more agile species (e.g. agile frog) the height should be at least 60 cm.

  – There must be no gaps or holes between the substrate and the fence. The barrier must be extended into the ground (5-20 cm) or lowered to the ground and anchored with mounds of earth or sand. To prevent amphibians from climbing over, bending back the top of the barrier to form a curve and even angling the barrier back on the bucket side is recommended.

  – Stakes to secure the barrier should be placed on the side away from where amphibians are moving.

Figure 7.4.56 – Temporary amphibian fencing and buckets installed at the intersection of a migration corridor where animals can be collected and transported to the other side of the transport infrastructure (Photo by: C. Rosell).

7.4.4 At grade fauna passages (level crossing)

For areas where under or overpasses cannot be built (i.e., due to topographic limitations) level crossings, also known as 'at-grade fauna passages', may be an alternative to facilitate ungulates crossing. Theoretically, these crossings lead large mammals across the road surface and warn drivers when animals are detected entering the passage area. Level crossings thus require an electronic animal detection system (ADS) and a driver warning system.

Current effectiveness evidences are limited to only some Nordic countries where level crossings are proven effective only on roads with up to 6,000 vehicles per day and only for larger mammals such as deer and wild boar. They are not suitable for smaller species or on busy roads with high speed limits.

Level crossings are suitable only on fenced infrastructure. They require fences to prevent animals accessing the road or railway outside the detection area where no driver warning would be triggered (Figure 7.4.57). While more research is needed, the first trials conducted have resulted in the following recommendations:

- At the passage, a 20 m fence perpendicular to the road or railway must be installed to provide a corridor that directs animals across the detection zone.
- The width of the open crossing section should not be smaller than 30 m to minimize the risk of animals walking along the infrastructure within the fencing.
- Road painting may be installed to delineate the crossing, and visually direct animals across the road or railway (Figure 7.4.58A). White lines can be painted on the road to assist drivers see animals (Figure 7.4.59A). Electrified mats are useful to avoid animals to leave the area designated for crossing and walk onto the causeway.
- To help prevent animals walking onto the shoulders of the infrastructure, uneven surfaces (i.e., crushed stones) (Figure 7.4.58B) or rubber cone rugs (Figure 7.4.58B and Figure 7.4.59A) may be placed between the fence and the causeway.
- Warning signs activated by ADS must be installed to warn drivers when animals are nearby or on the causeway (Figure 7.4.59B; see Section 7.2.2 – Driver warnings).
- Speed limits in areas with level crossings are strongly recommended to increase traffic safety. Maximum speed in these areas should never exceed 80 km/h, although a safer speed limit is 50 km/h.

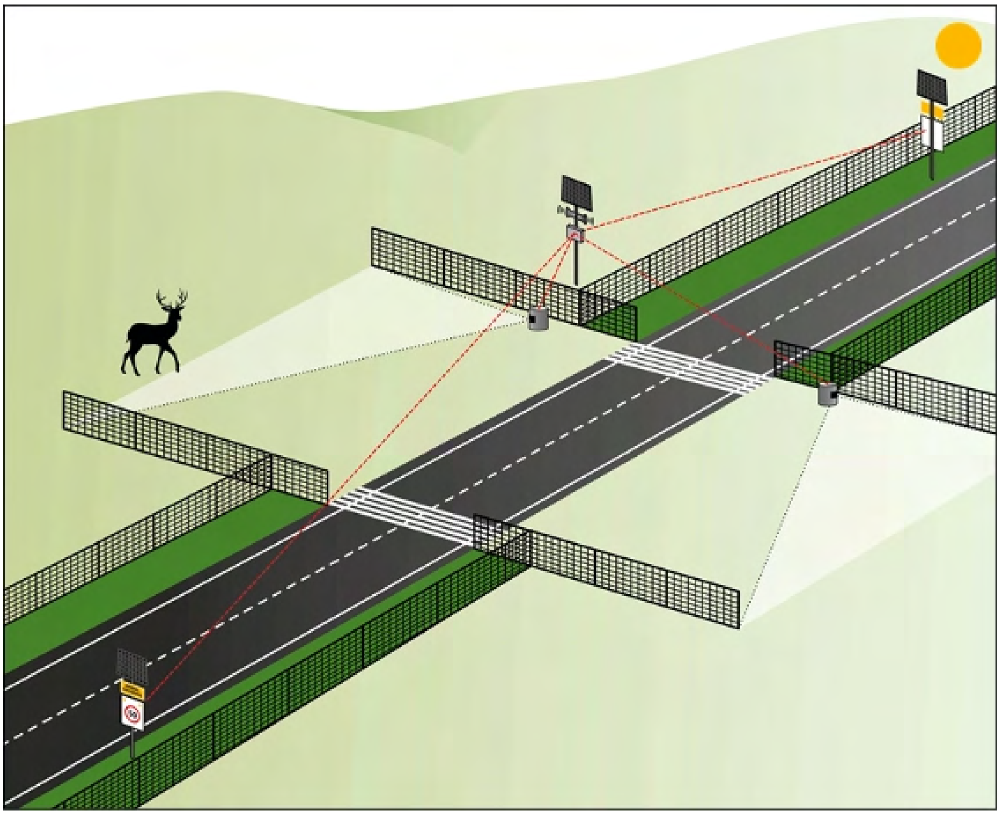

Figure 7.4.57 – Design of a fauna passage at grade. A maximum width of 30 meters opening is recommended (Source: EnviroPlanning AB – Adapted by: AT Minuartia).

To avoid; Less favourable; Optimal.

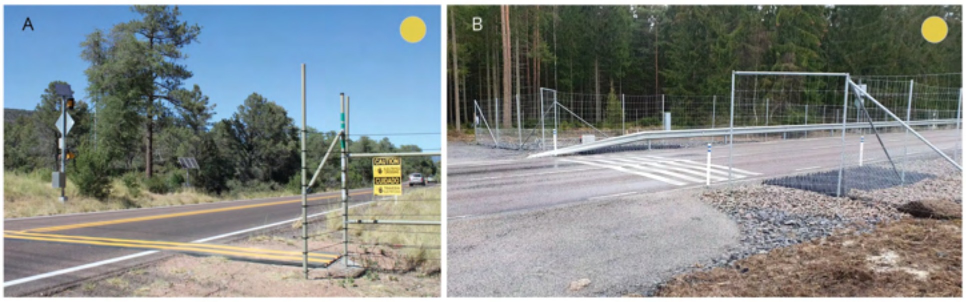

Figure 7.4.58 –Two different solutions to impede animals turning and walking onto the infrastructure. A: An electrified mat over the road in Arizona, USA (Photo by: C. Rosell) and B: crushed stone and rubber cone rugs placed at the shoulder of a road in Sweden (Photo by: M. Elfström – EnviroPlanning AB).

To avoid; Less favourable; Optimal.

Figure 7.4.59 – Complementary warning measures to drivers improve the efficiency of at grade passages. A: White lines help animals to be seen on the road (Photo by: M. Elfström – EnviroPlanning AB); B: ADS warning signs installed with an at grade passage are activated when an animal is detected on or near the causeway (Photo by: C. Rosell).

To avoid; Less favourable; Optimal.

← 7.3 Other measures to reduce mortality and disturbance

7.5 References →

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