LIFE SAFE-CROSSING

PREVENTING ANIMAL-VEHICLE COLLISIONS

GUIDANCE AND INFORMATION ON THE PROCEDURES AND CRITERIA TO BE USED FOR THE ASSESSMENT OF THE POTENTIAL INTERVENTIONS TO BE REALIZED IN EXISTING CROSSING STRUCTURES

REPORT DEVELOPED IN THE FRAME OF ACTION A4: Analysis and mapping of existing crossing structures for potential use by the target species and other interventions on the roads

December 2019

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PREVENTING ANIMAL-VEHICLE COLLISIONS - ACTION A4

Date: December 2019

Responsible partner: MINUARTIA

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II. Data Base contents: 'Transversal structures characterisation'

III. Guidelines to adapt transversal structures and increase use by large carnivores and other wildlife

These documents have been produced to assess the development of actions to be undertaken at each study area in the framework of the LIFE SAFE-CROSSING Action A4. They include unpublished data and also information from handbooks which use has only be authorised for internal purposes of the LIFE project. For any other external use, a request must be sent to Minuartia for authorisation or transfer to the responsible organisation (IENE or Spanish Ministry for Ecological Transition and Demographic Challenge).

1. Introduction

The LIFE SAFE-CROSSING (LIFE17NAT/IT/464) project aims to implement actions which reduce the impact of roads on some priority species in four European countries: the Marsican brown bear (*Ursus arctos marsicanus*) and wolf (*Canis lupus*) in Italy, the Iberian lynx (*Lynx pardinus*) in Spain, and the Brown bear (*Ursus arctos*) in Greece and Romania. This will be done mainly through

- Installation of Animal-Vehicle Collision Prevention Systems on the most critical road segments
- Adaptation of crossing structures to enhance connectivity for the target species
- Development of activities to increase the attention of drivers regarding the risk of collisions with the target species

In this context the main objective of the Action A4 is **to identify existing road crossing structures which could be used by target species but require adaptations to the structure and/or its surroundings**. Removal of barriers on roadsides verges and modification of any factor increasing target species mortality risk are also to be undertaken. These defragmentation actions will contribute to the reduction of target species (and other wild mammals) mortality risk and the barrier effect of roads in the study area. Moreover, it would benefit people by reducing hazards caused by animal-vehicle collisions.

This action is based on the results of Action A3, and other pre-existing information provided by project partners, and will be preparatory for Action C2.

The information included in this report consists of **general instructions and tools provided to partners** to develop Action A4. Its **goal is to unify methods applied in each study area and guarantee that actions that will be undertaken are based on scientific evidence and existing knowledge compiled in Handbooks on wildlife and traffic**.

The three main documents produced and delivered to partners are included in the Appendix and listed below:

- **I. Field form and Instructions for characterization of transversal structures.**
- **II. Data Base contents: 'Transversal structures characterisation'.**
- **III. Guidelines to adapt transversal structures and increase use by large carnivores and other wildlife.**

After Actions A4 and C2 arecompleted, the partners are expected to contribute new information from each study area based on the resulting use of transversal structures by target species 'Before' and 'After' the upgrade. Once validated and completed, the specifications and complementary tools, such as the Field form, developed in this Action are planned to be included in the 'Guidelines for monitoring and management of road kills and mitigation measures to reduce this conflict' to be produced jointly by all project partners as an output of the Action E7.

2. Study areas

Action A4 is developed in the three participant countries and the study areas listed below.

- **Greece**

  Study area: Kastoria and Florina provinces (identified as 'GR Kastoria - Florina').
  Target species: **Brown bear**.
  Preselected roads: Egnatia highway (**A29**) along 55km sub-segment 'Siatista-Koromilia'.
  Project partners: CALLISTO; EGNATIA ODOS.

- **Italy**

  Study area: Abruzzo, Lazio and Molise National Park (identified as 'IT PNALM').
  Target species: **Marsican brown bear.**
  Preselected roads: national road 83 Marsicana (**SS-83**) cuts the A zone (Strict Nature Reserve), Val Fondillo- Villetta Barrea km 53 - 58. Another area is the same road (83 Marsicana) Gioia Vecchio - Pescasseroli km 35 - 41 where some straight sections result in high traffic speeds. Another two roads were also selected to broaden the characterization of potential road transversal structures: **SR-509** and **SP-17** roads.

  Project partner: PNALM.
  Study area: Majella National Park (identified as 'IT PNMajella').
  Target species: **Marsican brown bear**.
  Preselected roads: **SP-487** Caramanico road, two sections of the **SS-5** Tocco da Casauria-Popoli: km 187-182,2 and km 178-176,3, and the **SS-17** Popoli-Roccaraso km 88,5-136,8. Four more roads sections were also selected to broaden the characterization of potential road transversal structures: **BSA**, **FOR**, **SP-54**, and **SP-84** roads.
  Project partner: PNM.

- **Romania**

  Study area: Curbura Carpatilor (SE Carpathians; identified as 'RO Curbura Carpatilor).
  Target species: **Brown bear**.
  Preselected roads: DN1/E68: Comarnic - Brașov (48 km), DN1/E68: Codlea - Perșani (8 km), DN1-A: Cheia – Săcele (30 Km) and DN13/E60: Măieruș – Hoghiz (20 km). Another road section was also selected to broaden the characterization of potential road transversal structures in this area: **DN73** road.
  Project partners: MARIN DRĂCEA.

- **Spain**

  Study area: Doñana National Park and Sierra Morena (identified a ES_Doñana-Sierra Morena).
  Preselected roads: In Doñana A-481, from Chucena-Villamanrique km 11-18, and in Sierra Morena, A 3001 -A3100 and A-421 km Villafranca de Córdoba-Villanueva de Córdoba (A25). In this study area no upgrading of underpasses is planned because such interventions were already implemented in the framework of the LIFE IBERLINCE project. Actions on adaptation of the roadside vegetation management will be undertaken to improve roadside visibility allowing drivers to see animals that are close to the road, and animals to be aware that a vehicle is approaching.

3. Methods and results

The analyses of existing road transversal structures and identification of modifications which allow an increase in the probability of use by target species for crossing roads, have been developed incorporating the steps described below. In order to standardise and unify procedures between the three study areas, each step was facilitated by providing three tools: a Field form, a Database and Guidelines, which that are the results of this Action and are included in the Appendix.

a) **Draft of the '<u>Field form and instructions for characterization of transversal structures'</u> (see <u>Appendix I</u>) to be used in field surveys for inventory of existing transversal structures in each study area.**
A document including a standardized field form to register data relating to road transversal structures as well as instructions to complete it during the field work was developed by Minuartia. The use of these procedures allowed the standardization of methods applied by different partners with regard to vocabulary (e.g. names given to different type of structures, types of fences, etc.), methods to measure the structures and other important factors that needed to be carried out in the same standard way in all the study areas. The document facilitates the analyses of transversal structures -particularly underpasses- with a view to selecting which are the most suitable to be adapted as fauna passages, but also, as a basis for their monitoring, before and after adaptation.
The field form includes all the information required to record important features that have been identified as factors that can affect the use of wildlife crossings and it is based on the experience of the partner on several projects monitoring wildlife crossings on roads and railways. The form was provided to project partners prior to undertaking the inventory of potential underpasses to be upgraded. Each project partner carried out the field surveys on preselected roads in the study areas with the goal of characterizing potential existing transversals structures to be adapted as wildlife passages for target species (particularly Brown bear and Marsican brown bear). Structures under the road (underpasses) were selected as the main type to be adapted.

b) **Creation of the <u>database: 'Transversal structures characterisation' (see Appendix II)</u> including all data recorded in the field from different study areas.**
A database in EXCEL software was developed by Minuartia and provided to all partners. The database includes fields that allowed the recording of all information gathered in the field form. It also facilitates the selection of the structures that have the best conditions to be adapted as wildlife crossings by filtering selected features from the set of structures inventoried in each study area (for example, to select those that fulfil the minimum dimensions requirements, have an absence of barriers at the entrances, and any other feature required).
Each partner completed the standard database, and a resume of their global contents is included in Appendix II).

c) **Draft of '<u>Guidelines to adapt transversal structures and increase use by large carnivores and other wildlife</u>' (see Appendix III) to assist partners with criteria to select structures and define actions to be undertaken in order to adapt as wildlife crossings.**
The document was drafted to provide advice to partners i) to select the best underpasses for adaptation to give target priority species and other wildlife a safe crossing at the road and ii) to identify the features which need to be modified on the structure and at its entrance and surroundings. Guidelines are based on standards provided in specific publications on the topic, Wildlife and Traffic. A European Handbook for Identifying Conflicts and Designing Solutions (Iuell et al., 2003, an output of the COST 341 Action, now being updated by the Infrastructure

and Ecology Network Europe -IENE- coordinated by Minuartia) and the Technical prescriptions for wildlife crossing and fence designs (Second edition, revised and expanded) (Ministerio de Agricultura, Alimentación y Medio Ambiente. 2016; Technical assistance by Carme Rosell, Marc Fernández and Ferran Navàs, Minuartia).

d) **Selection of underpasses to be adapted as wildlife crossings, design and implementation of modifications.**

This step of the Action is undertaken by each partner, who were invited to request complementary advice from Minuartia, if required, to guarantee an appropriate choice of structures to be upgraded and/or define appropriate actions to be undertaken.

Each partner will provide their report for this phase of the Action 4.

4. Conclusions

The present document represents an important basis for guidance to analyse, monitor and manage pre-existing crossing structures in order to improve their use by wild animals, and particularly the target species. It includes three different tools:

1) a description of the best approach to characterize the crossing structures, specifically describing the main parameters to be analysed and how they have to be measured

2) the database to store and analyse the data collected in the field

3) the main management interventions to be applied according to the characteristics of the different crossing structures.

Setting up a standard approach is important to allow a comparison of are the effectiveness of actions implemented in the different countries, and in diverse local conditions. The tools developed can be used also after the project and they have great transferability potential being useful in other regions or countries, as well as in projects targeting a wide range of target species.

The guidelines for the adaptation of the crossing structures will be updated during project development, also on the basis of the results of management activities developed in Action C2, the lessons learned and new best practices developed during the work. The guidelines are an important technical support for monitoring and management of road transversal structures and will be shared with local management bodies, such as road management authorities, protected areas staff, territorial administrations, researchers and other stakeholders, who often don’t have specific knowledge on how to intervene to increase ecological connectivity across roads and mitigate the problem of animal vehicle collisions.

As explained in the introduction, the results of the specific conservation actions and the monitoring of their effectiveness (Action C2 and D1) is also preparatory in developing the guidelines foreseen in Action E7.

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Appendix

I. **Field form and instructions for characterisation of transversal structures**
II. **Data Base contents: 'Transversal structure characterisation'**
III. **Guidelines to adapt transversal structures and increase use by large carnivores and other wildlife**

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PREVENTING ANIMAL-VEHICLE COLLISIONS - ACTION A4

I. Field form and instructions for characterisation of transversal structures

Date: February 2019

Responsible partner: MINUARTIA

This document contains the field form for registering data of road's transversal structures and instructions about how to fulfil it the field. Additionally, an excel file and field form model to be printed and used in the field are provided.

This information will allow to standardise the data registering. It will also provide the basis for future analyses and decision-making about which are the best structures to be adapted for encouraging its use by target species.

Identification and location of the structure	STRUCTURE CODE:	(TYPE_RoadCode_PK) ex: MUP_A2_55+100
Road code: ex: A2	**PK:** (kilometre point; 000+000) ex: 55+100	
Road stretch: (town to town) ex: *Brasov-Comarnic*	**Coordinates (X,Y):** (If GPS location is not provided)	

Main structural features

Type of non-wildlife crossing structures (With NO particular adaptations for wildlife)	**Type of Wildlife crossing** (Specific for wildlife or adapted to allow fauna use)
☐ Tunnel (TUN) ☐ Overpass (OVP) ☐ Viaduct (VIA) ☐ Underpass (UNP) ☐ Culvert / drainage (CUV) ☐ Other: ____________	☐ Ecoduct (ECO) ☐ Wildlife Overpass (WOP) ☐ Multi-use Overpass (MOP) ☐ Wildlife Underpass (WUP) ☐ Multi-use Underpass (MUP) ☐ Modified culvert (WCU) ☐ Amphibian tunnel (ATP)

Road transversal section:
☐ Flat ☐ Embankment ☐ Cutting ☐ Slopes combination

Structure section:	**Composition of the structure:**
☐ Circular ☐ Rectangular ☐ Vault ☐ Other: ______	☐ Simple ☐ Double ☐ Triple ☐ Other: ______

Visibility of opposite entrance: ☐ 0% ☐ 25% ☐ 50% ☐ 100%

Dimensions (m):
Height (H): Width (W): Length (L): Openness Index (Section/L):

Multicellular
Height (H): Width (W=W1+W2): Length (L): Openness Index (Section/L):

Construction material:
Structure ☐ Concrete ☐ Corrugated steel ☐ Other: ____________
Substratum material ☐ Concrete ☐ Corrugated steel ☐ Natural substratum (%): ______ ☐ Other: ______

Presence of water:
☐ No ☐ Yes, permanent ☐ Yes, temporal Water layer depth (cm): ______ Surface covered by water (%): ______

Dry ledges:
☐ One side Material: ________ Width (m): ________
☐ Both sides Material: ________ $Width_1$ (m): ________ $Width_2$ (m): ________

Uses of the passages:
☐ Cattle trail ☐ Pedestrian trail ☐ Forestry road (unpaved) ☐ Paved road
☐ Water channel ☐ Stream crossing ☐ Other: ____________

Other features:

Inspected by:	Date inspection:

	STRUCTURE CODE:	
	Entrance 1 (orientation side; ex: NE:____)	**Entrance 2** (orientation side; ex: SW:____)
Obstacles at the entrances		
Type of obstacle	☐ Stepped exit; num. of steps ___ height (cm): ____ ☐ Stone or concrete ramp; slope (º): __ ☐ Pit ☐ Riprap ☐ Other: ____________________	☐ Stepped exit; num. of steps ___ height (cm): ____ ☐ Stone or concrete ramp; slope (º): __ ☐ Pit ☐ Riprap ☐ Other: ____________________
Vegetation [1]		
Dominant vegetation	☐ Trees ☐ Bushes ☐ Herbaceous	☐ Trees ☐ Bushes ☐ Herbaceous
Representative species		
% vegetation coverage	☐ 0-4 ☐ 5-24 ☐ 25-49 ☐ 50-74 ☐ 75-100	☐ 0-4 ☐ 5-24 ☐ 25-49 ☐ 50-74 ☐ 75-100
Surroundings [2]		
Any activity causing disturbances at the vicinity? ☐ No ☐ Yes (which?): ____________		
Natural Habitat type/ Land use		
Distance to the entrance (m)		
Fences		
Typology	☐ Knotted wire mesh ☐ Absent ☐ Welded wire mesh ☐ Other: __________ ☐ Chain-link wire mesh Height (cm):___ Mesh size (cm):____	☐ Knotted wire mesh ☐ Absent ☐ Welded wire mesh ☐ Other: __________ ☐ Chain-link wire mesh Height (cm):___ Mesh fence (cm):____
Safety barrier	☐ Metal ☐ Wood ☐ B-wave ☐ New Jersey ☐ Other: ________ Height (cm):____	☐ Metal ☐ Wood ☐ B-wave ☐ New Jersey ☐ Other: ________ Height (cm):____
Adjustment to the structure entrances	☐ Yes ☐ No: openings or other	☐ Yes ☐ No: openings or other
Presence of specific adaptations	☐ Base reinforcements ☐ Outrigger ☐ Other: ______________________	☐ Base reinforcements ☐ Outrigger ☐ Other: ______________________
Other features:		
Field photos: (number photo reference)		

[1] Observed at field approximately covering 2-3 m from the crossing structure entrances.

[2] Analysed by GIS (buffer diameter distance according to the mean home range of target species)

STRUCTURE CODE:

Fauna registers during inspection

(Mark the species detected in each location; add the traces observed as: F: Footprint; E: Excrement; D: Direct observation)

Inside the passage	**Outside the passage**	
	Entrance 1 (orientation side:____)	**Entrance 2** (orientation side:____)
☐ Micromammal	☐ Micromammal	☐ Micromammal
☐ Rabbit ☐ Hare	☐ Rabbit ☐ Hare	☐ Rabbit ☐ Hare
☐ Fox ☐ Badger ☐ Marten ☐ Stone marten ☐ Otter ☐ Genet	☐ Fox ☐ Badger ☐ Marten ☐ Stone marten ☐ Otter ☐ Genet	☐ Fox ☐ Badger ☐ Marten ☐ Stone marten ☐ Otter ☐ Genet
☐ Brown bear ☐ European lynx ☐ Iberian lynx ☐ Wolf ☐ Wild cat	☐ Brown bear ☐ European lynx ☐ Iberian lynx ☐ Wolf ☐ Wild cat	☐ Brown bear ☐ European lynx ☐ Iberian lynx ☐ Wolf ☐ Wild cat
☐ Wild boar ☐ Roe deer ☐ Red deer ☐ Fallow deer	☐ Wild boar ☐ Roe deer ☐ Red deer ☐ Fallow deer	☐ Wild boar ☐ Roe deer ☐ Red deer ☐ Fallow deer
☐ Dog ☐ Cat	☐ Dog ☐ Cat	☐ Dog ☐ Cat
☐ Other: ____________	☐ Other: ____________	☐ Other: ____________

Type of wildlife crossing

[Source Smith, DJ. van der Ree, R. & Rosell, C. 2015. Wildlife crossing structures: an effective strategy to restore or maintain wildlife connectivity across roads. In: Handbook of Road Ecology (Van der Ree, R. Smith D.J. & Grilo, C. eds. John Wiley & Sons, Oxford.): 172-183]

Overpasses

Ecoduct (ECO)

Large overpass, usually > 50 m wide (min. recommended width in Europe 80 m), where habitats are continuous across the road. Due to their width, a diversity of habitat types (e.g. vegetation or soil types) can be included.

The main difference with wildlife overpasses is width and vegetation cover, however the terms are often used interchangeably.

Wildlife overpass (WOP)

Constructed above roads, specifically to provide connectivity for wildlife.

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

Landscape bridges and wildlife overpasses usually include fencing to funnel animals towards the structures.

Multi-use overpass (MOP)

Crossing structure above the road with multiple functions or goals, including the movement of wildlife. Other uses include farm or forestry access, cattle passage and recreational use. These overpasses may include modifications, such as addition of cover, to encourage use by wildlife.

Underpasses

Viaduct (VIA)

A long and often high bridge, typically supported on pillars, which carries a road or railway over a river or valley.

The landscape below these structures can be designed to conserve or maintain continuous riparian and aquatic habitats, thereby facilitating wildlife movement.

Usually combined with fencing.

Wildlife underpass (WUP)

Structure constructed below a road or railroad designed specifically to provide a safe crossing point for wildlife. Depending on underpass size, it can be used by small to large animals. Underpass types are predominantly bridges and box/pipe structures.

Usually combined with fencing.

Multi-use underpass (MUP)

Crossing structure under the road with multiple functions or goals, including the movement of wildlife. Other uses include drainage, farm or forestry access, cattle passages and recreational use. These underpasses may include modifications, such as fencing or addition of cover, to encourage use by wildlife.

Modified culvert (WCU)

Modified pipe or box culvert that allows a watercourse and/or drainage to flow underneath the infrastructure.

Modifications for use by wildlife often include dry ledges or shelves to provide dry passage, which are connected to adjacent habitat (Fig. 39.3).

The design and landscaping at the entrances must consider the needs of wildlife, not just erosion control.

Amphibian tunnels (ATP)

Often installed just below the road surface, these small pipes or purpose-built tunnels are specifically for the movement of amphibians. Often consisting of multiple tunnels in close proximity to each other, they require effective opaque fencing to intercept the amphibians and funnel them to the crossing structure.

Measuring crossing structures

[MAGRAMA. 2016. Technical prescriptions for wildlife crossing and fence design (2nd edition)] / MINUARTIA

H = Height

W = Width (the diameter for circular structures)

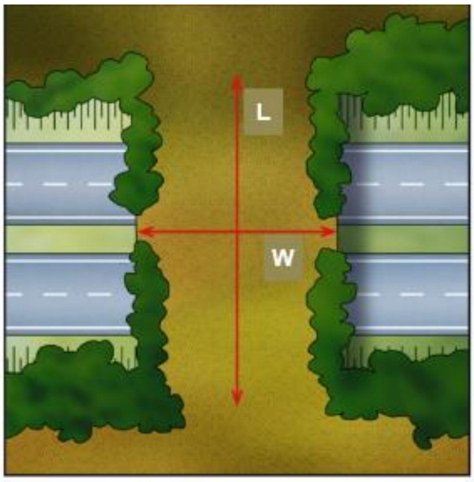
L = Length

S = Section

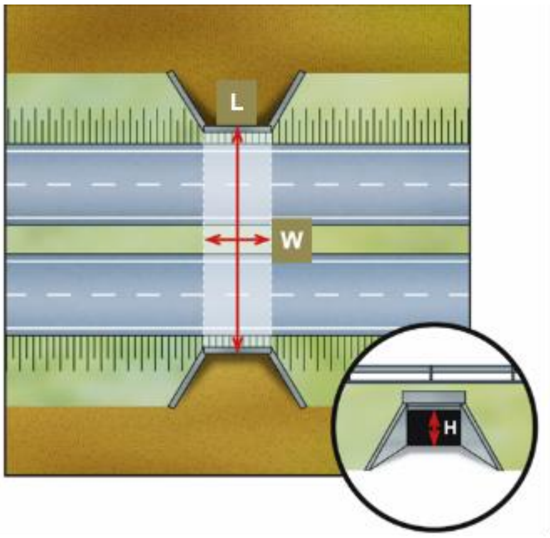
OI = Openness Index = Section / Length

Simple structures

Overpasses



Underpasses



Rectangular

$OI = S/L = (H \cdot W)/L$

Circular

$OI = S/L = (\pi \cdot (W/2)^2)/L$

Vault

$OI = S/L = ((\pi \cdot (W/2)*2)/2)/L$

Multicellular structures

Width (W) = $(W_1 + W_2 + W_n)$

$OI = S/L = (H \cdot W_{min.})/L$

Obstacles at the entrances

Stepped exit

Pit

Small wall

Stones/Riprap

Safety barrier

Metal b-wave

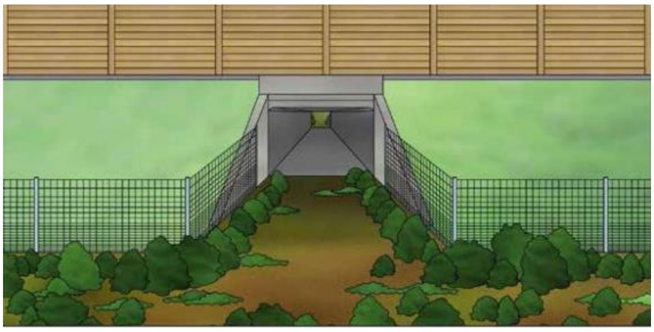
Wood

New Jersey

Fencing and mesh typologies

Example of proper adjustment of the fence to the structure entrance

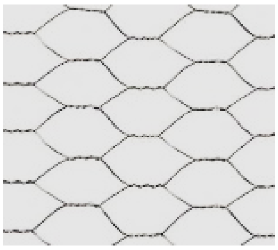
[MAGRAMA. 2016. Technical prescriptions for wildlife crossing and fence design (2nd edition)]



Knotted wire mesh

Chair-link wire mesh

Hexagonal wire mesh



Welded wire mesh

Reinforcement

Outrigger

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II. Database 'Transversal structure characterisation'

Date: December 2019

Responsible partner: MINUARTIA

II. Database 'Transversal structure characterisation'

Resume of data base contents

The inventory of transversal structures was undertaken in several preselected road sections at each study area. The goal was to characterize potential existing transversals structures to be adapted as wildlife passages for target species (particularly Brown bear and Wolf) to cross roads. Structures under the road (underpasses) were selected as the main type of structures to be adapted.

Each partner located the existing transversal structures in the preselected road sections and undertook the field work to characterize them. Main structural and landscape features were registered on the field using a **standardised field form and associated instructions** (Appendix I) and information was gathered in a common **Database in EXCEL format, provided to all partners**.

A total of **379 transversal structures** have been characterized and included in the database (see Table 1):

- 360 underpasses (95%)
- 19 overpasses (5%): 12 constructed at the A29 Egnatia Highway in Kastoria-Fiorina area, and 7 at SS17 road in the Majella National Park. Nevertheless, only underpasses were to be adapted.
- Registers of other road structures (e.g. junctions) or register without data information associated were excluded from the analysis of the data base (6 cases).

376 structures were not constructed or adapted to be used by wildlife and their functions are drainage, river crossing, roads or forestry roads crossing, etc. Three other structures, all of them at A29 Egnatia Highway, are fauna passages, as they were adapted to allow the crossing of wildlife:

- 1 Multi-use overpass
- 1 Multi-use underpass
- 1 Adapted culvert

Several structures are planned to be monitored and the results may be also included in the database.

Related to dimensions of the structures (see Table 2) and considering the recommendation of the European Handbook 'Wildlife and Traffic'.

From the total data from inventory, width or diameter dimensions data from 371 transversal structures have been provided.

- Only 29 structures are more than 15 m width which is the minimum recommended for a wildlife overpass to be used by large mammals.
- 47 structures have a width between 7 and 15 m, under the recommended width but still in a range that is being used by some ungulates such as wild boar.
- 295 structure have less than 7 m width, which means that are should not be considered suitable to be adapted as Brown bear crossing, except in particular cases such that bear is already using them or that are located in singular points with a strategic interest for ecological connectivity.

Table 1. Number and type of transversal structures characterized along roads on each study area. Wildlife crossing structures are identified with the symbol *. Other transversal structures were not particularly constructed or adapted to facilitate the crossing of wildlife even they can also be used by some species.

Roads	Type of transversal structure [1]									
	Overpasses			Underpasses						Total
	MOP *	OVP	Total	MUP *	WCU *	VIA	UNP	CUV	Total	
GR Kastoria-Florina	**1**	**11**	**12**	**1**	**1**	**7**	**27**	**97**	**133**	**145**
A29	1	11	**12**	1	1	7	27	97	133	145
IT PNALM			**0**					**22**	**22**	**22**
SP17								4	4	4
SR509								11	11	11
SS83								7	7	7
IT PNM		**7**	**7**			**13**	**59**	**7**	**79**	**86**
BSA							2		2	2
FOR						1	13		14	14
SP54							4		4	4
SP84							8	1	9	9
SS17		7	7			8	3		11	18
SS487						4	24	6	34	34
SUL							5		5	5
RO Marin Dracea			**0**			**123**	**1**	**2**	**126**	**126**
DN 1 A						23	1	1	25	25
DN1						7		1	8	8
DN73						6			6	6
E 60						68			68	68
E68						19			19	19
Total	**1**	**18**	**19**	**1**	**1**	**143**	**87**	**128**	**360**	**379**

[1] **MOP**: Multi-use Overpass; **OVP**: Overpass; **MUP**: Multi-use Underpass; **WCU**: Modified culvert; **VIA**: Viaduct; **UNP:** Underpass; **CUV**: Culvert/drainage.

Table 2. Mean width, standard deviation (SD) and range (min-max) of existing transversal structures characterized in roads of the study areas. N=371 (in 10 cases from the total of structures inventoried width was not registered).

Type of transversal structure	**Width (W) [1]**		**Number of transversal structures per width category [2]**				**Total**
	Mean ± SD (m)	**Range (m)**	**W < 2**	**2 ≤ W < 7**	**7 ≤ W < 15**	**W ≥ 15**	
GR Kastoria-Florina	**5,80 ± 13,88**	**0,80 - 125,00**	**9**	**107**	**19**	**7**	**142**
Multi-use Overpass	8,00	8,00 - 8,00			1		1
Overpass	8,59 ± 2,69	6,00 -15,00		3	7	1	11
Viaduct	56,83 ± 44,69	16,00 -125,00				6	6
Multi-use Underpass	4,00	4,00 - 4,00		1			1
Modified culvert	4,00	4,00 - 4,00		1			1
Underpass	6,00 ± 3,10	2,00 -12,00		16	11		27
Culvert/drainage	2,22 ± 0,74	0,80 - 6,00	9	86			95
IT PNALM	**1,50 ± 0,73**	**0,93 - 3,00**	**15**	**7**	**0**	**0**	**22**
Culvert/drainage	1,50 ± 0,73	0,93 - 3,00	15	7			22
IT PNM	**32,64 ± 103,82**	**0,70 - 830,00**	**29**	**32**	**8**	**15**	**84**
Overpass	226,29 ± 2,75,92	46,00 - 830,00				7	7
Viaduct	81,08 ± 89,96	4,00 - 240,00		1	4	7	12
Underpass	3,04 ± 2,73	0,80 - 16,00	23	31	4	1	59
Culvert/drainage	0,98 ± 0,29	0,70 -1,50	6				6
RO Marin Dracea	**21,28 ± 179,36**	**0,22 - 1992,00**	**24**	**72**	**20**	**7**	**123**
Viaduct	20,92 ± 181,50	0,22 - 1992,00	23 [3]	72	20	5	120
Underpass	16,50	16,50 -16,50				1	1
Culvert/drainage	45,20 ± 61,10	1,99 - 88,40	1			1	2
Total	**16,76 ± 114,99**	**0,22 - 1992,00**	**77**	**218**	**47**	**29**	**371**

[1] Values estimated using the minimum width measure. From the total of 379 transversal structures characterized, only a total of 371 included Information of dimensions (width).
[2] Dimensions grouped according to the minimum width size recommended for the different target fauna groups (see MAGRAMA 2016; **¡Error! No se encuentra el origen de la referencia.**).
[3] Type of structure should be reviewed as viaducts usually have large width, more than 2 m.

LIFE SAFE-CROSSING

PREVENTING ANIMAL-VEHICLE COLLISIONS - ACTION A4

III. Guidelines to adapt transversal structures and increase use by large carnivores and other wildlife

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Responsible partner: MINUARTIA

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The information provided is based in the following publications, co-authored by members of the Minuartia team, as well as their own experience on the topic.

Iuell, B., Bekker, G.J., Cuperus, R., Dufek, J., Fry, G., Hick, C., Hlavác, H., Keller, V., Rosell, C., Sangwine, T. Torslov, N. & Wandall, B. 2003. COST 341. Wildlife and Traffic. A European Handbook for Identifying Conflicts and Designing Solutions. KNNV Publishers. At present under adaptation by IENE (Infrastructure and Ecology Network Europe) 'Handbook Working Group'.

Ministerio de Agricultura, Alimentación y Medio Ambiente. 2016. Technical prescriptions for wildlife crossing and fence designs (Second edition, revised and expanded). Documents for mitigation of habitat fragmentation due to transportation infrastructures, No. 1. Ministry of Agriculture, Food and Environment. Updated version. Technical assistance by Carme Rosell, Marc Fernán0dez and Ferran Navàs). pp 258.

III. Guidelines to adapt transversal structures and increase use by large carnivores and other wildlife

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1. Introduction

Large carnivore distribution area in Europe is severely fragmented by existing linear transportation infrastructure. Defragmentation actions can be undertaken to restore ecological connectivity allowing bears, lynxes and other carnivore to safely cross roads and railways using appropriate structures over on under the infrastructure.

Tunnels and viaducts play a major role on maintaining ecological corridors across transportation infrastructure. Additionally, fauna passages (also called 'wildlife crossings') are key elements of the European Green Infrastructure helping to maintain or to restore ecological connectivity and movements of large carnivore across the landscape.

Modifying existing transversal structures which primary function is drainage or rivers crossing, forestry roads, cattle ways or pedestrian paths, to be used by wildlife allow them to be qualified as wildlife crossings. Three types of wildlife passages in the case of structures under the road: 'modified viaducts', 'multiuse underpasses' and 'modified culverts' (see Files 5, 7 and 9; Additional information).

To enhance underpasses to be used by target species is one of the main actions of the LIFE Safe-Crossing project. With this goal, the works undertaken in the frameworks of Action A4 have been:

- To **perform field surveys** for inventory of existing transversal structures on selected road sections, according to a standardise form provided (Document I)
- To **create a unified databased** including the information registered in the field (Document II).
- To **select structures to be adapted as wildlife crossing** considering the information provided in the present document but also on Action A3 based on analysis of animal-vehicle collisions (AVC) hotspots and movement of target species based on telemetry data of monitored individuals.
- To **identify actions required in each structure** to enhance the probability to be used by large carnivore.

Within this framework the goal of this document is to provide criteria and guidelines to select the structures to be adapted as wildlife crossings and to provide instructions for developing the actions to be undertaken. The information will be used to develop Action C2, which includes works to be undertaken on selected structures to enhance wildlife use of underpasses. The document is also the base for drafting a chapter on the final 'Guidelines for monitoring and management of road kills and mitigation measures to reduce this conflict' to be produced in the framework of Action E7.

Main target species considered in this document is Brown bear even if the adaptation of underpasses as wildlife crossing will also benefit other carnivore, ungulates and many other species. These actions will also benefit humans as they will improve traffic safety by reducing risk to collide with large animals.

Lack of previous experiences in Europe modifying existing underpasses to be used by large carnivore has required to adapt the existing guidelines for designing fauna passages, and particularly the European Handbook 'Wildlife and Traffic' (Iuell et al 2003; now being adapted by Infra Eco Network Europe Working Group). Information obtained along the development of the Life Safe Crossing project will allow to increase the knowledge on the topic and provide key information to enhance guidelines to be applied at European level.

2. Selection of transversal structures to be upgraded

2.1 Looking for best Cost/Benefit balance

To identify which structures can provide best cost/benefit ratio is a crucial step in the selection of the structures to be upgraded. This is due to the limited resources that can be invested on actions to improve use of underpasses by wildlife.

Such goal is not easy to be achieved. While cost (budget invested) per each structure adaptation can be calculated with accuracy, benefit for large carnivore populations may not be easy to evaluate. Several indicators could be provided to measure benefits:

- Number of target species crossing each structure per time unit; Minimum number of different individuals per target species using each structure. These data may be provided by monitoring the structures with camera or video devices. Even these variables do not really evaluate the positive impact of crossings enhancing long term viability of large carnivore population they could be considered a good 'proxy' to this effect.
- Reduction of large carnivore mortality in the road section.
- Animal-vehicle collisions in the road section.

At each study area these indicators could be provided Before and After undertaking the adaptations.

Experts from each area could provide also new proposals of indicators for measuring the benefits. Ideally, a genetic approach would be needed to measure the benefits of the actions in terms of genetic variability and consequently, long term population conservation.

2.2 Type of structures to be focused on

The type of infrastructures considered to be upgraded in the framework of the project are underpasses: structures constructed under roads and railways with different purposes. The types to be considered are:

Viaduct (VIA)
Underpass (UNP): they can be upgraded to be a Multi-use underpass (MUP)
Culvert/drainage (CUV): they can be upgraded to be a Modified culvert (WCU)

Wildlife crossings (specifically constructed for wildlife or multifunctional: wildlife and other uses)

Wildlife underpass (WUP)
Multi-use underpass (MUP)
Modified culvert (WCU)

Main features of wildlife crossings under roads and railways are described in Table 1. The terminology and definitions provided are based on the standard terminology appeared in specialised publications on the topic: Chapter 21 in the *Handbook of Road Ecology* (Smith, DJ. et. al 2015); *Technical prescriptions for wildlife crossing and fence design (2nd edition)* (MAGRAMA. 2016) and Chapter 7 *Wildlife and Traffic* (Iuell et al 2003).

Table 1. Description of wildlife crossings typologies under transportation infrastructure.

Type of wildlife crossing	Description
Underpasses	
Viaduct (VIA)	A long and often high bridge, typically supported on pillars, which carries a road or railway over a river or valley. The landscape below these structures can be designed to conserve or maintain continuous riparian and aquatic habitats, thereby facilitating wildlife movement. Usually combined with road perimeter fencing of the infrastructure that funnel the animals to the viaduct. Remark that not all viaducts could be qualified as wildlife crossings. Some of them are constructed to allow the passage of highways, paved roads, etc. and are not suitable for wildlife.
Wildlife underpass (WUP)	Structure constructed below a road or railroad designed specifically to provide a safe crossing point for wildlife. Depending on underpass size, it can be used by small to large animals. Underpass could be bridges, boxes or other constructive types. Usually combined with road perimeter fencing of the infrastructure that funnel the animals to the viaduct.
Multi-use underpass (MUP)	Crossing structure under the road with multiple functions or goals, including the movement of wildlife. Other uses include drainage, farm or forestry access, cattle ways or recreational use. These underpasses may include modifications to enhance the use by wildlife such as fencing to funnel the animals to the entrances, adaptation of the vegetation at the entrances, measures to avoid that water completely cover the surface, etc.
Modified culvert (WCU)	Modified pipe or box culvert that allows a watercourse and/or drainage to flow underneath the infrastructure. Modifications for use by wildlife often include dry ledges or shelves to provide dry passage, which are connected to adjacent habitat. The design and landscaping at the entrances must consider the needs of wildlife, not just erosion control.

2.3 Criteria to be applied in the selection process

Factors to be evaluated for choosing best existing transversal structures to be adapted as wildlife crossings, and particularly to be used by Brown bear are related to:

I. Location: attributes related to landscape and road section

II. Uses of the structure

III. Dimensions of the structure

The selection criteria to be considered are listed below. Each partner could use the list of criteria provided to check in the database of inventoried structures, which fit more as potential candidates to be upgraded. The expert and local knowledge could also be a valuable complement in the selection process.

Location

Several features related to structures location are important to be evaluated in order to prioritise which are the best candidates to be adapted.

Criteria that structures prioritised to be adapted as wildlife crossings should accomplish are also provided.

a) Land use, habitat type and ecological connectivity

Structures that should be prioritised to be adapted as wildlife crossings are those:

- Located in areas with habitat uses selected by target species.
- Located on areas identified as ecological corridors or areas of particular interest for ecological connectivity.
- Absence of human disturbances: buildings, illuminated areas, fenced grounds or any activities that can cause disturbances to wildlife.

b) Road sections with high frequency of Animal-Vehicle Collisions (AVC)

Structures that should be prioritised to be adapted as wildlife crossings are those:

- Located in or nearby road sections where AVC clusters were identified in the analyse undertaken in Action A3. Both types of significant AVC clusters 'low sureness' (group 2) and 'high sureness' (group 3) could be considered as road sections where existing transversal structures could be adapted to enhance use by wildlife.

c) Road sections with high frequency of crossing points

Structures that should be prioritised to be adapted as wildlife crossings are those:

- Located in areas intensively used by Brown bear close to roads where crossing points hotspots were identified in the analyse undertaken in Action A3. If there are already big structures such of tunnels or great viaducts, the adaptation of other transversal structures may not be needed on those sections.

Uses

While some uses at fauna passages can be compatible with wildlife crossing (e.g. livestock, pedestrian, cycle, forestry track and drainage), other ones can compromise it (e.g. heavy traffic flow, sleeping places for humans, storage for agricultural machinery, etc.).

To prioritize the adaptation of underpasses constructed for:

- Drainage: particularly river crossings or small water streams
- Cattle trails
- Pedestrian trails
- Forestry unpaved roads

Paved roads, particularly those with medium or high traffic intensity should not be adapted as wildlife crossings.

Dimensions

To modify the dimensions of transversal structures once they are built requires costly investments. Therefore, dimensions should be one of the criteria to select transversal structures to be adapted. References on Brown bear preferences for wildlife crossing dimensions are scarce. A large width over 15 m is recommended for large mammals, including brown bear (Iluell et al. 2003). So, it is recommended to prioritise the adaptation of Width ≥ 15 m; Height ≥ 3,5 m; Openness index (section/length) ≥ 0,75

Nevertheless, in several monitoring studies it has been recorded the use of smaller structures by this species (unpublished data from Fundación Oso Pardo and Egnatia Odos). So, structures under recommended dimensions could in exceptional cases, be upgraded trying to enhance wildlife crossing.

Large underpasses adapted according to dimension's requirements for Brown bear will also benefit other smaller carnivores and other mammal species.

A resume of criteria to be applied for the selection of the existing transversal structures to be adapted is provided in the following boxes.

Selection criteria: structures to be adapted to enhance Brown bear crossing frequency

I. Related to LOCATION FEATURES

	Structures to be prioritised
Surrounding habitats	✓ High quality habitat for target species in the surroundings ✓ Located in areas of interest for ecological connectivity ✓ Absence of human disturbances close to the entrances
Mortality of target species	✓ Located in road sections where AVC clusters are identified. (sections with high frequency of AVC and high large carnivore mortality) Analyses undertaken in Action A3
Presence of target species (where information provided by telemetry is available)	✓ Located in areas used by target species close to roads. Analyses undertaken in Action A3 Where both sides of the road are used by target species but no road casualties are observed, a detailed inspection of the area should be undertaken to establish if 1) there is already an structure such as a tunnel, viaduct or other, providing crossing opportunities (no need to undertake mitigation measures or 2) there are no such a big structure; in this case, the adaptation of an existing transversal structure could benefit the viability of the population.

II. Related to the USES to be combined with wildlife use

	Structures to be prioritised
Uses (primordial functions of the structures)	✓ Drainage: particularly river crossings or small water streams ✓ Cattle trails ✓ Pedestrian trails ✓ Forestry unpaved roads Paved roads, particularly those with medium or high traffic intensity should not be adapted as wildlife crossings

III. Related to structure DIMENSIONS

	Structures to be prioritised
Width; Openness index	✓ Width ≥ 15 m; Height ≥ 3,5 m; Openness index ≥ 0,75 Structures that do not accomplish these minimum dimensions (standards provided in the European handbook), could in exceptional cases, be upgraded trying to enhance wildlife crossing. This is because monitoring has shown that structures with smaller sizes are also used by Brown bear, probably because they are located in strategical location for connectivity.

3. Actions to be undertaken to upgrade transversal structures

3.1 Identification of features to be modified

Once identified which structures are candidate to be upgraded (see section 2), next steps are to evaluate which actions need to be undertaken and estimate costs. The recommended procedure is:

I) To analyse which are the ideal characteristics of the three types of wildlife crossing under the roads, which are included on the files of Additional information:

Viaduct (VIA) > File 5
Wildlife underpass (WUP) - Large mammals > File 6
Multi-use underpass (MUP) > File 7
Modified culvert (WCU) > File 9

As actions to be undertaken should be based on target species requirements, it is also recommended to consider Files 24 and 25 (see Additional information) including recommendations for Brown bear and for Iberian lynx.

II) To compare the features of the potential structures to be adapted (included in the Database) with the instructions provided in the files. The characterization of structural and surrounding variables of the transversal structures (see Table 2, Document I and Document II), helps to evaluate which are the features to be modified to enhance the use by target species. For already built transversal structures, there are features which are hardly feasible to be modified (or at least not at the best cost/benefit ratio, e.g. dimensions), but there are other ones with can be adapted.

Features of the structures and related elements which could be modified with moderate costs are the following:

- Structural features related to the presence of substratum and water at underpasses.
- Human disturbances and compatible uses with fauna passages
- Obstacles at the entrances
- Vegetation
- Fencing

In the next sections factors to be evaluated for each feature are explained.

Monitoring before-after the application of the measures will provide information on the resulting effectiveness of the adaptations undertaken. If non-effectivity or issues are detected, improvements and changes could be planned to ensure proper functionality of the transversal structures as fauna passages.

It is important to remark that to ensure long term effectivity of the adaptations regular maintenance is required.

Table 2. Main features of the inventory of the crossing structures characterized on the field surveys.

Type of variable	Variables
Identification and location of the structure	Structure code
	Road code
	Road stretch
	PK (0+000)
	Coordinates UTM X
	Coordinates UTM Y
Main structural features	Type of crossing structure: Tunnel; Overpass; Viaduct; Underpass; Culvert/drainage; Ecoduct; Wildlife Overpass, Multi-use Overpass; Wildlife Underpass; Multi-use Underpass; Modified culvert; Amphibian tunnel.
	Acronym type of crossing structure: TUN; OVP; VIA; UNP; CUV; ECO; WOP; MOP; WUP; MUP; WCU, ATP.
	Road transversal section: Flat; Embankment; Cutting; Slopes combination
	Structure section: Circular; Rectangular; Vault; Not applicable
	Composition of the structure: Simple; Double; Triple; Other
	Visibility of opposite entrance (%): 0; 25; 50; 100
	Height (m)
	Diameter (m)
	Width (m)
	Minimum width (m)
	Section
	Length (m)
	Openness index
	Relation Width/Length
	Structure construction material: Concrete; Corrugated steel
	Substratum material: Concrete; Corrugated steel; Natural substratum
	Natural substratum (%)
	Presence of water: No; Yes, temporal; Yes; permanent
	Water layer depth (cm)
	Surface covered by water (%)
	Dry ledges: Material and width
	Uses of the passages: Cattle trail; Pedestrian trail; Forestry road (unpaved); Paved road; Water channel; Stream crossing; Other.

[1] e1: entrance 1; e2: entrance 2 is used to describe features for each side of the structure.

Table 2 (Cont.) Main features of the inventory of the crossing structures characterized on the field surveys.

Type of variable	Variables
Obstacles at the entrances	Entrance orientation (e1/e2)[1]: N; NE; NW; S; SE; SO; E; W
	Type of obstacle (e1/e2): Stepped exit; Stone or concrete ramp; Pit; Riprap; Other
	Number of steps (e1/e2)
	Step height (e1/e2) (cm)
	Ramp slope (e1/e2) (º)
Vegetation	Dominant vegetation (e1/e2): Trees; Bushes; Herbaceous; Absent
	Representative species (e1/e2)
	Vegetation coverage (e1/e2) (%): 0-4; 5-25; 25-49; 50-75; 75-100
Surroundings	Activity disturbances at the vicinity: No; Yes (which)
	Natural Habitat type/Land use (e1/e2)
	Distance to the entrance (e1/e2) (m)
Fences	Type of fences (e1/e2): Knotted wire mesh; Welded wire mesh; Other; Absent
	Height fence (e1/e2) (cm)
	Width chain-link fence (e1/e2) (cm)
	Safety barrier (e1/e2): Metal; Wood; B-wave; New Jersey; Other; Absent
	Height safety barrier (e1/e2) (cm)
	Adjustment (e1/e2): No (openings or other); Yes; Not applicable
	Specific adaptation (e1/e2): Base reinforcements; Outrigger; Other
Other features and observations	Observations
	Inspected by
	Date inspection
	Field photos

[1] e1: entrance 1; e2: entrance 2 is used to describe features for each side of the structure.

3.2 Structural features

For more details, see Files 7, 9, 12 (Additional information) and Chapters 7.3.1-7.3.3 and 7.3.5 in Wildlife & Traffic (Iuell et al. 2003)

a) Substratum

The standard recommendation to enhance wildlife crossing through underpasses in relation to the inner surface is to provide fauna passages with dried, natural substratum surface. Concrete is also suitable although less recommended. Corrugated steel must be avoided.

Main surface adaptations are:

→ To provide the underpass with natural substratum covering the whole inner surface and entrances areas to connect the structure with the surrounding natural environment.

→ If corrugated steel is present at the bottom of the underpass/culvert, create a flat base by covering the surface with a concrete stripe together with natural substratum coverage.

→ To install piles or rows of stones and logs along the viaduct or underpasses is useful to provide refuges for small fauna and encourage the use of the structure.

b) Dry ledges

Transversal structure surface should not be completely covered by permanent water sheet, neither for long periods during the seasonal flooding. Dry ledges are not recommended to enhance the use of underpasses by Brown bear but are useful to improve the use by other carnivores.

Main water drainage adaptations are:

→ To construct a ditch to guide the water along the underpass and ensure a proper drainage if the presence of water is permanent or very frequent. It is possible to excavate the land at the lateral site/s of the structure surface to create large dried sections to be used by wildlife (see Figure 1).

→ To consider the installation of wood ledges or the construction of concrete ones to enhance Lynx (European and Iberian lynx) crossing. Many other small and medium carnivores (all species of Mustelidae, Foxes and Genets particularly) use dry ledges for crossing.

Figure 1. Drainage conduction using a ditch along on site of the underpass offers a large dry surface to be used by wildlife. Installation of opaque screens help on reducing traffic disturbances from the road or railway line above the underpass. Source: MAGRAMA 2016.

3.3 Compatible uses with fauna passages

For more details, see also File 7 (Additional information) and Chapter 7.3.3 in Wildlife & Traffic (Iuell et al. 2003)

Human activity disturbances close or at the underpasses should be avoided or minimised. Main disturbances are caused by vehicle traffic, light and noise, but also other perturbations can deter wildlife use of the transversal structure.

Common disturbances detected at fauna passages and actions to reduce them are:

a) Traffic

→ If combined with low traffic, the central surface may be paved or covered with gravel, but lateral strips of natural soil must be adapted for wildlife use (provide a 2 m wide unpaved strip at least one side of the underpass).

→ In wildlife underpasses specific for wildlife use, install large stone blocks at the entrances of large underpasses or beneath viaducts to prevent vehicles from accessing and/or crossing those structures specifically adapted for animals.

b) Noise and light

→ To install opaque screens to reduce disturbances by vehicles (light and noise) of road traffic above the underpass. Install them (height ≥ 2 m) at the top of the structure on both sites of the underpass entrances, ensuring complete continuity with fences (see Figure 1).

→ To undertake regular inspections to detect and repair defects on screens (holes, incorrect adjustment with fences or damages). To avoid vandalism, screens should be made of durable materials (e.g. treated timber, stained concrete or metal).

c) Other human activity disturbances

→ To remove any inappropriate material and prevent any inadequate use such as storage of agriculture machinery, to stable cattle, human sleeping places, installation of landowners fencings, and other that are often located in underpasses.

3.4 Obstacles at the entrances

For more details, see also Files 6, 7, 9 and 12 (Additional information)

To ensure the use of transversal structures, it is essential to avoid and remove obstacles that hinder the access of wildlife.

Obstacles detected at the entrances and actions to reduce their barrier effect are:

a) Steps or undercuts

→ To replace steps by ramps. Stone bed ramps are recommended to prevents future water erosion degradation (e.g. culverts with frequent running water). Ramp slope: < 45º (see Figure 2).

b) Wall or concrete steep ramp

→ To replace wall by ramps, or correct inclination by providing ramps with less slope (< 45º). Stone bed ramps are recommended to prevents future water erosion degradation.

c) Pit

→ To cover drainage pits with elements to allow that fauna can cross it such as a slab of concrete.

d) Debris obstruction

→ To remove plant debris and rocks accumulation; restore the access once cleared if needed.

→ Check if grids, rods or other element contribute to debris accumulation. Evaluate if it is possible to readjust or replace the element with a more effective design.


Figure 2. Eroded exit of a drainage. It is usual that culvert accesses degrade due to water erosion of natural substrate creating steps or significant height difference between the concrete base of the transversal structure with the adjacent land. Continuity could be restored by construction stone bed ramps at the exists of culverts. Photos: MINUARTIA.

3.5 Vegetation

For more details, see also Files 5, 6, 7, 9 and 12 (Additional information)

To enhance the use of the wildlife crossings, entrances and surroundings must also be adapted. Revegetation is essential for funnelling animals towards crossing structures by connecting the surrounding habitats with the entrances of the underpasses. This is commonly combined with the installation of fences adjusted to the entrances of transversal structures (see Figure 3 and section 3.6).

Main recommendations related to revegetation are:

a) Vegetation at the entrances

- → To plant vegetation in hedgerow-like strips parallel to and outside the perimeter fence to guide animals into the structure entrances and to provide shelter and protection from traffic noise and lights (Figure 3)
- → To plant vegetation right next to the entrances, plant the vegetation perpendicularly to the infrastructure.
- → To undergo regular inspections and restore when needed to ensure a proper integration of vegetation with the surrounding habitats and to guarantee that no overgrown vegetation prevent animals from accessing the underpass.

b) Vegetation along the structure

- → If riparian vegetation along watercourses is present beneath a viaduct, to preserve or restore it to maintain the connectivity.
- → Revegetation inside long multi-use underpasses or modified culverts are usually not possible due to conditions unsuitable for the vegetation growth and particularly due to darkness or lack of humidity.

c) Species composition

- → To plant local species, selecting those adapted to conditions in the surroundings of the structures and with low maintenance requirements.
- → To plant species with edible fruits attractive to bears or other species.
- → To undertake regular mowing and pruning of the vegetation to maintain the composition design and prevent the vegetation form overgrowing to avoid hindering wildlife use of the transversal structure or damaging fences).

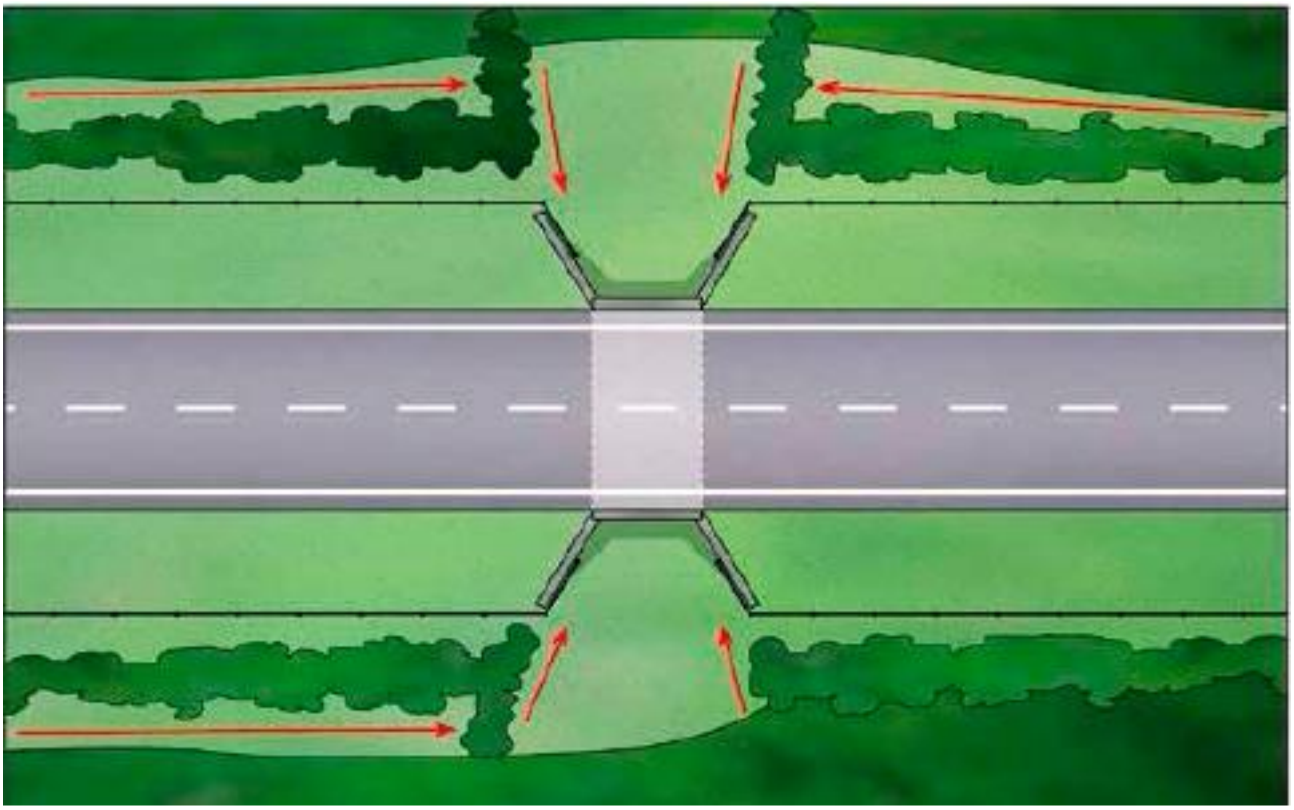

Figure 3. Diagram of vegetation distribution and fencing in relation to wildlife crossing entrances. Source: MAGRAMA 2016.

3.6 Fencing

For more details, see also Files 13, 24, 25 (Additional information) and Chapter 7.4.1 in Wildlife and Traffic (Iuell et al. 2003)

Fencing is a key element to avoid animal mortality and reduce road/railway accidents. Well designed and installed, fences prevent the access of wildlife onto road causeways or railway tracks. Fencing should always be installed in combination with wildlife crossing structures or other safe crossing paths for animals since fences increase the barrier effect.

Effective fencing should be specifically designed and installed according to wildlife groups requirements. Height, mesh size and type, and fence installation are essential factors to be considered for Brown bear and Lynx (see Files 24 and 25 of Additional information).

Main recommendations related to fencing are:

a) **Brown bear** (see file 24)
   - → Height ≥ 3 m and 80 cm outrigger on a 45º angle pointing away from the road.
   - → 8 x 10 cm triple chain-link mesh with 2,7 mm wire.
   - → Reinforcement of the bottom of the fence with a 1,5 m wide horizontal mesh skirt, buried on the outer side of the fence.
   - → Reinforcement of fences posts to prevent bears from tearing down the fence.

b) **Lynx** (see file 25)
   - → Height2-2,5 m and outrigger on a 45º angle pointing away from the road.
   - → Base must be buried.

c) **Requirements of fences at the entrances**
   - → Fences should lead to the entrance of transversal structures in order to funnel wildlife towards safe crossing path, without leaving gaps or creating traps for animals by adjusting fences to the passage entrances (fence posts tie in perfectly with the structure wings or abutments).

To undergo regular inspections of fences to detect and repair holes or any other damage to the mesh or the poles. Incorrect adjustment between the bottom of the fence and the ground or between the fence and the crossing structures entrances should be detected and repaired.

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III. Guidelines to adapt transversal structures and increase use by large carnivores and other wildlife

Additional information. Technical prescription files

Reference:
Ministerio de Agricultura, Alimentación y Medio Ambiente. 2016. Technical prescriptions for wildlife crossing and fence designs (Second edition, revised and expanded). Documents for mitigation of habitat fragmentation due to transportation infrastructures, No. 1. Ministry of Agriculture, Food and Environment. Updated version. Technical assistance by Carme Rosell, Marc Fernández and Ferran Navàs). pp 258.

File 5. Modified viaducts

File 6. Large mammal underpasses

File 7. Multi-use underpasses

File 9. Modified culverts for terrestrial animals

File 12. Wildlife crossing entrances and surface adaptation

File 13. Fences for large mammals

File 24. Specific recommendations for Brown Bear

File 25. Specific recommendations for the Iberian Lynx

Target species and groups

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

Uses

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

Basic features and prescriptions

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

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

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

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

Dimensions

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

Photo: Territory and Sustainability Department, Government of Catalonia.

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

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

Construction types

● Various

Adaptation

Conservation of habitats located under the structure

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

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

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

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

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

Access adaptation

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

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

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

Possible variations to the basic proposal

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

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

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

Maintenance

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

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

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

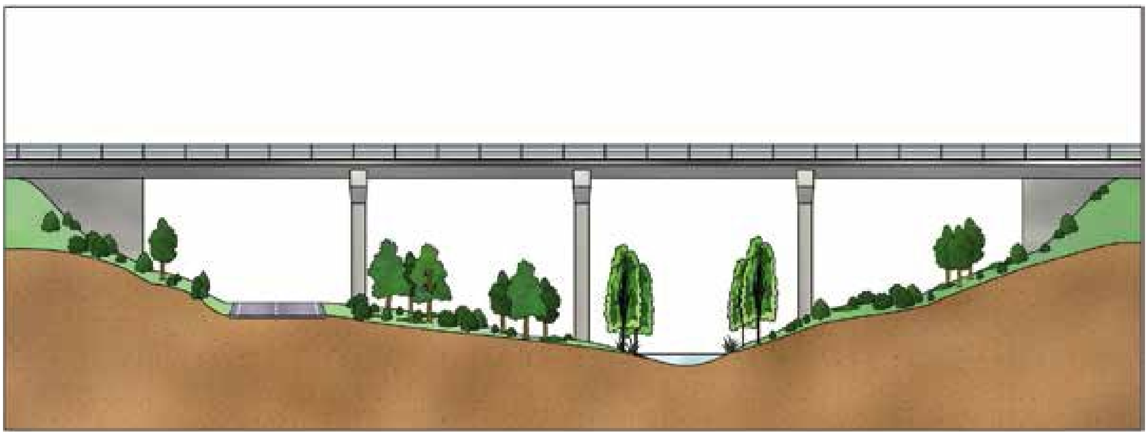

Figure 5.1. Distribution of different uses under a viaduct: watercourse, revegetated areas kept dry, and a road located near one of the viaduct abutments. Piles must be located outside the river channel to preserve the continuity of the riparian corridor. If a road runs beneath the viaduct, its verges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

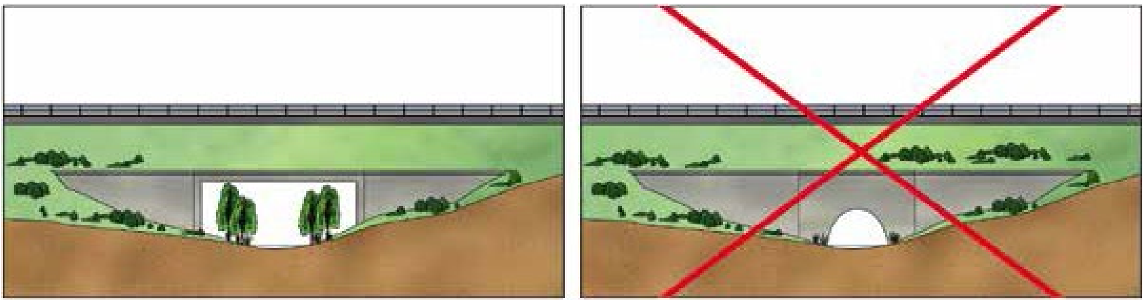

Figure 5.2. Frame bridges and archs are less suitable than viaducts for roads that cross a river valley. If such structures are used, their size should permit the continuity of the riparian vegetation.

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

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

Common bad practices and mistakes

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

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

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

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

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

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

Target species and groups

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

Other target groups

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

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

Uses

- Exclusively for wildlife.

Basic features and prescriptions

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

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

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

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

Dimensions

- Minimum height: 3.5 m.

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

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

- Recommended width for optimised effectiveness: 15 m.

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

Photo: C. Rosell.

Construction types

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

Adaptation

Interior adaptation

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

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

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

Entrances

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

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

- If the road infrastructure above the crossing carries heavy traffic, opaque screens must be installed at the top of the structure to reduce disturbance caused by vehicle traffic.
- The material used for these screens must be highly durable and have a low risk of damage by vandalism.
- Large boulders, tree trunks etc. at the underpass entrance prevent uncontrolled access by vehicles. Transversal barriers (e.g. timber or metal rods set 50-70 cm above the ground) that do not obstruct the passage of wildlife are another alternative (Fig. 1.11).
- Signposts prohibiting vehicular traffic should be installed.

Possible variations to the basic proposal

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

Maintenance

- Proper fence installation and maintenance must be planned to ensure that any damage is detected and repaired.
- Maintenance work should include monitoring for inappropriate use of the underpass and its surroundings (e.g., by vehicles or for temporary construction material storage) which may hinder its use as a wildlife crossing point. Rubbish and any other such material must be removed.

Figure 6.1. Diagram of a large mammal underpass.

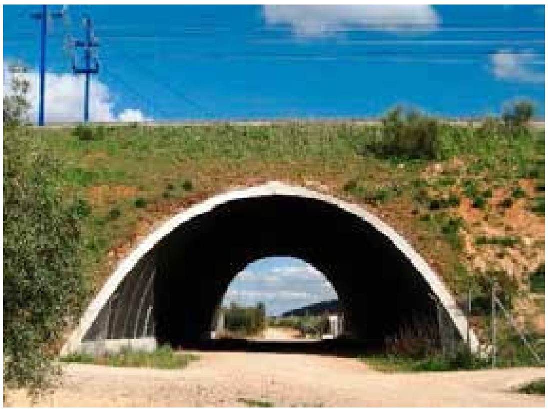

Figure 6.2. Broad single arch underpass without partitions. Photo: ADIF.

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

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

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

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

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

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

Common bad practices and mistakes

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

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

Target species and groups

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

Other target groups

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

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

Uses

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

Basic features and prescriptions

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

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

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

Dimensions

- Minimum height: 3.5 m.

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

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

Photo: C. Rosell.

- Recommended width for optimised effectiveness: 15 m.

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

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

Construction types

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

Adaptation

Underpass interior

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

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

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

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

Location of the section for vehicle traffic

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

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

Entrance adaptation

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

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

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

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

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

Possible changes to the basic proposal

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

Maintenance

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

Figure 7.1. Diagram of a multi-use underpass.

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

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

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

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

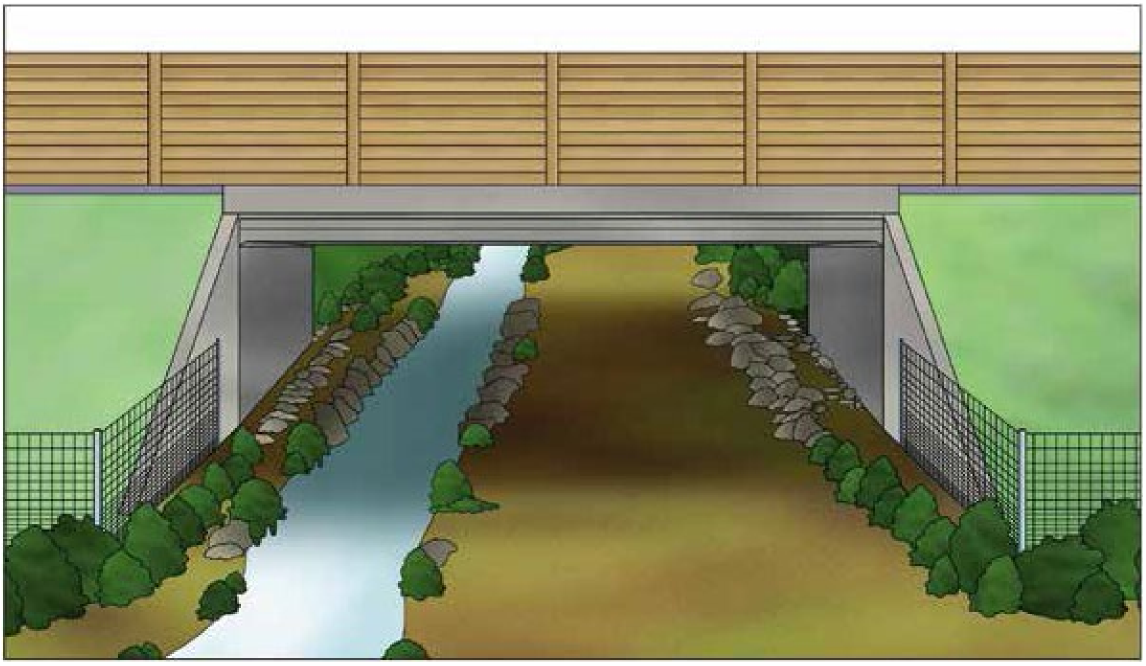

Figure 7.6. A ditch along one side of the structure leaves a large section free for use by wildlife.

Common bad practices and mistakes

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

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

Target species and groups

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

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

Other target groups

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

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

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

Uses

● Multi-use: Wildlife crossing and drainage.

Basic features and prescriptions

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

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

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

Photo . C. Rosell.

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

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

Dimensions

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

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

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

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

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

Construction types

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

Adaptation

Interior

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

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

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

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

Entrances

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

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

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

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

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

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

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

Possible variations to the basic proposal

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

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

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

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

Maintenance

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

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

This monitoring is particularly necessary after floods.

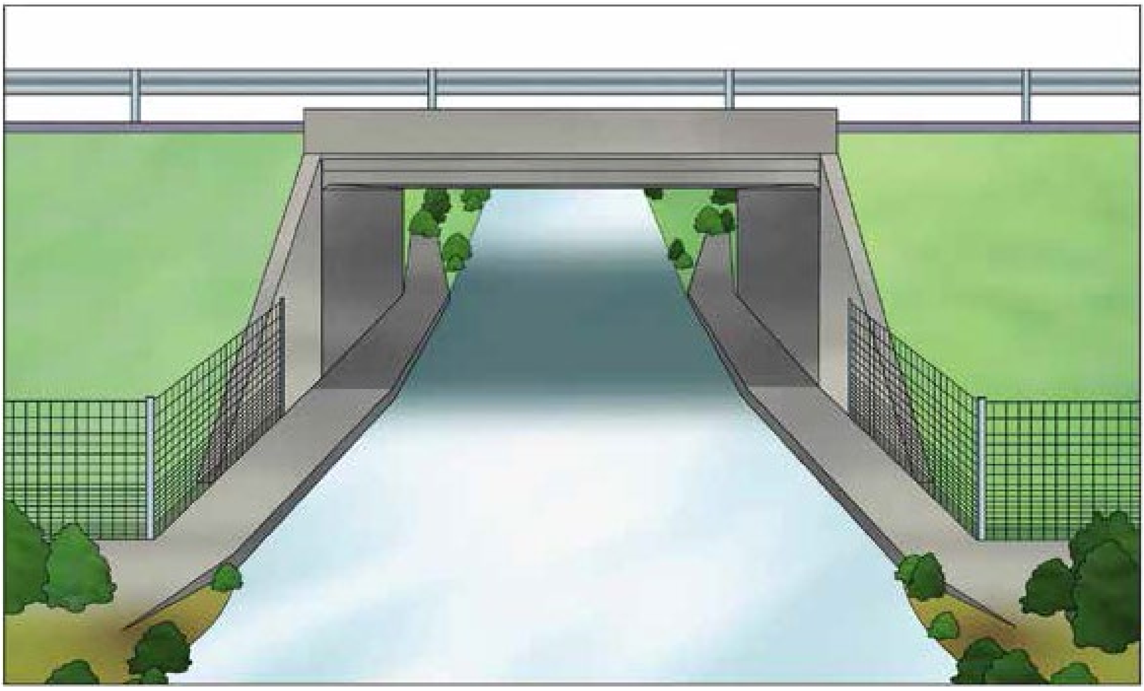

Figure 9.1. Diagram of a culvert adapted for terrestrial wildlife.

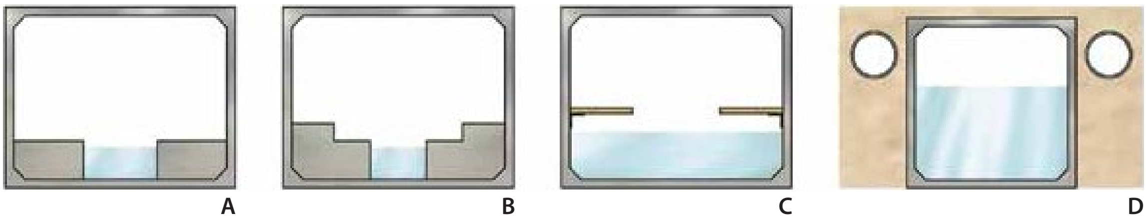

Figure 9.2. Cross sections of culverts with dry platforms. Lateral concrete ledges can have different heights if there are major variations in the water level (B). Platforms (C) allow culverts to be adapted without reducing their section. Option D is not recommended for general use. It is only applicable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

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

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

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

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

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

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

Common bad practices and mistakes

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

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

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

Target species and groups

- All groups.

Basic features and prescriptions

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

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

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

Vegetation and wildlife refuges on crossings

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

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

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

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

Photo: C. Rosell.

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

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

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

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

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

Walls and fences

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

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

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

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

Earthworks

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

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

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

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

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

Maintenance

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

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

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

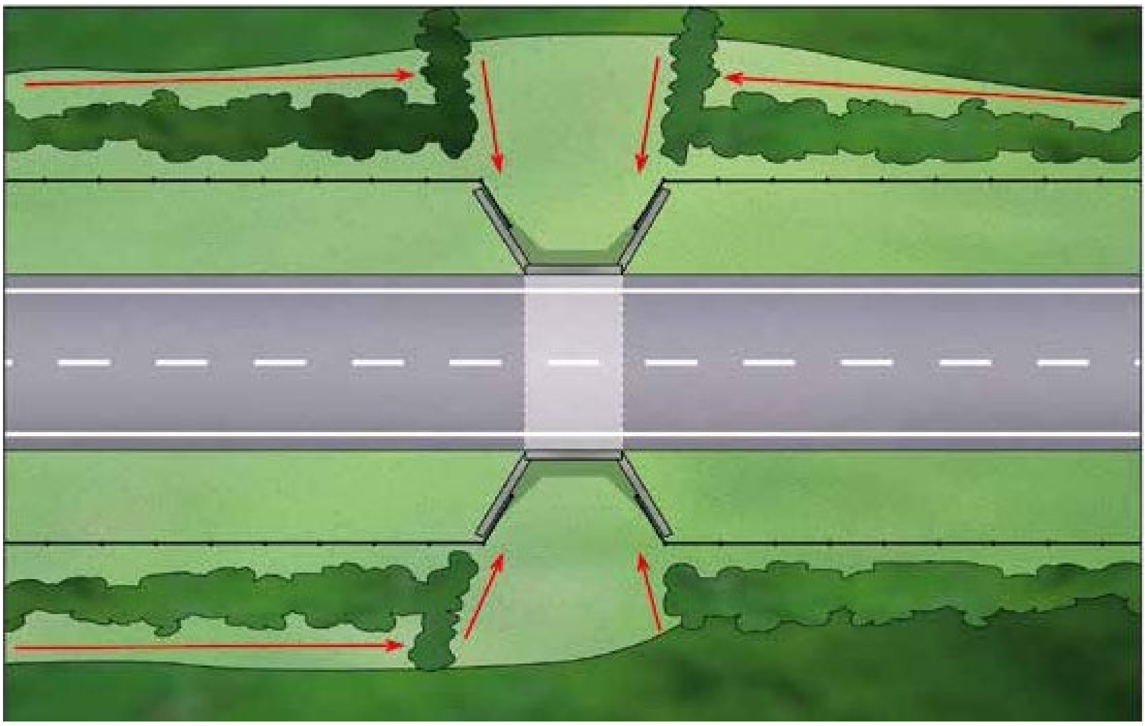

Figure 12.1. Diagram of vegetation distribution in approaches to wildlife crossings.

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

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

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

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

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

Common bad practices and mistakes

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

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

Target species and groups

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

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

Basic features and prescriptions

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

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

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

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

Discontinuous fences

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

Photo: Roads Department, Government of Madrid.

fenced sections lead directly to one of these structures.

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

Fence mesh types and installation

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

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

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

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

Dimensions

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

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

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

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

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

Recommendations for certain species

Reinforcements for wild boar

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

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

Reinforcement for bears

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

Specific fencing for Iberian lynx

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

Maintenance

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

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

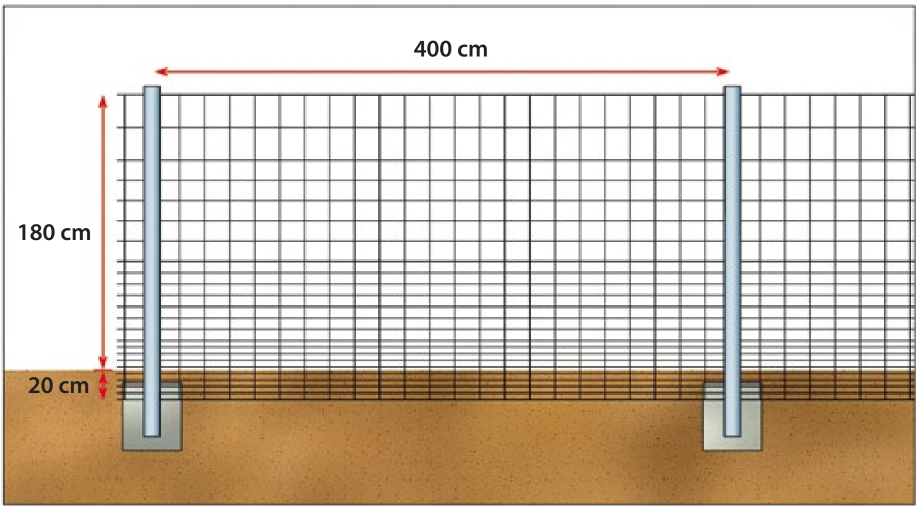

Figure 13.1. Diagram of a fence for large mammals.

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

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

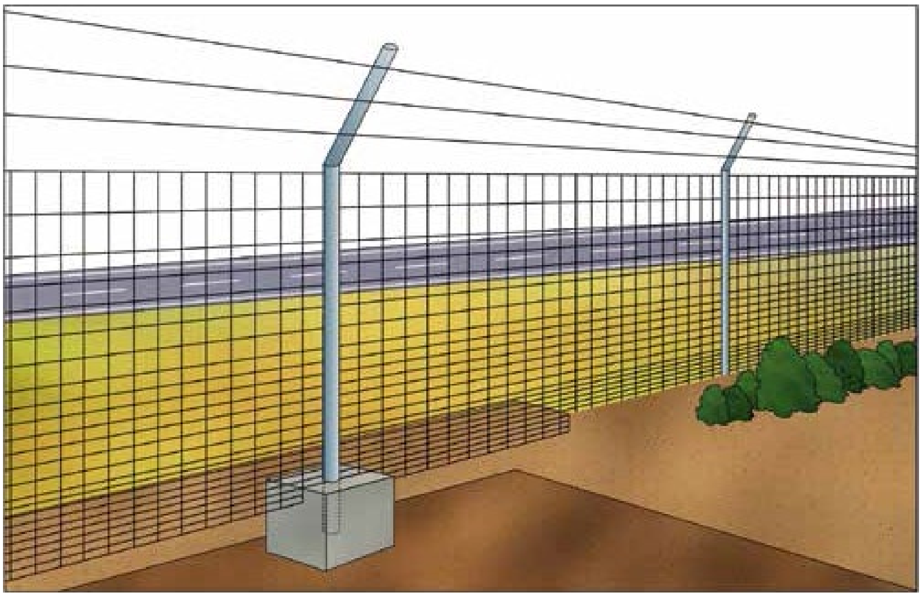

Figure 13.4. A fence can be extended upwards using outrigger poles angled away from the road, topped with galvanized barbed wire. The base of the fence should be buried.

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

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

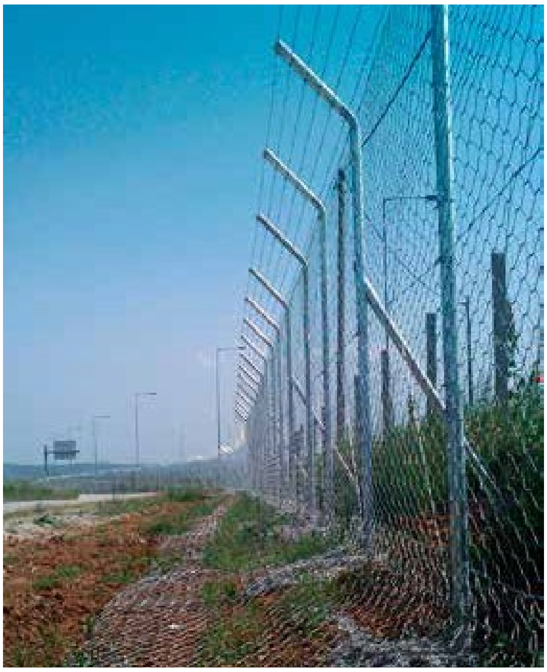

Figure 13.7. Specific fence for bears, with an outrigger at the top and skirting at the bottom (prior to burial). Photo: L. Georgiadis.

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

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

Bad practices and common mistakes

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

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

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

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

Introduction

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

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

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

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

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

Suitable crossing structures for brown bear

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

Photo: Oso Pardo Foundation.

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

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

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

Specific fencing for bears

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

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

Introduction

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

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

Suitable crossings structures for the Iberian lynx

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

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

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

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

Photo: LIFE + Iberlince

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

Prevention of lynx access to roads

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

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

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