LIFE SAFE-CROSSING
‘PREVENTING ANIMAL-VEHICLE
COLLISIONS’ LIFE17 NAT/IT/000464

Guidelines to reduce large mammal and traffic conflicts

Upgrading structures to provide safe wildlife passages and other measures to reduce road mortality risks

LIFE SAFE CROSSING
PREVENTING ANIMAL-VEHICLE COLLISIONS

NATURA 2000

AGRISTUDIO s.r.l. · Callisto · COSMOTE · EGNATIA ODOS · Fundația Carpați – Carpathian Wildlife Foundation · Hellenic Republic Region of Western Macedonia · ICAS · minuartia · Parco Nazionale d'Abruzzo Lazio e Molise · Parco Nazionale della Majella · Junta de Andalucía – Consejería de Medio Ambiente y Ordenación del Territorio

LIFE SAFE-CROSSING. Preventing Animal-Vehicle Collisions
Demonstration of Best Practices targeting priority species in SE Europe
(LIFE17NAT/IT/464)
Project duration: 2018-2023

Coordinating beneficiary: Agristudio Srl

Associated beneficiaries:
Agencia de Medio Ambiente y Agua de Andalucia, Spain
Consejería de Sostenibilidad, Medio Ambiente y Economía Azul, Spain
CALLISTO Wildlife and Nature Conservation Society, Greece
COSMOTE Kinites Tilepikoinonies Single Member AE, Greece
Egnatia Odos S.A, Greece
Fundația Carpați, Romania
MINUARTIA, Spain
National Institute for Research and Development in Forestry 'Marin Drăcea', Romania
Parco Nazionale d'Abruzzo Lazio e Molise, Italy
Parco Nazionale della Maiella, Italy
Provincia di Terni, Italy
Region of Western Macedonia, Greece

CREDITS OF THE DOCUMENT

Responsible partner: MINUARTIA logo
Authors: Rosell, C. (MINUARTIA), Ricci, S. (AGRISTUDIO); Fernández L.M. (MINUARTIA); Voumvoulaki, N. (EGNATIA ODOS SA), Mertzanis, Y. (CALLISTO), Psaralexi, M. (CALLISTO); Mertens, A (AGRISTUDIO)
Contributors: Majella National Park (Giovanna Di Domenico, Antonio Antonucci); Abruzzo, Lazio e Molise National Park (Roberta Latini, Maria Psaralexi); Michal Bil (CDV), Lazaros Georgiadis
Support/cooperation: Infra Eco Network Europe (IENE); Horizon 2020 BISON project; Spanish Ministry for Ecological Transition
Acknowledgements:
This publication has been co-financed by the LIFE Fund of the European Union
Recommended citation: Rosell, C., Ricci, S., Fernández L.M.; Voumvoulaki, N., Mertzanis, Y., Psaralexi, M., Limperopoulos, G., Mertens, A. 2023. *Guidelines to reduce large mammal and traffic conflicts. Upgrading structures roads to provide safe wildlife passages and other measures to reduce road mortality risks.*
Life Safe-Crossing 'Preventing animal-vehicle collisions. Demonstration of Best Practices targeting priority species in SE Europe'.
LIFE SAFE-CROSSING Project, Italy.
Published by: LIFE SAFE-CROSSING, Italy.

ISBN:
DOI:
Cover photos:

LIFE SAFE-CROSSING
‘PREVENTING ANIMAL-VEHICLE COLLISIONS’ LIFE17 NAT/IT/000464

Guidelines to reduce large mammal and traffic conflicts

Upgrading structures to provide safe wildlife passages and other measures to reduce road mortality risks

Contents

1 Introduction

1 Introduction

The distribution area of large carnivores in Europe is severely fragmented by existing linear transport infrastructure which are one of the main threats to biodiversity. Large carnivore conservation is affected by impacts caused by infrastructure such as mortality due to collisions with traffic, barrier effect and habitat loss and disturbance. European policies aim to restore nature and rewilding is an active process in many countries [Rewild van Meerbeek et al., 2019; Carroll and Noss, 2020; Carver et al., 2021], resulting in increasing large mammal numbers and expansion of its distribution areas. The extensive European road and railway networks with more than 7M km [all continent] under operation [Eurostat, 2022] pose great challenges to guarantee the coexistence with large carnivores. Existing infrastructure needs to be upgraded to guarantee its efficiency and safety and adapted to increase resilience facing extreme weather events linked to climate change. Infrastructure upgrading and adaptation plans provide huge opportunities for transformative change adopting global mitigation strategies which benefit biodiversity while achieving sustainable and safe transport networks.

A raising awareness about the problem and knowledge about mitigation measures contribute to be applied in new and existing infrastructure to reduce the impacts of transport infrastructure on biodiversity. Existing infrastructure built decades ago are still causing important impacts on wildlife species, including large carnivores, and actions are needed in them to defragment the landscape and contribute to biodiversity conservation [De Montis et al., 2018; Sijtsma et al., 2020 REF, existing plans].

The LIFE SAFE-CROSSING project 'Preventing Animal-Vehicle Collisions – Demonstration of Best Practices targeting priority species in SE Europe' (LIFE17NAT/IT/464) aimed at implementing actions to reduce the impact of roads on some priority species in four European countries: Marsican brown bear (*Ursus arctos marsicanus*) and wolf (*Canis lupus*) in Italy, Iberian lynx (*Lynx pardinus*) in Spain, and Brown bear (*Ursus arctos*) in Greece and Romania. These species are severely threatened by road infrastructures, both by direct mortality as well as by barrier effect. In order to mitigate these the objectives of the LIFE SAFE-CROSSING project were:

- to reduce the risk of traffic collisions with the target species
- to improve connectivity and favour movements for the target populations
- to demonstrate the use of innovative Animal-Vehicle Collision (AVC) prevention tools
- to increase the attention of drivers about the risk of collisions with the target species

The project was developed from 2018 to 2023, included 4 countries (Italy, Greece, Romania and Spain) and 29 Natura 2000 sites, and involved 13 partners, among which NGOs, private companies and public bodies. Defragmentation actions can be undertaken to restore ecological connectivity, allowing bears, lynxes and other carnivores to safely cross roads and railways. These measures can involve using appropriate existing structures over or under the infrastructure, managing the vegetation along the infrastructure to increase visibility or guide wildlife or applying new technologies that contribute to reduce the risk of roadkill.

Tunnels and viaducts play a major role in maintaining ecological corridors across transport infrastructure. Additionally, wildlife passages (also called 'fauna passages' or 'wildlife crossings') are key elements of the European Green Infrastructure networks, helping to maintain or to restore ecological connectivity and movements of large carnivores across the landscape. Existing transversal structures with a primary function related to drainage or river crossing, forestry and cattle roads, or pedestrian paths, can be modified for wildlife use, turning them into wildlife passages.

These transversal structures are more effective in combination with fences, although this increases the barrier effect. Alternatively, new technologies are also providing solutions for those areas where no transversal structure exist, using animal detection systems to reduce collision risk without increasing the barrier effect that fences cause.

The goal of this document is to provide criteria and guidelines for designing measures to be applied on roads (and many on railways) under operation to reduce large mammal mortality risk and provide them with safe crossing passages. Actions described are based on evidence-based knowledge, particularly on the European handbooks 'Wildlife and Traffic: A European Handbook for identifying conflicts and designing solutions' (Iuell et al., 2003) and its updated version (Rosell et al., 2022), 'Biodiversity and Infrastructure: A handbook for Action' (Rosell et al., 2023) and on the results of the actions and monitoring undertaken along the LIFE SAFE-CROSSING project.

The measures are presented in two different sections. One of them is focused on Animal Vehicle Collisions – Prevention System and other measures suitable to be applied in local roads with low to moderate traffic intensity, while the other is focused on upgrading existing transversal structures which together with fencing may be the most effective solutions in motorways and main roads with high traffic intensity.

To establish an accurate diagnosis about the problem and involving all relevant stakeholders are as important as applying the correct measure for each situation. Therefore, sections regarding the identification of conflict areas and information about Policy and stakeholders to be involved are also included in these guidelines.

The LIFE SAFE-CROSSING target species are large carnivores, mainly Brown bear, wolf and Iberian lynx. Nevertheless, many of the actions will also benefit other species of large mammals, mainly ungulates, and also other wildlife. These measures also have the crucial role to benefit people improving traffic safety by the reduction of the hazard of collision with large animals.

A lack of previous information about experience in Europe in modifying existing underpasses to be used by large carnivore has required the adaptation of existing guidelines for designing fauna passages, and particularly the European Handbook 'Wildlife and Traffic' (Iuell et al 2003; Rosell et al., 2022; 2023). Information obtained during LIFE SAFE-CROSSING project implementation will provide increased knowledge on the topic and key information on enhancing guidelines to be applied at European level.

2

Impact of roadkill on large carnivore populations

2

Impact of roadkill on large carnivore populations

Currently, there are more than seven million km of linear transport infrastructure across Europe of which approximately 6.6 million km are from roads (Eurostat, 2022; Seiler et al., 2023). These roads fragment the landscape causing several impacts on biodiversity. Large carnivores interact with roads frequently due to their large home ranges, and because they have high dispersal rates and long dispersal distances making frequent, long-range movements across the landscape (Ceia-Hasse et al., 2017). Therefore, large carnivores are expected to be affected by roads more than less-mobile species. Furthermore, their low reproductive rates and long generation times also render them more susceptible to road effects, as they are less able to recover from population declines (Grilo et al., 2015).

2.1 | Road mortality

Road mortality is the most pronounced and well documented road effect upon wildlife. It is estimated that ~29 million mammals are killed every year on European roads (Figure 2.1; Grilo et al., 2020) becoming one of the main causes of human-related mortality with an impact that reaches far beyond the kill and beyond the collision locations. Wildlife-vehicle collisions leave a clear genetic imprint on populations as they reduce effective population sizes, limit gene flow, and increase genetic isolation (Ibisch et al., 2016; Seiler et al., 2023).

In Europe, most AVC registered involve large ungulates, such as wild boar (*Sus scrofa*) and roe deer (*Capreolus capreolus*), because they are an important risk for traffic safety. Estimates on large carnivores are scarce, partially due to small sample sizes (Colino-Rabanal et al., 2011), although they are an important threat for many of them (Grilo et al., 2015; Ceia-Hasse et al., 2017). Large carnivore-vehicle collisions have important financial implications associated with property damage and insurance costs, but also raise road safety issues as they may result in human injury or death. The nature of these collisions as well as the overarching ecological significance these species have, render them a priority in conservation efforts and mitigation strategies.

Figure 2.1. Roadkill poses a big risk for wildlife, especially for large carnivore and endangered species (Photos by: LIFE SAFE-CROSSING).

2.2 | Barrier effect

Roads also create a barrier or filter effect on wildlife. While mortality is higher in non-fenced roads with medium traffic intensities, barrier effect is stronger in roads with high traffic intensities or in fenced roads without wildlife passages (***refs). Filter effects is species and individual dependant, since some species and some individuals are more prone to take risks, trying (and occasionally) succeeding to cross roads. Because of this, filter effect is affected by road mortality as 'would be crossers' are removed from the populations.

Although less evident than road mortality, barrier and filter effects are important threats for biodiversity. The lack of gene flow among populations has deleterious effects in the long-term and may lead to population bottlenecks and local populations are eventually prone to extinction due to stochastic events. Large carnivores are especially vulnerable to this effect due to their low reproductive rates and long generation times (Grilo et al., 2015).

Solutions to reduce roadkill risks need to consider the importance of maintaining or restoring ecological connectivity in order to sustain viable populations in the long-term.

2.3 | Disturbances

Roads and its associated traffic also cause disturbances to wildlife related to light, noise and chemical pollution (***refs). Their effects have not specifically studied on large carnivores, but their effects have been proven in several taxa, such as plants, insects, birds, and others (Sordello et al., 2019; 2022; Rosell et al., 2023).

However, several studies have established the road avoidance behaviour of large carnivores (Basille et al., 2013; Kautz et al., 2021; Ripari et al., 2022). This behaviour include selecting habitats with low density of roads, using roads to travel or forage at night when traffic is lower, or

3

Mitigation strategy and measures to be applied

3

Mitigation strategy and measures to be applied

3.1 | Identification of conflictive sections of road: a first step to solve the conflict

Identifying the road sections where mitigation measures need to be applied is the first basic step to be able to solve the problem. However, this is not straightforward, therefore different methods have been developed to reach this goal as accurately as possible (Minuartia, 2019; University of Rome 'La Sapienza', 2020).

The most common approach is to analyse data on carcasses found on roads to estimate roadkill rates and select those road sections with higher numbers of collisions. This information is usually collected by traffic authorities, but also by citizen science or specific projects in certain road sections (i.e., in protected areas). It is also important to identify where animals are crossing safely in order to ensure these areas are maintained safe. This information can be collected, for example through radio collared animals (Minuartia, 2019).

Another alternative is to develop statistical models of species movement (for one or several species together) to identify where ecological corridors may be established and cross this information with road networks to identify potential risky sections (MAGRAMA, 2016).

All these methods have their strengths and weaknesses, so the selection of one or another needs to be evaluated on a case by case basis. Ideally, two or more of these methods could be combined if available information and data allow to do so.

3.2 | Data required

Within the LIFE SAFE-CROSSING project, in order to inform the decision-making process about the location of mitigation measures to be undertaken, the first step was to gather information on the impact of road mortality on large carnivore and to analyse movements of individuals in relation to roads in different study areas based on data provided by the project partners.

At the same time, this information provides a baseline situation, before the application of mitigation measures, and allows the evaluation of mitigation measure´s effectiveness by comparing the situation before and after the measures are implemented.

To identify **animal-vehicle collision clusters**, roadkill data from 2009-2018 were gathered by partners from the different study areas (Table 1). This data included roadkill from target species, but also from other wildlife (wild carnivore and ungulate species) as indicators of potential crossing corridors on a road. Inclusion of these registers also helped to enhance the power of clustering identification by providing larger sample data sets.

For the identification of **road sections with clusters of road crossing** and in order to detect the **areas close to roads which are more intensively used** by the project target species, telemetry data from 79 radio-collared brown bears collected between 2005-2019 were analysed (Table 2). Furthermore, information from previous studies establishing core areas for the Iberian lynx was also used (Illanas et al., 2017).

Table 1. AVC data gathered from each study area and included in the analysis.

Study areas	Target species		Ungulate species		Wild carnivores		Total
GR Kastoria-Florina	**Total** Bear Wolf	**57** 51 6	**Total**	**0**	**Total** Wild cat Badger Fox Marten	**27** 3 4 15 5	**84**
IT PNALM	**Total** Bear Wolf	**20** 4 16	**Total** Red deer Roe deer Wild boar	**105** 53 24 15	**Total** Wild cat	**5** 5	**130**
IT PNM	**Total** Bear Wolf	**25** 2 23	**Total** Red deer Roe deer Wild boar	**91** 13 19 59	**Total** Wild cat Badger Fox Marten	**38** 4 26 7 1	**154**
RO Curbura Carpatilor	**Total** Bear	**27** 27	**Total**	**0**	**Total**	**0**	**27**
ES Doñana - Sierra Morena	**Total** Iberian lynx	**120** 120	**Total**	**0**	**Total**	**0**	**120**
TOTAL		**249**		**196**		**70**	**515**

Table 2. Number of target species individuals monitored by telemetry methods in each study area.

Study areas	Target species	N individuals monitored	Mean interval between locations
GR Kastoria-Florina	Brown bear	**23**	Differences between bear individuals; 1 to 2 locations/hour
IT PNALM	Marsican Brown bear	**23**	Differences between bear individuals and months; in Summer season a mean of 1 location/hour
IT PNM	Marsican Brown bear	**1**	1 location/hour during 10 days/month
RO Curbura Carpatilor	Brown bear	**32**	Differences between bear individuals; 1 to 4 locations/2 hours
ES Doñana - Sierra Morena	Iberian lynx (1)	**-**	**-**
TOTAL		**79**	

3.3 | Data analyses

3.3.1 | AVC clusters

To identify AVC clusters KDE+ method (Bíl et al., 2013) was applied. This method stems from the Kernel Density Estimation (KDE) (e.g., Chung et al. 2011) which estimates the probability density function of the underlying data using a kernel function (see Figure 3.1a). It is a nonparametric method, not making any assumption about the underlying distribution of AVC and without establishing a subjective threshold to define clusters (see Figure 3.1b). The framework of the standard KDE method was extended by introducing repeated random simulations (Monte Carlo method) to objectively determine the level of significance (threshold).

Risk locations are identified in places where the estimated probability density function exceeded the threshold (see Figure 3.1c). Resulting significant clusters can be ranked according to cluster strength, which quantifies the degree of violation of the null hypothesis: 'AVC are uniformly distributed along a road section'. This process of statistical testing is, in contrast to other approaches, objective and allows the user to focus on important clusters. The ranking of the clusters makes it possible for the user to rank all the significant clusters from the most hazardous to the least.

It should be pointed out that the KDE+ is applied to lines (transportation network), not to areas. It is not dependent on predefined section lengths. In addition, the KDE+ method typically returns more focused results than the KDE or other applied methods (Bíl et al., 2016).

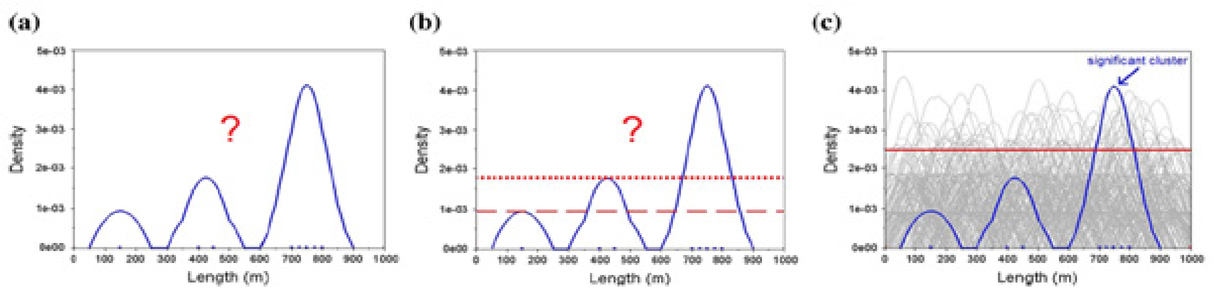


Figure 3.1. The KDE with an unknown threshold (a), two subjectively chosen thresholds (dashed and dotted lines) (b) and the KDE+ method (c). The blue line shows the estimated probability density function of AVC. The grey lines represent KDEs of uniformly distributed data (Monte Carlo simulation). The horizontal red line is the 95th percentile level (Figure extracted from Bíl, et al 2016).

There is a subsequent statistical test applied in the KDE+ analysis, which provides results regarding the 'importance' for each cluster. In other words, the first test is applied to identify and localise significant clusters (the KDE+ method itself), while the second test is applied to highlight the most important locations. Hence, three types of clusters are identified:

- Non-significant cluster (not further processed).
- Significant cluster with 'low reliability', which could be false positives, due to the rather low cluster strength or low number of records in cluster.
- Significant clusters with 'high reliability', which only show a probability of 5 % or less of a false positive. Group 3 is a subset of group 2.

To get the best cost benefit from mitigation measures it is recommended that these measures are focussed on group 3 clusters, although other clusters included in group 2 could also be considered (see Figure 3.2).

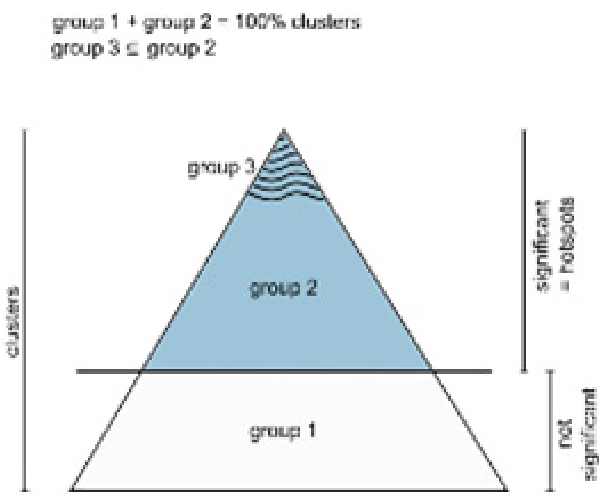


Figure 3.2. Types of AVC clusters identified by the KDE+ method. Group 3 clusters are statistically significant clusters with high reliability.

3.3.2 | Telemetry data

Telemetry data was analysed in two different ways. To identify the road sections with clusters of road crossing, lines representing linear movement paths were created from consecutive location points, identifying intersection with road segments and analysing these points with KDE+ method (see Section 3.2.1).

To quantify the use of areas beside roads, two hexagonal grids (1 km and 400 m in diameter) were created over the study areas and then estimate the time by monitored animals in each cell. To do so, each GPS point was weighted as 1 / [*number of locations acquired in a particular day by a specific animal*]. This procedure ensured that outcome weights of a cell were not overrated due to temporal/spatial correlation of location counts, since the more point density the less weight of one point. Then, the weights of all points included in each hexagonal area were added when the number of telemetry points acquired in one day by one animal reaches 2 or more.

A distance of 100-400 m can be considered for a bear's perception scale of its surroundings and/or response to 'roads risks' (Falcucci et al. 2009, Ditmer et al. 2018). The different grid sizes are provided to offer two different scales for evaluating the areas more frequently used by bear, for instance, the grid of 400 m could be interpreted as a scale of a bear's perception of its most immediate surrounding (e.g. for comparing the areas more used right next to a road), while 1 km gives the phenomenon a greater scale, more related to land uses and habitat features of the areas nearby roads.

Maps
An online viewer was produced as a tool for exploring the different information layers of results. The access to the viewer (http://www.cdvgis.cz/~kubecek/ags/safecrossings/index.php) is restricted by a password to ensure data confidentiality. Other files were also created to help visualize or evaluate the information (see Table 4).

Files of the main results were also sent to partners to allow them to do further evaluation using Geographic Information System (GIS) software and/or other data management software (see Table 4). GIS layers were all projected in the same Coordinate Representation System (ETRS89/EPSG:3035).

As mentioned before (see section a)), all clusters can be ranked according to their 'importance' (group 2 or 3 category). When working with **AVC cluster files** both cluster group types can be distinguished by the parameter 'upper interval of global strength' (GStr_CI_1) value:

- Group 3: Clusters with values > 0 are considered as significant clusters with high reliability.
- Group 2: Clusters with values < 0 are considered as significant clusters with low reliability.

To visualise files of the **area beside roads used more often by Brown bear** a gradient quantity variable can be visualised, where the darker colour of a cell corresponds to an area more frequently used by target species (see Figure 3.3)

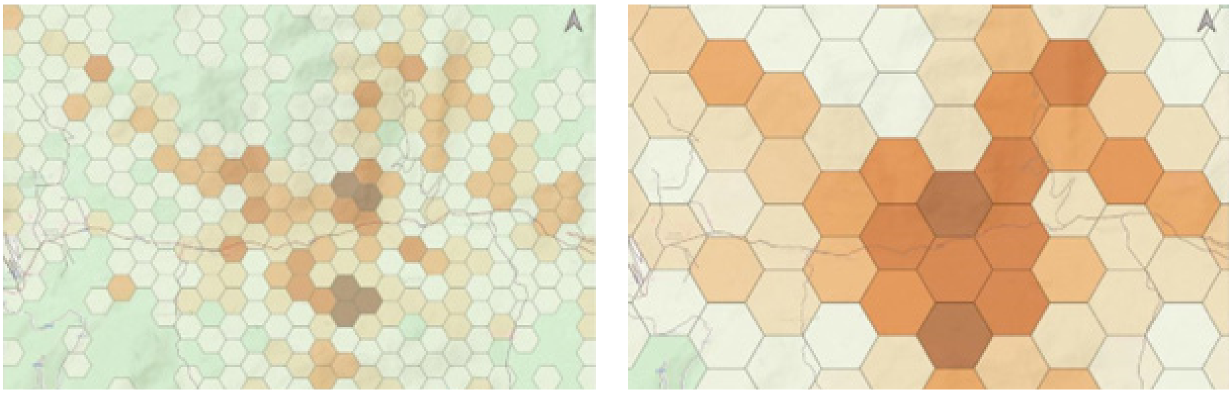


Figure 3.3. Use of the areas beside roads identified with hexagonal grid cells. The darker the colour of a cell, the more frequently used the area is by Brown bear and Marsican brown bear. Above, grid cell of 400 m diameter; below, grid cells of 1km diameter.

3.4 | Combination of criteria to select road sections of intervention

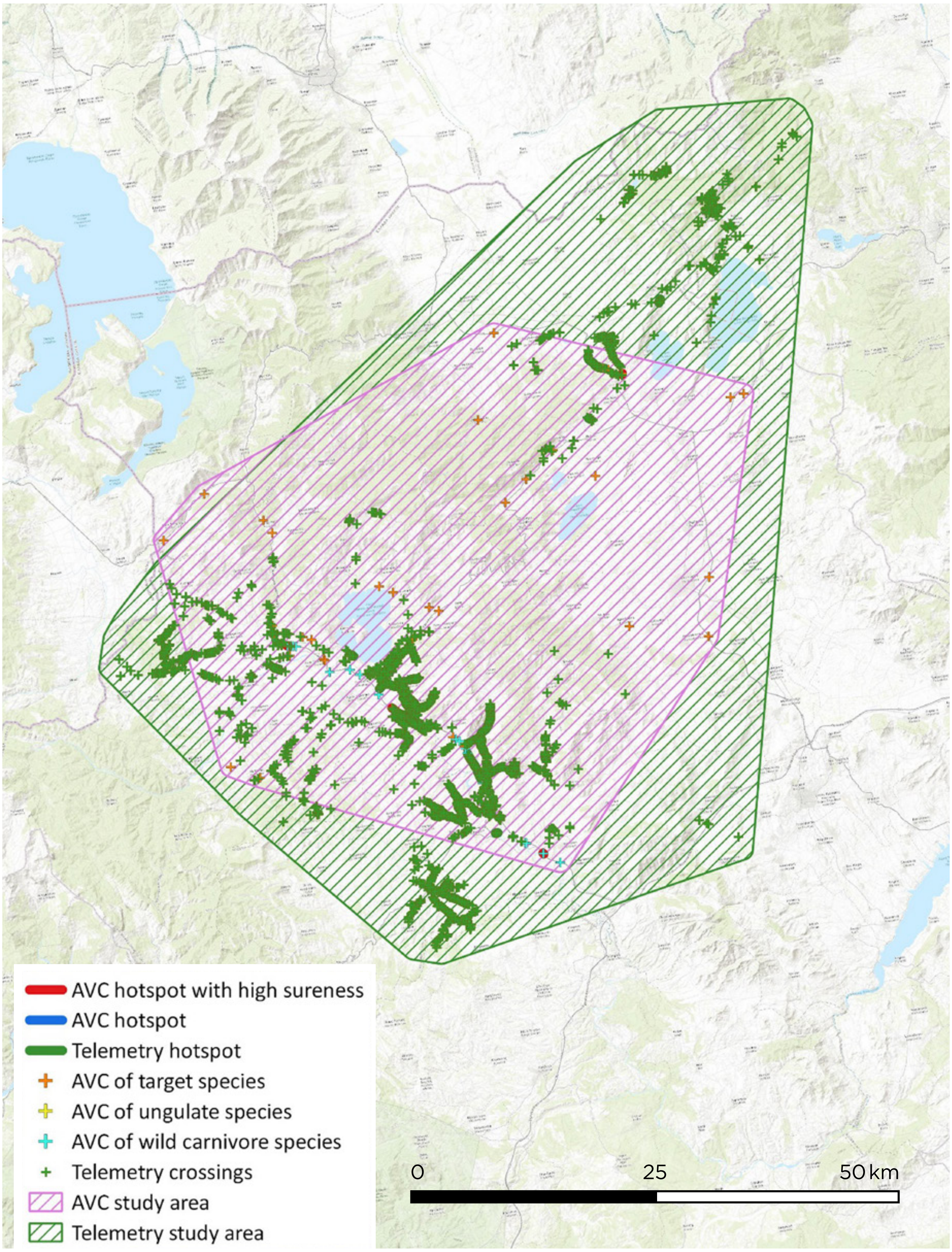


Figure 3.4. Results of the analysis distributed among partners included information regarding AVC (including all significant AVC clusters and each AVC event) and telemetry. Source: LIFE SAFE-CROSSING, 2019.

It is important that statistical analyses are adapted to local conditions in order to try and maximise positive results. To do so, local knowledge should be incorporated in the interpretation of the results, evaluating how they can be locally implemented.

Within the LIFE SAFE-CROSSING, results from all analyses were produced as shapefiles (.shp) and distributed among partners along with other spatial information, like road network and the original roadkill data (Figure 3.4). They were also included in an online viewer accessible to all partners. This combination of results and tools allow partners to further evaluate the information, by using Geographic Information System (GIS) software, even directly in the field by connecting to the online viewer. Furthermore, this eases communication and understanding with other stakeholders that can and need to be involved in the application of mitigation measures (see Section 7).

Figure 3.5. Previous information about AVC and important road crossing sections were corroborated with surveys. These pictures capture by camera traps show Brown bear approaching the road in Greece (A) and Romania (B). Photos by: CALISTO? (A) and INCDS? (B).

With this information, partners from each country collected additional data in order to i) corroborate the information provided was still relevant (since roadkill data in some locations include a long period of time), and ii) gather the 'before' data for the monitoring and evaluation of the mitigation measures implemented. Specifically, each partner conducted roadkill surveys and set up camera traps in the crossing points considered as priority areas (Figure 3.5).

3.5 | Selection of appropriate mitigation strategy/type of measure

Mitigation measures to be applied in road sections where conflicts between large mammal and traffic are registered must be identified according to diagnosis of the conflicts identified and target species requirements. However the infrastructure local features play a determinant role in the selection of the type of measures conditioning their feasibility, cost and effectiveness.

Choosing the appropriate measure ensures a better cost-effectiveness ratio, providing greater overall results. Key infrastructure and traffic factors to be analysed previously to selection of the mitigation measures are listed below (Figure 3.6):

1. **Traffic intensity** (number of vehicles per day). Several studies have shown that the amount of traffic has a binomial effect on wildlife mortality, reaching maximum numbers in medium traffic intensity roads ca. 5-7,000 vehicles per day (Grilo et al., 2015; Jacobson et al., 2016). Low traffic intensity roads have lower numbers of roadkill because there are less risk situations while in high traffic intensity roads AVC are reduced due to fencing is installed or animals develop a road-avoidance behaviour due to disturbance associated with frequent pass of vehicles. In roads with a low number of vehicles per day usually fencing and wildlife passages are not the best options and measures must be based in installation of signs activated by ADS and/or road verge maintenance.

2. **Vehicles speed** (circulation speed or posted limitation speed in the road section, if the first is not available). Some mitigation measures are not suitable to be applied when vehicles circulate at high speeds because of several reasons. For example signs activated by ADS or virtual barriers, require some time to be activated and do not achieve effectiveness when speed of circulation is high (over 70 km/h).

3. **Cross road section** (depending on local topography and design: plain terrain / cutting / embankment). Different cross road sections have an influence on the possibilities of wildlife to access the carriageway, being more difficult in a steep embankment than in a plain section. On the other hand, roads located between cuttings offer possibilities to adapt existing overpasses to be used as fauna passages, while roads over embankments offer potential to adapt underpasses or viaducts. This also condition the feasibility and cost of the construction of new wildlife passages.

4. **Fencing.** Appropriate fencing reduces roadkill risks impeding animals to access the carriageway, and is an essential element to guide the animals to safe wildlife crossings. When fencing is already installed their reinforcement and adaptation of existing transversal structures are often the best solution to be applied to reduce roadkill and reduce barrier effect.

5. **Temporary or permanent closing.** For some specific location and target spe-

cies road sections can be closed either temporarily or permanently. This has been applied more frequently for other taxa, like amphibians in mating season, but can also be applied for example to dawn/dusk hours where many large mammals are mostly active, migratory corridors in migration season, etc.

Figure 3.6. Road features such as those described in the present section determine the selection of mitigation measures to be applied (Photos by: PNALM, Junta de Andalucía and Minuartia).

3.6 | Types of defragmentation measures

Local roads are generally not fenced and concentrate the vast majority of animal casualties. On the other hand, these roads are more permeable to wildlife than high capacity infrastructure, having a lower barrier effect. There are different measures aiming to achieve this double purpose that can be applied in local roads. Conversely, roads with high capacity are usually fenced and involve relatively low numbers of AVC. However, they pose other impacts on biodiversity, like strong barrier effects that fragment populations, risking their persistence in the long-term.

The mitigation strategy to address these impacts is different depending which type of road is causing them. Therefore, it is key to carefully evaluate their fit to the road conditions (see Section 3.5) to improve its effectiveness. Below the available mitigation measures are grouped accordingly to the type of road (Figure 3.7).

Measures most appropriate to be considered for high capacity transport infrastructure are:

1. **Fencing**. This is one of the most effective measures to reduce AVC, but it increases the barrier effect roads pose on wildlife. To avoid this, fences should always be installed in combination with wildlife pas-

sages. It is important to pay attention to the specific recommendations depending on the target species and conduct appropriate maintenance to ensure their effectiveness.

2. **Wildlife passages.** They are structures designed and managed to facilitate the safe movement of wildlife across transport infrastructure. It can be specifically designed for wildlife use, or modified to combine wildlife crossing with other uses. Many overpasses and underpasses can be used by fauna to cross roads and railways, however this name must be reserved for those structures which have been particularly constructed or upgraded to provide the function of fauna passages. This is important because infrastructure operators must provide specific long-term maintenance appropriate to wildlife and ecological connectivity.

Measures most appropriate to be considered for local roads are:

3. **Wildlife awareness signs.** Several types could be applied. Standard signs are the most common measure applied by road operators in sections with frequent AVC. They aim to alert drivers about the potential presence of wild animals on the road so they drive more cautiously. However, they have been proven ineffective because drivers became habituated and tend to ignore them (Huijser et al., 2015). Two alternative types are recommended to avoid driver's habituation:

   - **Temporary reinforced standard signs.** They are only displayed in high risk seasons, i.e., mating season. These signs often are reflective panels bigger than standard signs.

   - **Signs with Animal Detection Systems (ADS).** Signs including flashing lights -and usually messages such as 'Slow down'- activated only when there is an animal in the vicinity of the road which is registered by thermal or movement detectors or by radars.

4. **Animal Vehicle Collision Prevention System (AVC/PS).** This device is a combination of signs with ADS and wildlife deterrents. The additional benefit of this combination is that it alerts both, the drivers and the animals approaching the road. They could be activated only in specific conditions, for example, when speed of the vehicle is over a fixed threshold. This solution is further explained in section 4.

5. **Wildlife deterrents.** There are different types of wildlife deterrents (visual, acoustic, olfactory) but all of them aim to dissuade animals from accessing the road or to drive them away from it. One of the main drawbacks of these devices is the rapid habituation of wildlife to the stimuli (D'Angelo & van der Ree, 2015). Recently, new approaches for acoustic deterrents, such as using different sounds with biological meaning for the target species and only when an actual threat is present, are showing more promising results (Babińska-Werka et al., 2015; Seiler & Olson, 2017; Lodnert, 2021).

6. **Road verge management.** This measure is addressed to avoid attraction of animals to road causeways and to increase visibility reducing roadkill risk. It involves vegetation management but also other actions such as avoiding the location of waste containers close to roads which is common in rural roads. This measure is often applied in combination with previous ones.

In any case, it is important to conduct monitoring of the measures implemented to evaluate its effectiveness. When possible, this monitoring should follow the BACI (Before-After-Control-Impact) approach which requires gathering data with standardised methods before and after the implementation of the measures and if possible, comparing road sections where the measure has been applied with other sections in the vicinities with no mitigation measures.

Evaluating effectiveness of roadkill mitigation measures is always difficult because different reasons influence the number of AVC. For example, numbers of AVC can occur if target species population sizes increase even if the measure is having an effect in reducing AVC numbers. On the other side, an absence of AVC should be balanced with information about the presence of the species as they can be due to the measure but also to a reduction of the numbers of the animals in the road section. When a population increases in numbers or expands its distribution range and colonises new areas (e.g. thanks to restoring ecological connectivity) an increase in AVC numbers can be registered despite mitigation measures to reduce AVC frequency. Therefore, it is important to have information about the target species population dynamics surrounding the areas of intervention in order to evaluate the problem more accurately.

For large carnivores this evaluation is even more difficult, since the numbers of roadkill are usually low, needing longer periods of time to gather enough data.

Criteria to select most appropriate mitigation measure according to site conditions

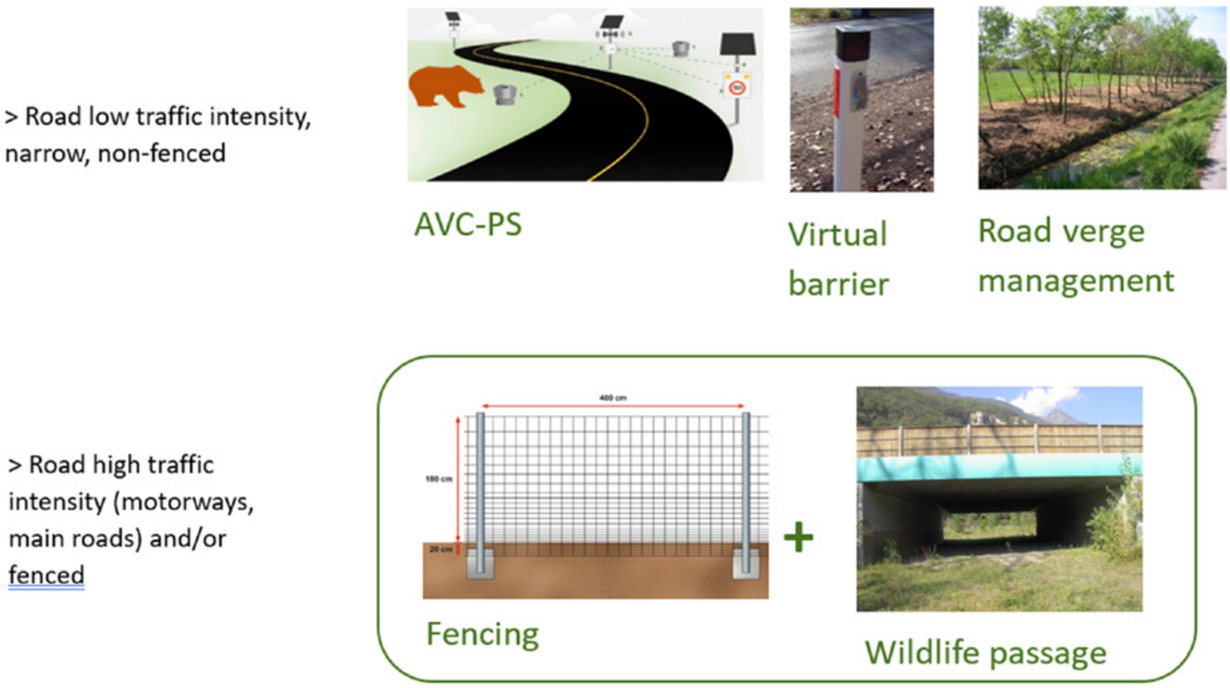
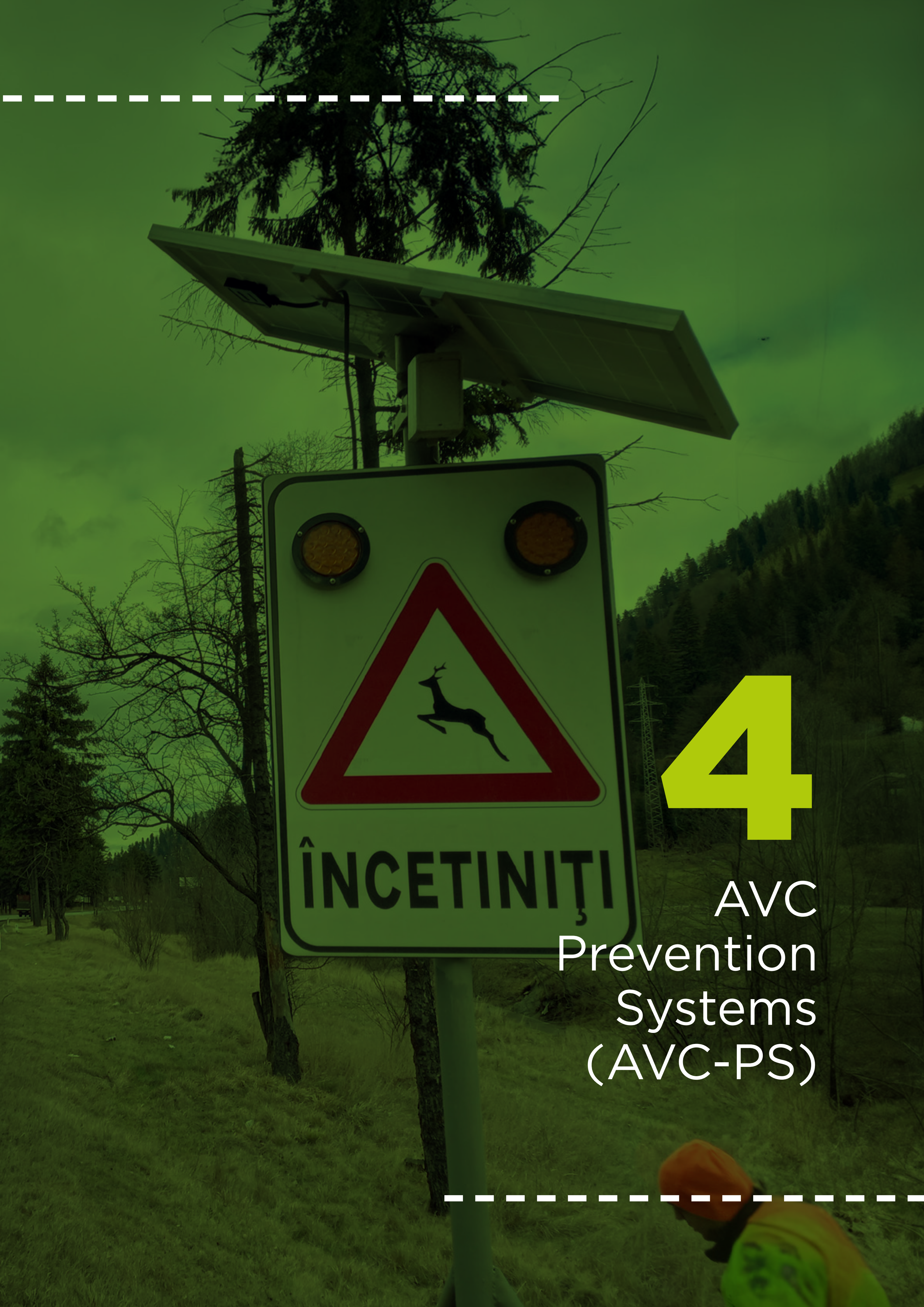


Table 3.7. Criteria to select most appropriate mitigation measure according to site condition.



4 AVC Prevention Systems (AVC-PS)

4

AVC Prevention Systems (AVC-PS)

4.1 | General description and technical characteristics of the components

REMARKS

- **AVC-PS are appropriate for use on local roads with low to moderate traffic intensity and vehicles circulating at speeds under 90 km/h.**
- **The installation must be adapted to each particular site and frequent checking of equipment and maintenance must be provided.**
- **A reduction in AVC has been demonstrated at many road sections where these systems have been installed. Poor installation design and not optimal ADS location causes reduced effectiveness.**

The AVC-PS is an innovative electronic system based on Animal Detection Systems (ADS) to prevent wildlife vehicle collisions. This system was first developed under the LIFE STRADE project and then improved in the framework of the LIFE SAFE-CROSSING project.

The system acts on wildlife and drivers simultaneously and functions as follows (Figure 4.1). A set of passive infrared (PIR) sensors (1) and/or thermal cameras detect the presence of an animal near the road and send the information to the electronic control unit (2). The control unit triggers an alert signal for drivers (3), urging them to slow down. A radar doppler sensor (4) measures whether the car actually slows down to a fixed threshold speed (50 Km/h usually). If so, the system ceases the warning. If not, the radar sends a signal back to the control unit which activates an acoustic deterrent device (5) to deter the animal from crossing.

All the components of the system are connected through a WIFI network and a modem sends an email, each time a component is triggered.

A specific software has been developed in order to store and classify all information registered by the system and through an App it is possible to control the device in real time. This functionality is important to facilitate ensuring proper functioning, but also to monitor its effectiveness.

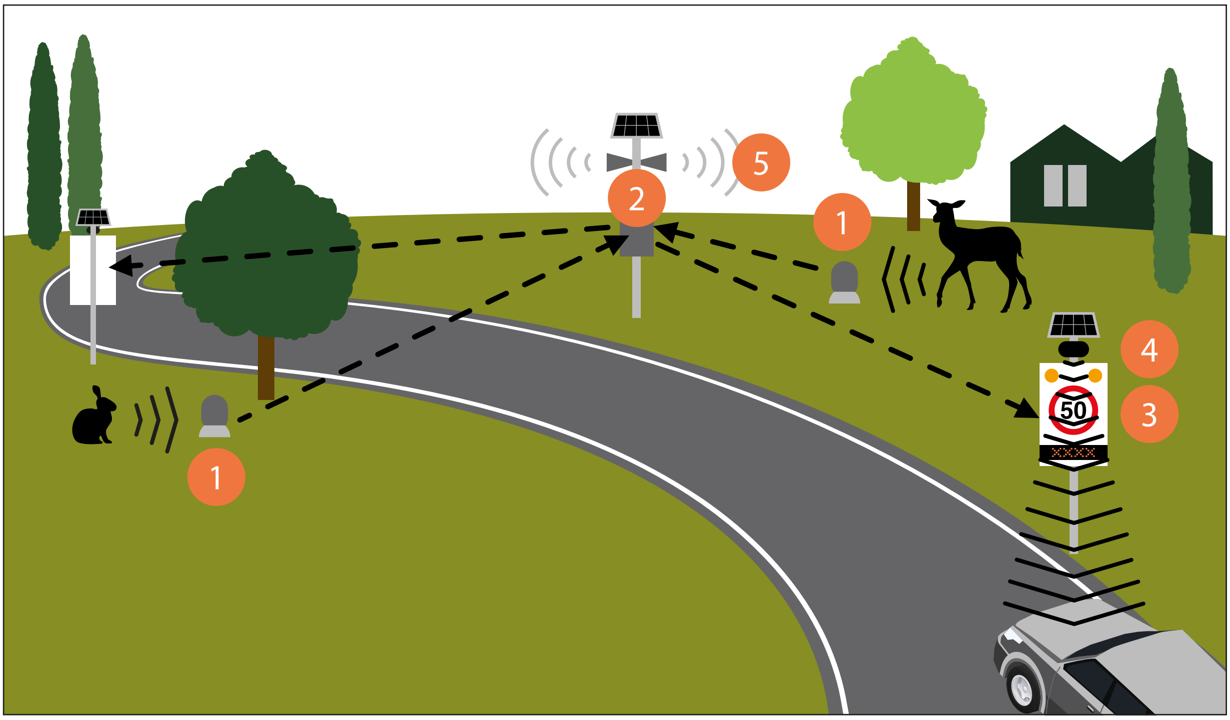


Figure 4.1. Diagram illustrating how the AVC-PS functions. 1. PIR sensors and/or thermal cameras / 2. Electronic control unit / 3. Wildlife awareness signal for drivers / 4. Radar doppler sensor / 5. Acoustic deterrent device. Source: LIFE SAFE-CROSSING.

Control unit

The control unit is the core of the system, using a microprocessor to receive and send information from and to the other components. It is contained in an electrical box installed on a steel pole of 90 mm diameter and 4.5 m height. It is powered by a battery of 55 Ah, charged by a 200 Watt solar panel (Figure 4.2). The router and modem as well as receivers for the PIR sensors are also inside the control unit box.

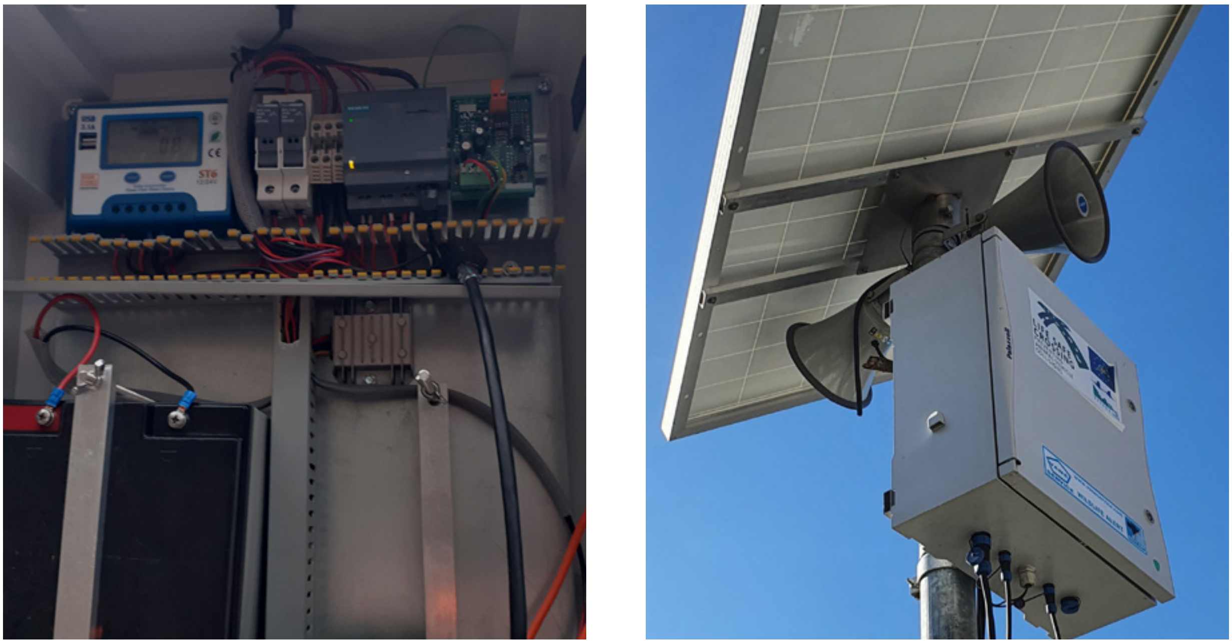


Figure 4.2. Control unit of the AVC-PS with solar panel. A. View of the interior of the box. B. General view of the control unit including electric box, solar panel, thermal camera and deterrent device. Photos by: LIFE SAFE-CROSSING.

PIR sensors

The PIR sensors are used to detect animals near the road. Several sensors are installed along the trails or paths used by animals to approach the road (Figure 4.3A-B). They can be installed directly onto a tree or on a pole.

The PIR sensors have the following characteristics:

- Detection range: max 12 m; angle 90°.
- Standby time can be programmed: 5 sec or 120 sec.
- Power supply: 9 volt lithium battery.
- They can be installed at a maximum distance of 200 m from the central unit.

Thermal camera

A thermal camera is another option to detect animals approaching the road. It registers the heat produced by a live body, warmer than the background and converts it into a visible image on a screen. It cannot detect animals behind an obstacle (e.g. a tree or a wall). The detection area of the thermal camera can be programmed to take into account the direction of movement of animals (Figure 4.3C). For each activation, the thermal camera sends 3 snapshots and records a video. The thermal camera is located in a central unit box and has both an optical and thermal lens.

Technical characteristics are the following:

- Detection range: ~ 100 m.
- Field of view: H 87.8° V 63.8°.
- Power supply: solar panel.

Figure 4.3. AVC-PS detection systems. A and B: PIR sensors used to detect the presence of animals approaching the road. C. Thermal camera installed in a central unit box; D. Visual and thermal images of a programmed detection area shown on a computer screen.
Photos by: LIFE SAFE-CROSSING.

Awareness signs for drivers and radar doppler

Awareness signs for drivers are installed on both sides of the road. The dimensions are 60x90 cm, consisting of the traditional wildlife crossing warning sign and two flashing lights. Below this panel there is a digital panel of 20X40 cm. Both panels are installed on a steel pole of 60 mm diameter and 4 m height (Figure 4.4). The panels are powered by a battery of 55 Ah charged by a 100 Watt solar panel. On the steel pole above both panels there is a radar doppler to measure the speed of approaching vehicles. Depending on the size of the vehicle, the detection distance of the radar doppler is ~ 100-200 m. Behind the flashing light panel there is an electrical box housing the battery, a receiver and transmitter to communicate with the central unit.

Figure 4.4. Wildlife sign connected to animal-detection systems, with flashing light and digital panels including a message to warn drivers about the presence of an animal on the road or its verges. Photos by: Minuartia. LIFE SAFE-CROSSING.

Once the PIR sensors or the thermal camera are activated by the presence of an animal close to the road, the message 'ANIMAL ON THE ROAD' appears on the digital panel. If at the same time, the radar doppler registers the presence of a vehicle, the panel starts flashing the warning lights and the digital message switches continuously between 'ANIMAL ON THE ROAD' and 'SLOW DOWN'.

Acoustic deterrent

If an animal is detected close to the road when a vehicle is approaching at high speed (over 50 km/h), recorded tracks of different types of sounds can be activated, alerting the animal and deterring it from attempting to cross the road. An MP3 player is located in the control unit and the sounds are emitted by two 30 Watt loudspeakers installed on the top steel pole holding the central unit (Figure 4.5).

The sounds include human voices and dogs barking and were specifically chosen to have a strong association with potential risk for large carnivores and ungulates. The different sounds are played randomly in order to avoid possible habituation by wildlife. They are activated only if an animal and a car approaching faster than 50 km/h are detected simultaneously. During a period of 3 minutes since the animal has been detected any car detected will activate the acoustic deterrent. This is a way to reduce the roadkill risk for animals that stay in the surroundings of the road after being detected.

Figure 4.5. Loudspeakers to emit deterrent sounds mounted above the central unit of the AVC-PS. Photo by: LIFE SAFE-CROSSING.

Software and App

The functioning of the AVC-PS can be controlled in real time through an App which allows to check if the system is working appropriately as well as to program its operating time and to access videos taken by the thermal camera (Figure 4.6).

System activations are classified by an internal software that receives messages sent by the modem. The data collected are:

- Activation of the PIR sensors.
- Activation of the thermal camera with attached snapshot
- Activation of the MP3 player
- Vehicle speed reduction

The data registered can be exported as an Excel file and can be visualised as a table on hourly basis or in a graph format.

The activation of PIR sensors and thermal cameras correspond to the times when the presence of an animal close to the road has been detected. The activation of the MP3 player means a 'risk situation' since it involves an animal detected close to the road and a vehicle detected travelling at more than 50 Km/h.

Speed reduction means a decrease of at least 20 Km/h after 4 seconds since the first detection of an animal, when the flashing light and digital warning panels are triggered. This parameter is recorded as 'Yes' or 'No'.

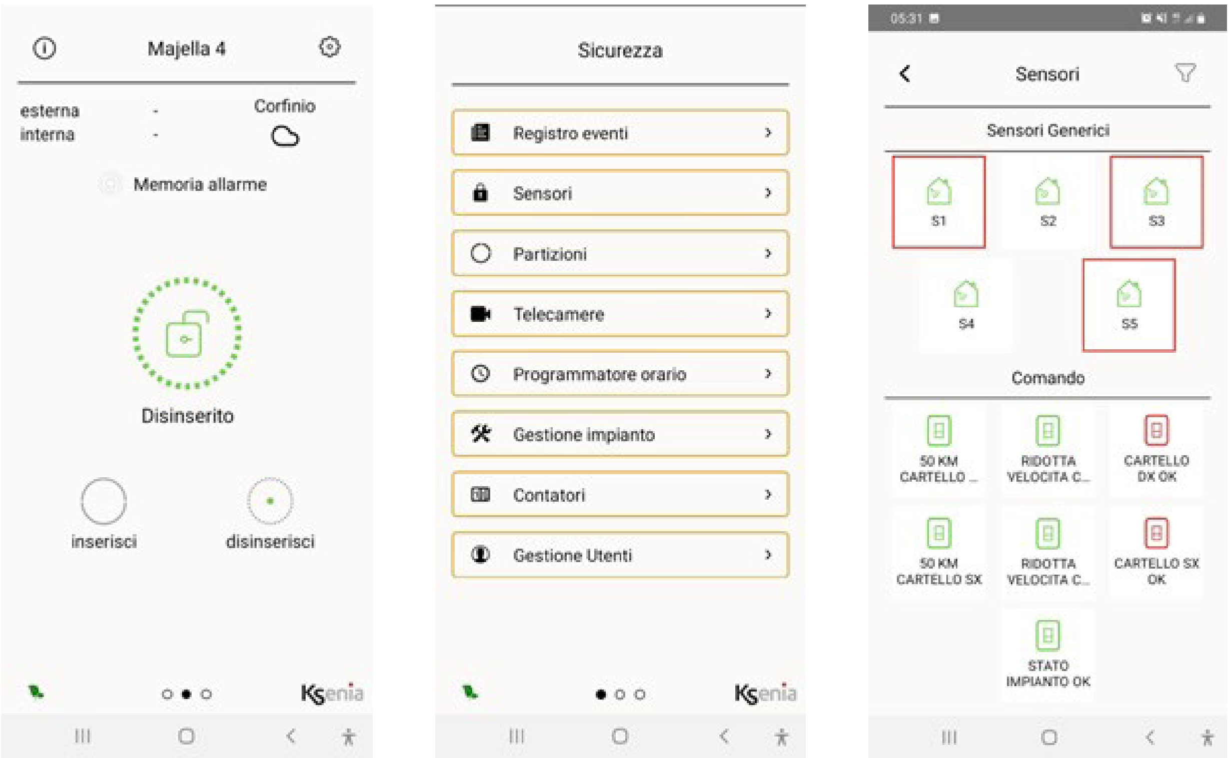


Figure 4.6. Existing App allows to test in real time the functioning of the system, activate or desactivate specific sensors, and register which components have been activated.
Photos by: LIFE SAFE-CROSSING.

4.2 | Installation of the AVC-PS on the road

The installation of the system must be authorised by the local road management authority and undertaken in cooperation with road operators. Joint inspection by experts in wildlife behaviour together with road and traffic technicians is recommended to agree the optimum position of all the system components.

The steel pole for the central unit has to be installed as close as possible to the section where higher numbers of animal crossings (or AVC) have been registered, at the side of the road, preferably at straight sections. The two panels including warning signs must be located 200-300 m from the central unit, one at each side of the road corresponding to the direction of traffic, allowing enough time for drivers to slow down. Visual and barrier free contact between the flashing light panels and the central unit is preferable to avoid obstructing signal transmission. Where visual contact is not possible, a signal repeater must be installed to maintain signal transmission.

The PIR sensors have to be installed at a maximum of 200m from the central unit and located in the vicinity of the road, close to trails or paths that large mammals use to approach the road before crossing. The location must be adapted to local conditions, but must guarantee that an approaching animal is detected with enough time before a vehicle arrives at this potential crossing point. Height above the ground must be chosen according to target species (Figure 4.7).

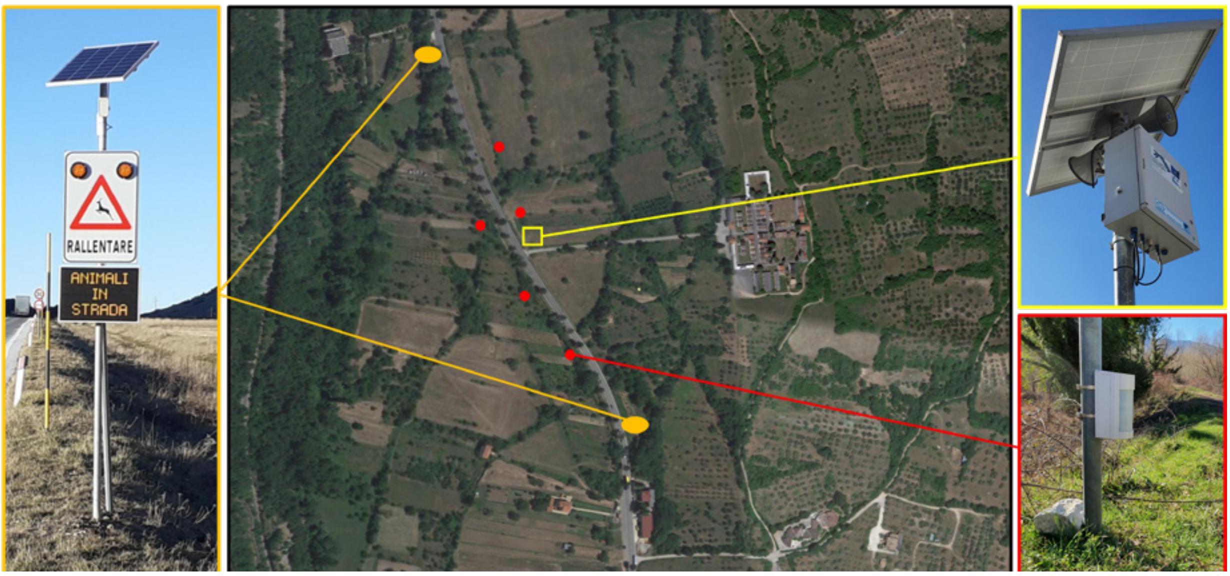


Figure 4.7. Position of the different components of an AVC-PS. Example from Maiella National Park. Road SS 17 in Pettorano, including 5 sensors and 1 thermal camera. Photos by: Maiella National Park.

4.3 | Maintenance and attention points

AVC-PS requires regular inspections both remotely and on site, to check appropriate functioning. Remote inspections can be undertaken through the App which can check if all components are working properly. While on-site work is required to solve any problems detected, a monthly visual inspection to ensure correct functioning is also necessary. Two people must be on site, one to move along the detection area to activate PIR sensors and/or the thermal camera, simulating the presence of an animal, and the other to check the correct functioning of the warning panels for drivers and the timing of the acoustic deterrent activation.

Most common problems and attention points are:

• **Battery charge**
The solar panel must be in full sun and not be shaded by the branches of trees.
The solar panel regulator fuse must be checked and, if necessary, replaced.
During winter months with periods of prolonged bad weather, particularly in more mountainous areas, it could be necessary to install an external battery to ensure the system does not shut down due to lack of battery charge.

• **Cable corrosion**
In humid or coastal areas or where salt is used to grit roads, especially in mountainous or colder areas with higher frequency of gritting, cables are susceptible to corrosion and require more frequent replacement.

• **Internet connection**
It is very important to check internet coverage levels on site before the installation of the AVC-PS. If coverage problems appear after the installation, an antenna can be installed to increase the power of the signal.

• **Data storage**
Storage capacity of SIM cards must be checked. Systems including thermal camer-

as need at least 15 Gb/month, while systems that only involve PIR sensors can operate with 5 Gb/month.

• **PIR sensors**
The area in front of the PIR sensors must not be covered by vegetation. Regular inspections and maintenance are required, particularly during spring and summer.

The installation of a camera trap device is highly recommended to monitor if the PIR sensors are really being activated by wildlife (or humans) or if 'false positive' activations are occurring due to PIR failures (Figure 4.8). This also contributes to gathering information about the behaviour of target species crossing the road.

Correct position of the PIR sensors must be checked preferably with the help of a dog, which simulates the movement of wildlife, in order to ensure detection is happening correctly through all the passages. This is also important to select the right height above the ground at which the sensor must be installed to detect the target species.

• **Thermal camera**
This device is suitable only in open areas with low vegetation because, in forested or even bushy areas, the vegetation creates obstacles blocking the detection of wildlife body heat.

One thermal camera can detect wildlife on both sites of the road. However, some vehicles such as large trucks may activate the operation of the warning signs when they enter the detection area, creating a 'false positive', with no wildlife approaching the road. In this case it is necessary to change the programming of the detection area or the camera.

Correct setup of the thermal camera detection area must be undertaken with the help of a person simulating the movement of wildlife in order to determine the effective detection range. Changes can be made modifying the orientation and settings of the camera.

• **Video downloading**
Videos recorded by the thermal camera must be regularly downloaded and stored. Analyses of such images may provide information about the animals' reactions to the acoustic scaring device, helping to evaluate possible habituation and to identify which of the sounds used are more effective.

Figure 4.8. Maintenance of the different components of the system is key to ensure an appropriate functioning. Photo by: LIFE SAFE-CROSSING.

4.4 | Monitoring

The evaluation of the effectiveness of AVC-PS was undertaken within the framework of Life Strade and LIFE SAFE-CROSSING projects. In both cases, a significant reduction in AVC was achieved at many – but not all – the road sections where this measure was applied. In cases of a failure to achieve a reduction of the roadkill number, a key issue is to determine if all the elements of the electronic system are properly installed and functioning. The location of PIR sensors and thermal cameras, their sensitivity and appropriate data transmission to the central unit are critical for success.

In the LIFE STRADE project (LIFE STRADE, 2017) the number of AVC registered in the period before the installation of AVC-PS (12-34 months) was compared with the AVC registered after the installation of the systems (14-30 months), along the whole monitored segment. AVC data included information registered by the staff of the project and by the provincial administration. The monitoring was undertaken at 12 local road sections including 128.5 km, all of them with low-medium traffic intensity (variation from 2,000 to 10,000 cars per day) and speed limited from 70 to

90 km/h. The reduction of AVC achieved varies from 38.61% to 100%, except in one case, where no differences in the AVC number before and after the installation of the device were registered.

Within the framework of the LIFE SAFE-CROSSING, monitoring is being undertaken in all project areas. In the Maiella National Park it has been conducted for a longer period of time and data collected provides preliminary results. AVC-PS have been installed on 4 local road segments over a total of 2.1 km where traffic volume is between 2,000-3,500 cars per day and speed limit is fixed at 50 or 70 Km/h. Roadkill data before the installation of the devices (2009-2021) was provided by the road and traffic administration and complemented with data gathered by the National Park technical staff and other observers. Moreover, since 2019 the road segments were systematically monitored twice per month by the technical staff of the National Park to record all animals found dead before and after the installation of the AVC-PS (see Section 3.4). All roadkill data was compiled in a database by the National Park.

Preliminary results in this study area show a decrease in the number of AVC after the installation of the AVC-PS in three of the four road segments (Antonucci & Di Domenico 2023; Table 3, in the sector Majella 3 no AVC occurred before the installation nor after that). The number of AVC in these three segments shows a reduction of 65% (2019-2021 vs 2022-2023) (Table 3) with a reduction range of 100% to 10%. Appropriate location of sensors covering the wildlife movement areas is critical to ensure effectiveness.

Several studies developed in the USA (Huijser et al., 2015) and more recently in Europe (Bhardwaj et al., 2022)show that active wildlife warning signs activated by ADS, even without the use of the acoustic deterrent, achieve an important reduction in the numbers of AVC and are more effective than standard warning signs. New technologies enable the constant improvement of accuracy and reliability of such devices based on ADS. The challenges are to guarantee that i) the system is always activated when an animal approaches the road – avoiding a 'False negative' when the system is not activated by an animal crossing the road – and ii) all or most of the activations of the system are caused by the approach of animals, or humans, but not by other factors – avoiding 'False positives' when the system is activated by factors that are not a risk to traffic.

Table 3. Number of large carnivore and ungulates roadkill registered before and after the installation of the AVC-PS in four road sections in the Maiella National Park project area (from Antonucci e Di Domenico 2023). Note: In Majella 4 both AVC registered after the installation occurred in an area not covered by any of the installed sensors.

Code of road section with AVC-PS	Road length (m)	Before (2019 - March 2021)	After (March 2021 - May 2023)	Roadkill reduction
Majella 1	526	8	0	100%
Majella 2	472	10	9	10%
Majella 3	518	0	0	-
Majella 4	624	13	2	85%

The behaviour of animals when the acoustic deterrent is activated is another interesting topic of investigation. Sounds such as voices of humans and barking dogs are emitted by the acoustic deterrent in the AVC-PS when an animal approaches the road and a vehicle approaches faster than 50 km/h simultaneously. Sounds that animals can associate with real potential risks, like a danger or alarm call from the same species or human voices) have been demonstrated to be more effective than sounds with no meaning for wildlife (Babińska-Werka et al., 2015; Seiler & Olson, 2017; Berndt, 2021; Bhardwaj et al., 2022a, and references therein).

The revision of the images recorded by the camera traps and the thermal cameras (Figure 4.9) provide interesting information about behavioural responses to the sounds emitted by the AVC-PS. A pack of wolves frequently was observed in Maiella National Park stopping and waiting to cross the road until the acoustic warning sound of human voices and dogs barking stopped playing. Wild boar and deer were observed running away from the road or interrupting foraging activity and increasing attention to their surroundings when the acoustic deterrent was activated. Monitoring of the animals' behaviour will continue in order to verify the possible occurrence of habituation phenomena.

Figure 4.9. Wolves and deer images from thermal cameras of the AVC-PS installed in the Maiella National Park. Photo by: LIFE SAFE-CROSSING.

5

Visual and acoustic deterrents: ‘virtual barrier’

5

Visual and acoustic deterrents: ‘virtual barrier’

5.1 | General description and technical characteristics of the components

REMARKS

- **VB is a visual and acoustic deterrent that can be installed on local roads with low to moderate traffic intensity and vehicles circulating at a speed under 90 km/h.**
- **It is functioning only during the night as it is activated by vehicle headlights.**
- **The measure aims to modify animal behaviour, ideally to stop the animal moving towards the road or move away from it while vehicles are passing, and enabling them cross freely when there are no vehicles.**
- **The effectiveness in terms of reduction of AVC has not yet been established on the roads where is being tested in the framework of the LIFE SAFE-CROSSING, as monitoring is ongoing.**
- **Effects on the behaviour of target species living in areas adjacent to roads must be investigated.**

The wildlife deterrent system known as ‘virtual barrier’ (VB), consists of electronic devices that produce sound and light stimuli when activated by sensors that detect the headlights of approaching vehicles. These stimuli aim to deter wildlife entering the road when vehicles are passing.

The system is conceived as a row of electronic units, located at distances of 50 m maximum, mounted on road posts or safety barriers on both sides of the road, all along the stretch where animals cross frequently (Figure 5.1). The sound and light emitted by the electronic units are directed towards road verges, away from the road platform. Each unit is powered by a lithium battery charged by a solar cell and has strobing LEDs, which emit blue and amber light, and two sound settings, one recommended for rural areas and a higher frequency (less audible to people) recommended for residential areas.

The main difference between VB and ‘warning wildlife reflectors’, which have been proven to not be effective (Brieger et al., 2016; 2017; Benten et al., 2018a; 2018b; 2019), is that when the sensor detects headlights from a vehicle, the VB actively emits deterrent stimuli instead of just reflecting the light from vehicles like wildlife reflectors do. Moreover, a variation in the sounds and lights stimuli emitted assists with avoiding animal habituation.

In the frame of the LIFE SAFE-CROSSING project VB was installed on 36.5 Km of roads in Spain, Romania and Italy. In the Maiella National Park a new type of devices was installed which units are wirelessly connected. When the first unit is activated triggers the following units, which can be particularly useful in the road segments with many curves. Each chain of connected devices is composed by 12 units.

Figure 5.1. Virtual Barrier emitter units installed on road post in Spain and Italy.
Photo by LIFE SAFE-CROSSING.

5.2 | Installation of the virtual barrier on the road

The installation of the virtual barrier must be authorised by the road management authority and must be carried out in cooperation with road operators.

The units can be mounted on road posts or holding in safety barriers, walls or other roadside features (Figure 5.2), spaced at 50 metres from each other. On the other side, the same units must also be installed but not be aligned opposite each other, being displaced 25 m. Following these guidelines, 40 units are required to cover 1 km of road on both sides.

Figure 5.2. Installation of the Virtual Barrier emitters of sound and light on a road safety barrier (A) and in road posts (B). Photo by LIFE SAFE-CROSSING.

5.3 | Maintenance and attention points

Virtual barrier units have a low cost of purchase and installation and require only moderate maintenance when compared with other mitigation measures such as AVC-PS. Maintenance tasks to be undertaken and main attention points are:

- The sensors activating sounds and lights when vehicle headlights hit them must be periodically cleaned.
- Regular cutting of road verge vegetation is necessary, more often in spring and summer.
- On mountain roads, snow can cover the devices during some periods in winter. The virtual barrier units can also be damaged in such conditions.
- It is recommended to check that the units are properly activated by headlights of passing vehicles at least once a month. This survey must be undertaken in darkness, by a team of at least two persons, one to drive a vehicle along the section where devices are installed and the other to walk along the road verge to verify the emission of light and sound. In cases of malfunctioning, the problem may be the battery charge or an electrical fault which may require assistance from the manufacturer.
- If monitoring camera traps are installed to investigate animals' reaction, special attention should be paid to ensure these are installed where they cannot be activated by approaching vehicles.

5.4 | Monitoring

The effectiveness of VB is still controversial. In a three-year trial of a VB installed to reduce wildlife roadkill in north-eastern Tasmania, Fox et al. (2019) reported a 50% reduction in roadkill number, concluding that the system had the potential to substantially reduce roadkill rates. This conclusion was criticised by Coulson & Bender (2019), who stated that evaluation of the effectiveness of the VB was not possible due to the many flaws in the design and analysis of the previous study. Fox & Potts (2019) replied in another paper defending their conclusion and reporting reductions in roadkill after installation of VB in AVC hotspots in Austria.

Within the frame of the LIFE SAFE-CROSSING project, the effectiveness of VB in reducing AVC is not yet established. Evaluation is undergoing in two test sites in Romania, one in Spain and two in Italy, with a total of 16.5 km of roads with VB being monitored. Preliminary results (Table 4) are positive with a reduction of AVC in all road sections where VB were installed. However, the numbers of AVC registered before the installation were too low to evaluate the significance of the data. Moreover insufficient time has elapsed since the installation to demonstrate any conclusive result about the potential habituation of the animals.

Table 4. Number of large carnivore and ungulates roadkill registered before and after the installation of the Virtual Barrier in several study areas. Source: Abruzzo and Molise National Park; Maiella National Park; Junta de Andalucía and National Institute of Forest Management and Research 'Marin Dracea').

Code of road section with VB	Road length (m)	Before Period year-year (n month and n AVC)	After Period year-year (n month and n AVC)	Roadkill reduction (%)
Abruzzo 1	5			
Maiella 1	9			
Majella 2				
Spain 1	4.5			
Romania 1	2			
Romania 2	3			

6

Driver and road user awareness signs campaigns

6

Driver and road user awareness signs campaigns

REMARKS

- **Driving behaviour is a critical issue in the avoidance of accidents involving animals. Driving attentively and at low or moderate speed is a key factor in avoiding collisions with wildlife on roads.**
- **Awareness and information campaigns addressed to drivers and local communities about how to reduce the risk of hitting a large animal on local rural roads is essential to complement the application of mitigation measures.**
- **Effective, informative road panels design must be based on appropriate communication strategies. The use of short clear messages is required, combined with images that make clear to drivers the risk of colliding with a large animal crossing the road as well as their power (by appropriate driving behaviour) to avoid collisions and contribute to preserving wildlife.**

Raising the awareness of drivers about the hazard of wildlife vehicle collisions is an important tool to mitigate the wildlife roadkill risk and increase traffic safety. Driving behaviour is too often underestimated as a risk factor, even though low speed and high attention are critical in avoiding a collision when a driver encounters an animal crossing the road.

Within the framework of the LIFE SAFE-CROSSING project, a great effort was made to promote awareness raising campaigns through the production of information materials (leaflets, posters and stickers) as well as organisation of public meetings, dissemination of information to media and involvement of local driving schools (Figure 6.1). A videogame for children, both future drivers and also influencers of their parents' driving behaviour, was also produced.

Figure 6.1. Poster distributed in local driving schools to raise awareness and provide information about how to behave behind the wheel to avoid collisions with large animals. Photo by LIFE SAFE-CROSSING.

Innovative information road panels were used to raise drivers' awareness as standard wildlife awareness signs has been demonstrated to have little or no effect on driver behaviour (Huijser et al., 2015) due to habituation resulting from permanent signs that become meaningless even if animals are present. The installation of such standard signage is in many cases undertaken just to fulfil legal requirements or avoid legal conflicts for road management authorities in the event of accidents involving wildlife.

The challenge was to produce information panels which really motivate a change in driver behaviour, prompting them to reduce their speed and pay increased attention.

From a communication point of view a stimulus is effective when, on a perceptual - cognitive level, the information given is read according to an unequivocal order, with sufficient time to be interpreted in an easy, memorable and engaging way. For this reason, a test of which type of roadside, large-scale poster panel was the most effective was developed. Four different prototypes of panels devised using 4 different creative hypotheses were developed and tested applying neuro-marketing techniques. Over 30 native speaking, driving licence holders were shown each prototype in a virtual reality setting and their responses were evaluated using neuroscientific tools (Figures 6.2; 6.3).

The participants were fitted with an eye tracker and were subjected to an electroencephalogram (EEG) (Figure 6.3). An eye tracker is a device that records eye movements, measuring the corneal reflection through infrared light. It indicates:

- which part of the panel a person is observing at any time
- how this person collects information that will be analysed in the brain
- how long this person lingers on details

An EEG records changes in electrical potential generated by the brain. It helps in the understanding of which contents are easy to understand and coherent depending on predetermined aims. It measures when people:

- are attentive
- memorise
- refer to pre-existing knowledge
- struggle to elaborate information.

At the end of the experiment a qualitative interview was carried out. This is a tool commonly used to deepen people's experiences and the meaning they give to them.

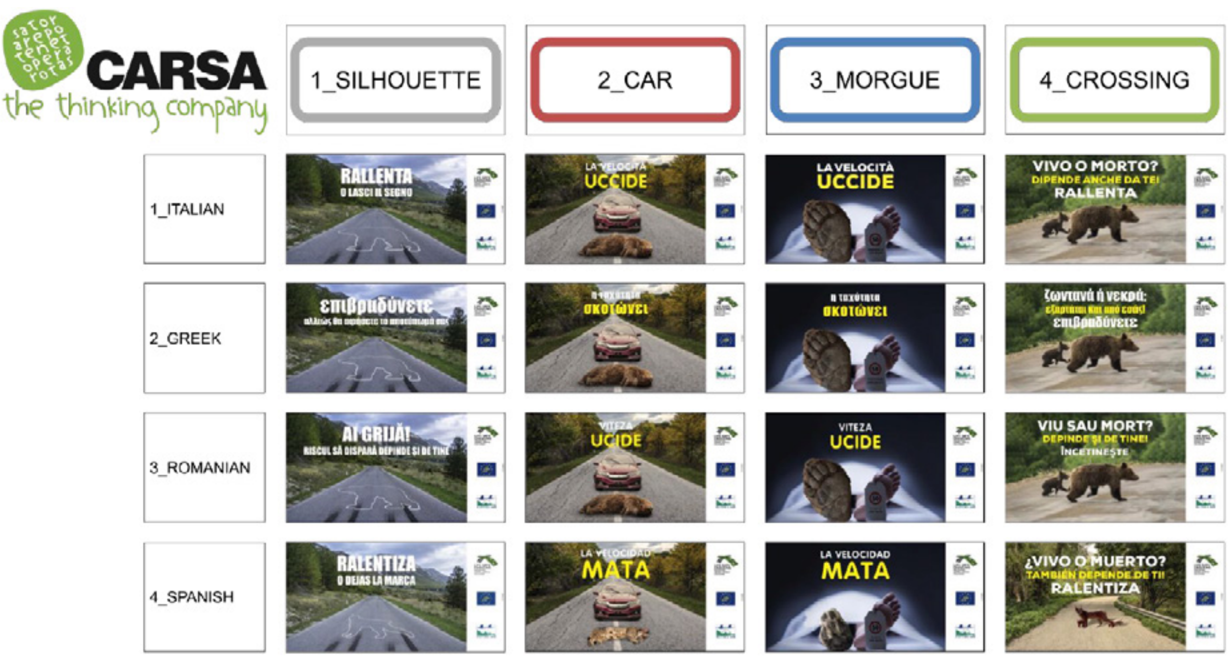


Figure 6.2. Innovative informative roadside panels including four creative messages tested in the study carried out in the LIFE SAFE-CROSSING project. Source: CARSA.

Figure 6.3. Test undertaken using neuromarketing techniques to select the most effective design of roadside panels to be installed. Photo by Carsa.

The results obtained were used to select messages that best achieved the goal of making drivers aware of the importance of reducing speed to avoid a crash with an animal. Best results are achieved by panels which included the short, clear message 'SLOW DOWN. SPEED KILLS' centred over an image of a female Brown bear with a cub crossing the road (Figure 6.4). This result indicates that the best results can be achieved by using clear images showing the hazard but also communicating in a positive way, the potential to keep wild animals and their offspring alive if drivers are calm and attentive. A second panel design was selected in this case with an image showing the damage caused by a crash between a car and a bear.

In order to monitor the effectiveness of the roadside panels installed, a questionnaire was submitted to drivers in the study areas. Altogether 1,319 respondents filled out the questionnaires from the four project countries. After exposure to the information posters, on average, 77% of all respondents stated they changed their driving behaviour by slowing down and driving more attentively. The large majority of respondents indicated that installing these types of roadside poster-panels would be beneficial in protecting large carnivores. Even if this survey was not based on a statistical sample design, it reflects the success of this action and the importance of improving human communication of important messages when facing the challenge of reducing large carnivore road mortality.

Figure 6.4. Roadside awareness raising panels installed in the project areas.
Photo by LIFE SAFE-CROSSING.

7

Road verge management

7

Road verge management

REMARKS

- **Verge management must avoid providing food or refuge to large mammals on roadsides. This could create an ecological trap, attracting animals to areas with high mortality risk and increase numbers of accidents involving animals.**
- **Avoid garbage containers to be located beside roads, keep a strip both sides of the road with vegetation cleared to not obstruct visibility of animals, or install discontinuous fencing with both ends finishing at entrances of crossing structures are measures that may be applied in hot spots to reduce AVC numbers.**
- **Appropriate roadside management require to be adapted to each particular site, according to road features, target species and landscape conditions. Changes registered over the time may require an adaptation of the maintenance tasks.**

The condition of vegetation and other features of roadside verges may have an influence on large mammal roadkill risk. Attractive vegetation providing food resources or refuge, salt used for de-icing on mountain roads or the presence of garbage containers are some of the factors that have an influence on the risk of accidents involving large mammals such as Brown bear, wild boar and deer, and other (Leblond et al., 2007; Ouédraogo et al., 2020). A density of prey may also attract predators; e.g. an abundance of rabbits (*Oryctolagus cuniculus*) on roadsides may attract Iberian lynx and other predators with a resulting increased AVC mortality risk (Barrientos & Bolonio, 2007; Robles, 2007).

In road stretches where AVC hotspots are identified, it is recommended that a strip of at least 3 m along roadsides is cleared, cutting trees and dense shrubs to ensure good visibility of the animals on the roadside to drivers, allowing them to react accordingly and drive with caution (Rosell et al., 2023). This action could also benefit plant and animal species associated with open lands and pastures and possibly reduce the risk of forest fire spread (LIFE LINES, 2021). Nevertheless, in protected areas this measure may not be suitable - or even permitted – because of potential damage to specific vegetation communities and associated fauna.

Bushes and trees providing attractive food to Brown bears or any other species must not be planted on roadsides. To keep the rabbit population density low and preventing their construction of burrows on road verges could reduce predator attraction, reducing the Iberian lynx mortality risk.

Walls, discontinuous perimeter fencing and other obstacles that have an influence on large mammal movements must be defined, leading the animals to safe crossing points - preferably wildlife passages and other crossing structures such as under or overpasses. Large mammals tend to follow fencing till they reach the end and then attempt to cross, creating a point where AVC risk is increased.

Herbicides and any other potentially toxic products for wildlife must not be used in road verge management. These can affect ecosystems beside roads and some species such as predators and scavengers can be adversely affected by accumulating toxins from consumption of contaminated vegetation, prey species or carrion.

Assessment from wildlife and local experts is necessary to define the best management options to achieve a balance between all conservation goals, considering wildlife and ecosystems but also other essential requirements for traffic safety, people and the landscape.

Cooperation with road operators as well as local stakeholders is required. Traffic safety regulations establish standards that are obligatory in roadside management.

The influence of road verge management on biodiversity has been reviewed for many species and taxonomic groups (EPICroads, 2016; Villemey et al., 2018), including vertebrates (Ouédraogo et al., 2020). However, more research is needed to understand how verge management options influence different parameters, including roadkill. In the framework of LIFE SAFE-CROSSING project monitoring of the influence of clearing vegetation from road verges on wildlife roadkill is being evaluated.

Figure 7.1. Strip of verge cleared to allow visibility of wildlife beside the road.
This type of management could also benefit species of vegetation and invertebrates and reduce the risk of forest fire propagation
Photo by: Junta de Andalucía.

8

Wildlife passages and fencing: upgrading existing structures

8

Wildlife passages and fencing: upgrading existing structures

8.1 | General description

REMARKS

- Fencing combined with wildlife passages is the most effective measure to reduce AVC and the barrier effect on roads and railways with high traffic intensity.
- Fences create movement barriers which may also isolate populations and threat their long-term conservation. To avoid this impact fencing must be designed to lead animals to safe crossing points.
- Modifying existing underpasses and overpasses to become safe wildlife passages provide an optimal cost/benefit balance. Many species and ecosystems may benefit from improved infrastructure permeability.
- Selection and adaptation of structures to be modified as well as restoration of its connections with target species habitats are essential for a successful defragmentation plan.
- Appropriate integration of wildlife passages into the landscape contribute to enhance ecological connectivity, reinforce Green Infrastructure and guarantee long term conservation of target species populations. It also increase the resilience and safety of transport infrastructure.

Fauna passages combined with fencing have been identified as the most effective measure to reduce AVC and habitat fragmentation caused by large transport infrastructure (van der Ree et al., 2015; van der Grift et al., 2017). Wildlife passages are also key elements of the 'Green Infrastructure' (European Commission, 2003) contributing to preserve and restore ecological connectivity and playing a crucial role in the long term conservation of large carnivore and other wildlife populations. These measures are particularly recommended to be applied in high capacity transport infrastructure, such as main roads with heavy traffic and high-speed railways. Even if costs of construction are considerable higher than other measures such as wildlife awareness signs or virtual barriers (see Chapter 3) at long term they can provide an optimal balance cost benefit. This is because they have lower maintenance requirements and their use by large carnivore and ungulates have been proved to increase over time.

To enhance permeability of roads and railways under operation, upgrading existing transversal structures (overpasses and underpasses; Figure 8.1) to enhance their role as wildlife passages may be an effective measure to benefit biodiversity at a low or moderate cost. Constructing new large wildlife passages may also be required in crucial areas for ecological connectivity, where there are no suitable existing structures to be adapted.

Nevertheless, fencing must be always carefully planned and designed, not only to avoid large mammal access to carriageways and reduce its mortality risk, but also to lead animals to safe crossing points. Otherwise, the fence may have a strong barrier effect that could be detrimental for the long-term conservation of some target species. Other risks could be created by fences which are installed only at some sections of the road and not connected to crossing structures. In this case, an increase of the AVC may well be observed at the end of the fence.

On roads located in rural areas or crossing natural protected areas, where fencing may not be suitable, large mammals could be funnelled to wildlife passages and other crossing structures by an appropriate use of vegetation rows, dry stone walls or earthen mounds. Landscapers working together with wildlife experts and road operators can find appropriate solutions adapted to each specific condition.

Guidelines to design and construct wildlife passages could be found in several publications. At European scale, most relevant are the handbook *Wildlife and Traffic* (Iuell et al., 2003) updated and available online at IENE Biodiversity and Infrastructure Handbook (Rosell et al., 2023). Other useful recommendations to practitioners can be found in many other documents such as CEREMA, 2023; Hilthy et al., 2020; Smith et al., 2015; MAGRAMA, 2016.

Figure 8.1. Many existing structures (over and under linear transport infrastructure) may be adapted to increase their use by fauna becoming multiuse wildlife passages. These structures can combine wildlife crossing function with other uses such as drainages, cattle trails or forestry roads. Photos by: Minuartia; LIFE SAFE-CROSSING.

8.2 | Steps to select and upgrade existing structures for use by wildlife

Defragmentation actions to increase the transport infrastructure permeability could be planned at a particularly conflictive road section (e.g. where high frequency of AVC is registered), or at all the transport infrastructures in a region to guarantee the preservation or restoration of ecological corridors for large mammals and other wildlife.

The tasks to be undertaken must include 4 steps which are shown in Figure 8.2 and described below.

Fig 8.2. Steps for upgrading existing overpasses and underpasses to enhance their use by wildlife achieving an optimal cost/benefit balance.

• **Establishing clear goals** and outcome-based objectives for achievement must always be the first step to identifying works to be undertaken. The function of the structure (target species and/or need to provide habitat connections) will determine its structural and landscaping features. Different species show varied requirements, specifically when comparing different species of large carnivore and ungulates. While individual Iberian Lynx and even Brown bears have been registered using modified culverts, upgrading larger structures such as viaducts or large overpasses is required to guarantee that a structure can be used by a wide number of wildlife species. Larger structures also guarantee that they can be used not only by some individuals (e.g. young or resident) but by a wide variety of age categories and by individuals under dispersal. Moreover with an appropriate restoration of their surfaces and access these structures may host a wide variety of habitats where big and small organisms can be found.

• **An inventory of the existing structures at the sections** requiring defragmentation actions is the next task to perform (Section 8.2.1). This action allow to undertake an overall analysis of the road/railway infrastructure permeability identifying how many structures exist at the conflict transport infrastructure stretches and what features these have. This is essential in order to compare the requirement of target species with the features of structures that may be modified to provide safe crossings to them. Field inspection must be completed with information about the landscape and its uses in the surrounding areas. Local stakeholders contributions are also essential to identify uses or activities that potentially could cause disturbance to wildlife.

• **The selection of structures to be adapted as fauna passages,** seeking the optimal cost/benefit balance, is the next step (Section 8.2.2). The location, the type of crossing structure and landscape features in the surrounding land must be considered and compared to requirements of target species. This process aims to address the need to identify which structures have the best features and are located in most appropriate places, coinciding with sites where high numbers of AVC occur and/or fitting with ecological corridors and other areas where movements of large mammals are expected to be more frequent.

• **Identification of the interventions to be undertaken to adapt each structure** is the last step in the process (Section 8.2.3). It consists of comparing the characteristics of the structure selected with the appropriate features for wildlife passages for target species and designing the works to be undertaken in the structure and their surroundings to provide suitable conditions for wildlife use (Figure 8.3).

Throughout these steps, it is key to compare the cost for adaptation with the benefits that will be achieved, allowing investments in these structures which provide the best cost/benefit ratio to be selected. Due to the limited resources available it is important to choose those which will provide the maximum reduction in AVC and/or guarantee a maximum number of fauna crossings.
Even if such evaluation is not easy to undertake, one approach is to compare the cost of works to be undertaken in each structure adaptation - which can be accurately estimated by road designers - with the savings brought about by the reduction in the number of accidents involving large animals, in-

cluding the cost of injury to people, damage to vehicles and road structure and also logistics costs incurred by traffic police and road operators. A more accurate estimation should also include the benefits accruing from nature restoration and large carnivore population conservation.

The use of digital technologies, such as 'Building Information Models' from road operators and ecology experts allow the design of structural modifications as well as restoration of the accesses and surrounding land. These tools also provide opportunities to plan de inspection and maintenance tasks and compile monitoring data. They are essential tools to integrate biodiversity and infrastructure data and to facilitate the cooperation of wildlife experts and transport engineers.

Figure 8.3. Example of upgrading an overpass to a multiuse wildlife overpass. Works consist on providing vegetated strips and installing screens to reduce disturbance from traffic under the passage. All crossing structures with suitable features located in a conflictive road section can be upgraded at moderate costs. Photos by: Jean Luc Barrallier and Vicent Vignon.

8.2.1 | Characterisation of existing structures

a) Types of structures to be included in inventories to evaluate road/railway permeability

There are a wide number of transversal structures constructed on roads and railways under operation for different purposes (e.g. drainage, crossing rivers, forestry roads, cattle roads, pedestrian, cycle or horse trails) which are used, or can be modified to be used by large mammals. Transport infrastructure constructed in recent decades also include wildlife passages which are structures constructed or modified specifically to allow the crossing of fauna. The types of wildlife passages useful to large carnivores and ungulates are described in Table 5.

The inventory of structures already existing at the conflictive road section must include an overall evaluation of all structures, including underpasses and overpasses constructed for any purpose, and also wildlife passages if they exist. The different structures to be focused on when searching to provide safe passages for large carnivore and ungulates are listed below providing the acronyms to identify each structure.

Tunnels and viaducts, even if they have not been constructed specifically for wildlife, may also be included in the inventory of structures as they provide optimal ecological corridors if appropriate habitats across the structure are preserved or restored. Nevertheless, if they carry heavy traffic roads or railways they are not suitable to be adapted as wildlife passages.

OVER THE TRANSPORT INFRASTRUCTURE

Wildlife passages

- Ecoduct (ECO)
- Wildlife overpass (WOP)
- Multiuse overpass (MUO) combining wildlife passage with other uses

Other structures

- Tunnels (TUN)
- Overpass (OVP). Not adapted for wildlife. It may be upgraded to become a 'Multiuse overpass'

UNDER THE TRANSPORT INFRASTRUCTURE

Wildlife passages

- Adapted viaduct (VIA)
- Wildlife underpass (WUP)
- Multiuse underpass (MUO) combining wildlife passage with other uses.
- Modified culvert (WCU)

Other structures

- Underpass (UNP). Not adapted for wildlife. It may be upgraded to become a 'Multiuse underpass' to become a 'Multiuse overpass'
- Culvert/drainage (CUV): Not adapted for wildlife. It may be upgraded to become a 'Modified culvert'

Table 5. Types of wildlife passages suitable to preserve ecological corridors and provide safe crossing for large mammals. Wildlife passages are structures specifically designed for wildlife use, or modified to combine it with other uses. Fencing (or other elements) that funnels the animals to the entrances, screens to reduce disturbance by traffic and appropriate maintenance must be provided.
(Source: IENE Biodiversity and Infrastructure Handbook;Rosell et al., 2023).

Types of wildlife passages	Description
Overpasses	
Ecoduct; Green bridge; Landscape overpass (ECO)	Large structure over transport infrastructure to provide continuity of habitats from both sides. Due to their width, a diversity of habitat types (e.g. vegetation or soil types, stone rows or piles, ponds, etc.) could be included to facilitate optimal ecosystem connection.
Wildlife overpass; Fauna overpass (WOP)	Structure built over transport infrastructure specifically to provide a safe crossing point for wildlife and to connect habitats from both sides. The surface is covered with natural materials and soil allowing the growth of different species of vegetation. Other refuges for fauna such as stone or wood rows can also be installed.
Multiuse overpass (MOP)	Structure built over transport infrastructure with multiple functions including the movement of fauna. It combines wildlife and human uses such as small forestry roads, cattle passages or pedestrian paths. Modifications are included to encourage use by wildlife such as addition of strips covered by natural materials and vegetation, and screens to reduce traffic disturbance when required.
Underpasses	
Adapted viaduct; Landscape underpass (VIA)	Large structure, usually supported by pillars or arches, which carries transport infrastructure and enables the preservation of valuable ecosystems and ecological corridors below the structure. Preservation and restoration of continuous terrestrial, riparian and aquatic habitats below viaducts facilitate movement of multiple vertebrate and invertebrate species. Land uses and activities under the structure must be compatible with fauna movements and preservation of ecological connectivity. Viaducts must not be considered as wildlife passages when human disturbance or infrastructure with high traffic volume is beneath.
Wildlife underpass; Fauna underpass (WUP)	Structure built under transport infrastructure specifically to provide a safe crossing point for wildlife, typically large and medium-sized mammals, such as ungulates and large carnivores, but also for other vertebrates and invertebrates. Construction types are predominantly box, vault or beam platform structures. The substrate is covered with natural materials and soil allowing different species of vegetation growth where there is enough light and humidity. Elements such as stone rows may provide wildlife refuges inside.
Multiuse underpass (MUP)	Structure built under transport infrastructure with multiple functions including the movement of fauna. It combines wildlife and human uses such as small forestry roads, cattle or pedestrian passages. A drainage function including streams or other small waterways inside the structure is also compatible and may even lead fauna through the passage. Modifications are included to increase wildlife use such as fencing to funnel the animals, adaptation of vegetation at the entrances and measures to avoid excessive pooling of water.
Adapted culvert (WCU)	Modified pipe or box culvert that allows a watercourse and/or drainage to flow underneath transport infrastructure and includes adaptations to facilitate aquatic and terrestrial wildlife crossing. These often include dry ledges or shelves to provide dry passage, which are connected to adjacent habitats. The design and landscaping at the entrances is particularly adapted for the needs of wildlife, not only erosion control.

b) Features for each structure to be recorded

A detailed inventory linked to a GIS database must be performed where all existing structures are characterised. Some information can be obtained from analysing cartography resources while other must be compiled by field inspection.

Data to be recorded is listed in Table 6 including information at least about:

- Location: structure and road code, stretch and coordinates
- Structural features and use: shape, materials, dimensions, function, and other.
- Entrances: obstacles and vegetation.
- Land uses, habitats and activities in the surroundings.

Characterisation of the structures must be undertaken in cooperation with transport infrastructure stakeholders, using proper vocabulary to describe all structural features. In the framework of the LIFE SAFE-CROSSING project, all partners used standardised field sheets providing visual instructions about how to measure the structures and other topics (Figure 8.4). All information compiled was included in a common database.

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)
	☐ Ecoduct (ECO)
☐ Tunnel (TUN)	☐ Wildlife Overpass (WOP)
☐ Overpass (OVP)	☐ Multi-use Overpass (MOP)
☐ Viaduct (VIA)	☐ Wildlife Underpass (WUP)
☐ Underpass (UNP)	☐ Multi-use Underpass (MUP)
☐ Culvert / drainage (CUV)	☐ Modified culvert (WCU)
☐ Other: ______	☐ Amphibian tunnel (ATP)

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

Structure section: ☐ Circular ☐ Rectangular ☐ Vault ☐ Other: ______

Composition of the structure: ☐ 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:

Figure 8.4. Characterization of transversal structures at the conflictive road stretches in the study areas of the LIFE SAFE-CROSSING project was undertaken applying standardised procedures which provided data from over 370 structures (95% underpasses), that were included in a common database. Source: Minuartia, LIFE SAFE-CROSSING.

Table 6. Main features to be recorded from the potential crossing structures to be upgraded to enhance their use by wildlife.

Type of variable	Variables
Identification and location	Structure code
	Road/Railway code and stretch
	PK (0+000)
	Coordinates UTM X; UTM Y
Structural features	Type/ Acronym of crossing structure: see list in the text and Table 5 for Wildlife passages types
	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
	Dimensions: Diameter (m) or Height (m); Width (m); Length (m)
	Openness index (underpasses) or Relation Width/Length (overpasses)
	Structure construction material: Concrete; Corrugated steel
	Substrate material: Concrete; Corrugated steel; Natural substrate
	Presence of water: No; Yes, temporal; Yes; permanent; Water layer depth (cm); Surface covered by water (%)
	Dry ledges: Material; Width
Obstacles at the entrances	Uses of the structure: Cattle trail; Pedestrian trail; Forestry road (unpaved); Paved road; Water channel; Stream crossing; Other.
	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
	Steps Number (e1/e2); Height (cm)
	Ramp slope
Vegetation at the entrances	Dominant vegetation (e1/e2): Arboreal; Bushes; Herbaceous; absent
	Habitat type/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)

Table 6. (Cont.) Main features to be recorded from the potential crossing structures to be upgraded to enhance their use by wildlife.

Type of variable	Variables
Surroundings	Type of fencing: Knotted wire mesh; Welded wire mesh; Other; Absent
	Fence height fence (cm); Density (cm); Buried in the soil: yes; no
	Safety barrier: Absent; B-wave; New Jersey; Other; Height (cm)
	Adjustment to crossing structure entrances (e1/e2): No openings; Other
	Specific adaptation (e1/e2): Reinforcements; Outrigger; Other
Other features and observations	Additional information
	Inspected by / Date inspection / Photos

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

8.2.2 | Criteria to select structures to be upgraded

Main factors to be evaluated for choosing best existing transversal structures to be adapted as wildlife passages, and particularly for use of large carnivores and ungulates are related to:

I. Location
II. Use of the structure
III. Dimensions of the structure

A resume of criteria to be applied for the selection of the most appropriate existing transversal structures to be upgraded for wildlife use is provided in Figure 8.5 and described below.

Requirements to be fulfilled must be compared with those of the existing structures inventoried in the study area to select which have a better fit as potential candidates for upgrading. Expert and local stakeholders knowledge could also be a valuable complement in the selection process.

Criteria to select suitable structures to be upgraded for use by wildlife

Location

Several features related to the location of structures are important to evaluate which are the optimal structures for adaptation.

Overpasses and underpasses prioritised for adaptation as wildlife passages are those that accomplish the maximum number of criteria listed below.

Land use, habitat type and ecological connectivity

- Located in areas with good quality habitat providing resources (food, refuge and other) for target species
- Located in areas identified as ecological corridors or areas of particular interest for allowing movements of target species.
- Absence or reduced human disturbances: no presence of buildings, illuminated areas, fenced grounds or any activities that can disturb wildlife.

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

- Located in or nearby road sections where AVC clusters were identified (see chapter 3). In the framework of LIFE SAFE-CROSSING project the KDE+ analyses undertaken identified two types of significant AVC clusters: 'low sureness' and 'high sureness' which both were considered as road sections where existing transversal structures may be adapted to enhance wildlife use.

Road sections with high frequency of crossing points

- Located in areas intensively used by target species and close to roads where crossing points hotspots were identified. Brown bear was the target species evaluated in the project LIFE SAFE-CROSSING as an important amount of spatial data was available from telemetry. Structures located close to areas with high activity from the target species could coincide with already appropriate structures for crossing, such as tunnels or viaducts or WUP. The adaptation of other transversal structures may not be needed on those sections.

	STRUCTURES TO BE PRIORITISED
1. LOCATION FEATURES	
Surrounding landscape	✓ High quality habitat for target species ✓ Areas of interest for ecological connectivity ⊗ Structures with human disturbance or inadequate uses at the structure and/ or close to the entrances should not be adapted as wildlife passages.
Mortality of target species	✓ Located in road sections where animal-vehicle collision clusters are identified. Select stretches where high rates of wildlife mortality are recorded. Analyses must be undertaken with appropriate methods (KDE+ was the method used in the LIFE SAFE-CROSSING project).
Presence of target species (where information provided by telemetry or other techniques is available)	✓ Located in areas used by target species close to roads. Where both sides of the road are used by target species, but no road casualties are observed, an inspection of the area should be undertaken. If there is already a structure (e.g. a tunnel, viaduct or other) providing crossing opportunities there may be no need to undertake mitigation actions, however considering the modification of an existing structure may be necessary.
2. USES	
Primary functions of the structures which must be compatible with wildlife use	✓ Drainage: particularly structures including river crossings or small water streams ✓ Cattle trails ✓ Pedestrian, horse or cycle trails ✓ Unpaved forestry roads ⊗ Structures including paved roads, particularly those with medium or high traffic intensity should not be adapted as wildlife passages.
3. DIMENSIONS	
Width; Openness index (Standards from the IENE Biodiversity and Infrastructure Handbook)	✓ Overpasses Width ≥ 10 m (multiuse overpass); ≥ 20 m (wildlife overpass to be used by large mammals); ≥ 50 m (landscape overpass to restore ecological corridors). ✓ Underpasses Width ≥ 10 m (multiuse underpass); ≥ 15 m (wildlife underpass to be used by large mammals); Height ≥ 3.5 m; Openness index ≥ 0.75 Structures that do not meet the minimum dimensions provided, could also be upgraded to enhance wildlife passage in particular circumstances. For example where monitoring shows that they are already used by target species, even if crossing frequencies are low.

Figure 8.5. Features to be considered in the selection of existing structures (underpasses and overpasses) to be upgraded to become wildlife passages.

Figure 8.6. Presence of good quality habitats in the surrounding of the structure as well as data from Brown bear movements provided by telemetry (see section 3.4) were used in the LIFE SAFE-CROSSING project to assess the most suitable structures to be upgraded for enhancing large mammal use. Photo by: Abruzzo, Lazio and Molise National Park.

Uses by humans and wildlife

While some uses of fauna passages can be compatible with wildlife crossing (e.g. livestock, pedestrian, cycle, forestry track and drainage), others can compromise it (e.g. heavy traffic flow, rough-sleeping, storage of agricultural machinery, etc.).

Priority should be given to the adaptation of underpasses constructed for:

- Drainage: particularly river crossings or small water streams
- Cattle trails
- Pedestrian trails
- Unpaved forestry roads. Paved roads, particularly those with medium or high traffic intensity, should not be adapted as wildlife passages.

Evaluation of the use of existing structures by target species provide also useful information. Some individuals of large mammal species living in areas with roads constructed a long time ago have become habituated to use existing overpasses or underpasses not specifically constructed as or adapted to provide wildlife passage. Recording data about the species using the structure and crossing frequency (through tracks, camera trapping or other techniques) is also important to assess the structure's potential as wildlife passage and its needs for adaptation. It may be that structures are already intensively used by target species and do not require any modification, while others with limited use by fauna but located in areas critical for connectivity may be selected for adaptation.

Dimensions

To modify the dimensions of transversal structures once they are built requires costly investments. Therefore, this feature is one of the important criteria when selecting transversal structures for adaptation to enhance the use by wildlife.

According to the European standards (IENE Biodiversity and Infrastructure Handbook) a width over 10 m is the minimum recommended for multiuse overpasses and underpasses combining wildlife use with other uses such as drainage, cattle roads, pedestrian trails and other. A minimum width of 20 m for overpasses and 15 m for underpasses is recommended for structures specifically constructed to provide wildlife passages. In all cases a height of 3.5 m is recommended, as well as an openness index (width*height)/length) over 0.75 m in the case of underpasses.

Together with appropriate landscaping, these large structures may provide a fauna passage suitable not only for large mammals but also for a wide variety of species including small fauna.

However, even if large overpasses and underpasses are preferable, existing structures under the recommended dimensions could be upgraded to enhance wildlife crossing in roads and railways under operation. Monitoring of wildlife use of the existing structures could allow to identify which are the most suitable for adaptation. The use of underpasses with dimensions under the recommended standard by Iberian lynx, Brown bear and other species has been reported by several monitoring studies (unpublished data from Fundación Oso Pardo; Egnatia Odos SA; Callisto; LIFE Iberlince project). This fact is probably due that some individuals become habituated and learnt how to cross transport infrastructure existing in their home range areas for a long time. Nevertheless, data from monitoring of underpasses undertaken in Greece in the framework of LIFE SAFE- CROSSING found that a low openness index was one of the factors reducing the Brown bear crossing. Based on this data upgrading large structures is recommended.

8.2.3 | Identification of features to be modified

Once structures to be upgraded have been selected, the next step is to identify what modifications are needed on each structure. This step comes before the development of the detailed design and required budget.

A holistic approach must be applied when upgrading elements of transport infrastructure under operation. Any intervention is an opportunity not only to reduce impacts on large carnivore but also

- to enhance biodiversity
- to restore ecosystems and services they provide to society
- to improve resilience and adaptation of the transport infrastructure in the face of climate change.

Detailed design practice must search for synergies and apply nature-based solutions. The recommended procedure follow the steps described below.

I. Identify which type of wildlife passage is most suitable according to the conditions of existing structures.

Using the characteristics of existing structures as a starting point, the type of wildlife passage to be provided after upgrading must be identified (see Table 5. Section 8.2.1.). Optimal features recommended for each type of wildlife passage as well as target species requirements must be considered.

Fauna passages suitable for large mammal to be provided by the upgrading of existing structures are shown below:

Wildlife passage
(upgrading existing infrastructure)
Multiuse structures
- Multiuse overpass (MUO) – Upgrading Overpasses (trails, forestry roads crossing)
- Adapted Viaduct (VIA) - Viaducts (river, valley or wetland crossing)
- Multiuse underpass (MUP) - Underpasses (drainage, trails, forestry roads crossing)
- Modified culvert (WCU) - Culverts (drainage; large structures preferred)

In strategic locations where there are no suitable structures to be upgraded, but ecological connectivity needs to be restored, the construction of new wildlife passages should be considered. The type of specific wildlife passages for large mammals which could be suitable are:

Wildlife passage
(new construction)
Structures specific for wildlife
- Ecoduct (ECO)
- Wildlife overpass (WOP)
- Wildlife underpass (WUP) - Large mammals

II.
Compare standards recommended for wildlife passages with the present condition of potential structures to be upgraded.

All structures potentially adaptable and their key features must be included on geolocated databases, which provide the basis for using GIS tools and other digital technologies (such as BIM) to undertake evaluation and identify those key features that do not fulfil standards and which need to be improved. The characterization of structural and surrounding variables of transversal structures (see Table 6), helps evaluate which features need modification to enhance use by the target species.

Existing transversal structures can be expected to have features which cannot be easily modified and require important budget, such as modifying dimensions, while other modifications may be low or moderate cost.

III.
Identify and design the modifications to be undertaken to provide wildlife passages for large mammals and explore the potential to benefit other elements of biodiversity

Features of structures and related elements which could be modified at moderate cost are the following:

- Structural features related to the substrate; presence of water in underpasses.
- Human disturbance and uses.
- Obstacles at entrances.
- Vegetation.
- Fencing.

In section 8.2.2 factors to be evaluated for each of these features are described.

Opportunities to benefit other elements of biodiversity which may include all local species of flora, fauna and ecosystems, must also be considered at this step. The ecological restoration of both access to the structure and of the connections with natural habitats must be undertaken to enhance valuable ecosystems and the services they provide. Other synergies could be achieved by restoring vegetation in a way which reduces forest fire hazards and avoid propagating Invasive Alien Species.

Applying Nature-based Solutions must also be considered to contribute to lowering risks posed by extreme weather events linked to climate change while benefit biodiversity. For example, widening a drainage structure and landscaping appropriately provides an excellent wildlife passage and reduces the risk of flooding.

8.3 | Actions to be undertaken

8.3.1 | Structural features

a) Substrate

The standard recommendation to enhance wildlife crossing through underpasses in relation to the inner surface is to provide fauna passages with a dry, natural substrate surface. Concrete is also suitable though not highly recommended. Corrugated steel must be avoided.

In overpasses the surface must be covered by suitable soil to allow vegetation growth. It is recommend to use local soil including native seeds and do not apply fertilisers. Particular measures must be taken to avoid the propagation of Invasive Alien Species when works to provide appropriate substrate are undertaken.

Main surface adaptations are (Figure 8.7):

- Providing the underpass with natural substrate covering the whole structure surface and entrance areas to connect the structure with the surrounding natural environment. Vegetated strips are recommended to be provided at the entrances and also at the overpasses surface.

- If corrugated steel is present at the bottom of the underpass/culvert, creating a flat base surface by covering it with concrete together with a natural substrate covering.

- Installing piles or rows, stones or logs along viaducts or underpasses is useful to provide refuges for small fauna and encourage the use of the structure.

Figure 8.7. Natural substrate is recommended to enhance the use of transversal structures by wildlife. Vegetated strips must be maintained or restored at overpasses. Piles of stones o logs provide refuges for small animals. Photos by: LIFE SAFE-CROSSING (A); Minuartia (B).

b) Dry passages in drainages

The surface of transversal structures should not be completely covered by water permanently or for long periods, during seasonal flooding.

Dry ledges may be constructed at both sides of the structure to improve its use by small carnivores and other fauna (Figure 8.8). Nevertheless narrow ledges are not suitable for large carnivores and ungulates.

To provide dry soil strips at each side of the passage may be also achieved by excavation of a central ditch.

The main water drainage adaptations are:

- Constructing a ditch to guide the water along the underpass and ensure proper drainage if the presence of water is permanent or very frequent. It is possible to excavate one or other of the internal sides of the structure surface to create dry sections which can be used by wildlife.

- Constructing wood or concrete ledges at both sides of structures to enhance Lynx (European and Iberian lynx) crossing. Many other small and medium carnivores (e.g. all species of Mustelidae, foxes and genets particularly) use dry ledges for crossing.

Figure 8.8. Ledges at both sides of drainages can be useful for providing dry passages to small and medium size fauna. An alternative solution to upgrade underpasses for large mammal is to dig a ditch along the central part of the drainage (an example under construction is shown at right). Photos by: (A) Courtesy of the IENE Biodiversity and Infrastructure online handbook; (B) Minuartia.

8.3.2 | Disturbance and uses incompatible with fauna passage

Disturbance by human activity close to or at the underpass should be avoided or minimised. Disturbances are mainly caused by vehicle traffic, light and noise, but also other human activities can deter wildlife from using transversal structure.

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

Traffic

- If the passage is intended to incorporate low traffic use, the central surface may be paved or covered with gravel, but lateral strips of natural soil must be adapted for wildlife use, providing a 2 m wide unpaved strip on at least one side of the underpass.
- In wildlife underpasses which are specifically constructed for wildlife use, placing large stone blocks at the entrances prevents vehicle access and/or crossing of structures specifically adapted for animals.

Noise and light

- Installing opaque screens to reduce disturbances by vehicle light and noise above the underpass. Screens (height ≥ 2 m) should be placed at the top of the structure on both sides of the underpass entrances, ensuring complete continuity with fences (Figure 8.9).
- Undertaking regular inspections to detect and repair defects on screens (holes, incorrect fixing to fences or damage) is recommended. To avoid vandalism, screens should be made of durable materials such as treated timber, stained concrete or metal.

Other human activity disturbances

- Removing any inappropriate material and preventing disturbance through unintended uses such as storage of agriculture machinery, stabling cattle, rough-sleeping, installation of landowner fencing, and other disturbances that often happen in or around underpasses.

Figure 8.9. Opaque screens allow to reduce disturbance from traffic at wildlife passages. Photo by: Minuartia.

8.3.3 | Obstacles at entrances

To enhance the use of crossing structures by wildlife, it is essential to avoid and remove obstacles that hinder wildlife movements (Figure 8.10).

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

Steps or undercuts

- Replacing steps with ramps. Stone bed ramps are recommended to prevent future water erosion degradation (e.g. culverts with frequent running water). Ramp slope: < 45° (Figure 8.10).

Walls or concrete steep ramps

- Replacing walls with ramps will allow the access of fauna to the crossing structures (Figure 8.11).

Pits

- Covering drainage pits with elements that allow fauna to cross, such as a slab of concrete.

Debris obstruction

- Removing plant debris and rock accumulations; restore access once cleared if needed.
- Checking if grids, rods, trees or other elements contribute to debris accumulation. It may be necessary to evaluate whether removing, readjusting or replacing such features is possible.

Figure 8.10. A variety of obstacles for wildlife can be found at the entrance of structures such as big steps (left) which could be modified providing stone bed ramps (right). Photos by: LIFE SAFE-CROSSING.

Figure 8.11. 'Before and After' the construction of a ramp to allow bears to overcome a wall at he entrance of an underpass. Photos by: Egnatia Odos SA.

8.3.4 | Vegetation

To enhance the use of wildlife passages, their entrances and surroundings must also be adapted. Re-vegetation is essential to funnel animals towards crossing structures by connecting the surrounding habitats with the entrances of the structures, mainly to the underpass. This is commonly combined with the installation of fences tailored to fit the entrances of transversal structures (Figure 8.12).

Figure 8.12. Vegetation distribution and fencing must funnel wildlife to the entrance of wildlife passages and provide refuges at both sides of the structures. Wood screens may be installed to reduce disturbance from traffic. Source: by courtesy of the IENE Biodiversity and Infrastructure online handbook.

Main recommendations related to vegetation management are:

Vegetation at the entrances

- Planting vegetation right next to the entrances and leading fauna to accesses.

- Planting vegetation in strips parallel to and outside the perimeter fence guiding animals to the structure entrances and to provide protection from traffic noise and lights (Figure 8.12).

- Providing regularly inspection and maintenance to ensure an appropriate integration of vegetation with the surrounding habitats and to guarantee that no overgrown vegetation prevents animals from accessing the underpass.

Vegetation along the structure
- If riparian vegetation along watercourses is present beneath a viaduct, preserving or restoring it to maintain connectivity.

- Planting vegetation inside long multiuse underpasses or modified culverts is not usually possible due to conditions unsuitable for vegetation growth (by a lack of light and/or moisture).

Species composition

- Planting local species, selecting those adapted to conditions in the surroundings of the structures and with low maintenance requirements (Figure 8.13).

Figure 8.13. Vegetation allows to avoid erosion in embankments and to guide animals though the passage entrance. Local species are used for re-vegetation. Photos by: LIFE SAFE-CROSSING.

- Planting species with edible fruit, attractive to bear or other species at the entrances of the wildlife passage. However if the vegetation is very close to the road, edible fruit trees should be avoided to reduce the risk of bird-vehicle collisions.

- Undertaking regular mowing and pruning of the vegetation to maintain the composition design and prevent any overgrowth which hinders wildlife use of the transversal structure or damages fencing.

8.3.5 | Fencing

Fencing is a key element to avoid animal mortality and reduce road/railway accidents. Well designed and installed, fences prevent wildlife access onto road carriageways or railway tracks and lead fauna to crossing structures (Figure 8.14). Fencing should always be installed in combination with wildlife passages or other safe crossing paths for animals to reduce the barrier effect that fencing create.

Effective fencing should be specifically designed and installed according to wildlife species requirements. Height, mesh size and type, and fence installation are essential factors to be considered for Brown bear and Lynx.

Main recommendations related to fencing are:

General standards for large mammals

According to the European standards (IENE Biodiversity and Infrastructure Handbook - Fencing dimensions) the recommended mesh type and dimensions for large carnivores are:

- Height 300 cm above the ground. Chair link and welded mesh are suitable. Recommended mesh density for Brown bear is 10x10cm while for lynxes 5x5cm is recommended (Figure 8.15).
- Buried on the ground 20-50cm. In the case of Brown bear L-shaped form buried 20 cm vertical and 120 cm horizontal and covered by soil is recommended.
- A 80 cm outrigger on a 45°angle pointing away from the road is recommended.
- Reinforcement of fence posts to prevent bears from tearing it down.

Location of fences at the entrances of wildlife passages

- Fences must lead to the entrance of transversal structures in order to funnel wildlife towards the safe crossing path, without leaving gaps or creating traps for animals by tailoring fences to the passage entrance, where fence posts tie in perfectly with the structures wings or abutments at a height where it both prevents animals accessing the road but permits animals on the wrong side to escape the road area (Figure 8.14).

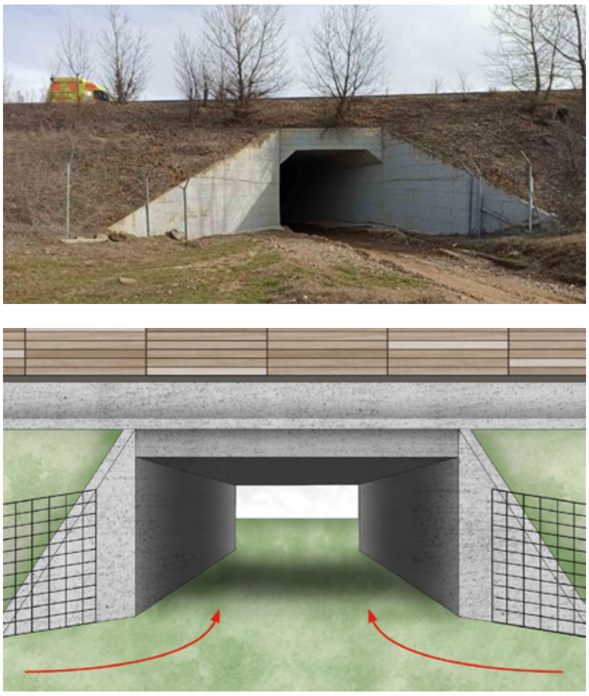


Figure 8.14. Fence fixed at the walls of the underpass funnel wildlife through the underpass and prevent access to embankments. Screen may be installed beside the road to prevent disturbance at the underpass. Photos by: Left - Egnatia Odos SA. Right - By courtesy of the IENE Biodiversity and Infrastructure online handbook.

Regular inspections of fences are required to detect and repair holes or any other damage to the mesh or poles. Incorrect adjustment between the bottom of the fence and the ground or between the fence and the crossing structure entrances should be detected and repaired.

Other minor modifications of fencing could be extremely important to reduce large carnivore roadkill risk. Brown bear often access roads in junctions of fencing with overpasses or underpasses. An elongation of the fence to avoid access to the carriageways could be required (Figure 8.15).

Figure 8.15. Fencing to prevent access of Brown bear to a road. Photo by: Lazaros Georgiadis.

Special adjustments should be made in cases where the fence crosses perimeter drainage ditches that need regular cleaning from debris (Figure 8.16).

Figure 8.16. Special adjustments must be provided in the intersection of fencing with perimeter drainage ditches. Photos by: Egnatia Odos SA and Minuartia.

8.4 | Innovative wildlife monitoring and visualisation tool

The evaluation of results of underpass upgrading was undertaken within the framework of LIFE SAFE-CROSSING project in Greece.
As a first step, 45 structures of different types (multiuse underpasses, culverts and viaducts) were selected on highway A29, Egnatia Odos, and were monitored over a 12 month period (Spring 2019-Spring 2020) via solar-panel/battery powered cellular (4G) cameras (Figure 8.17). The monitoring system was supported by a back-end infrastructure which is described below. The results showed that the main features that have an effect on the use of underpasses by Brown bear were: a) surrounding vegetation, b) structure dimensions; in particular the Openess Index and c) use by humans (Metzanis et al, 2023).

The evaluation of the effects of upgrading underpasses was undertaken based on the monitoring developed at 28 crossing structures during 8 months before and 8 months after upgrading (including summer, autumn and winter). The crossing frequency by Brown bear was compared. The results show that 32% of the upgraded crossing structures exhibited a statistically significant preferential use by bears. A longer study period may provide more conclusive results as wildlife requires an adaptation period. The monitoring also showed that cleaning of debris which was partly blocking the entrances to the structures appeared to be one of the most effective maintenance interventions. This both reduced obstacles to wildlife movements and at the same time increased the Openness Index of the structure (unobstructed width*height/length).

Regular inspections and maintenance are required to ensure the long-term effectiveness of the actions to promote wildlife use of the structures. Monitoring before and after the upgrading of underpasses and overpasses provides information on the effectiveness but also identifies any issue impeding the proper functionality of the transversal structures as fauna passages allowing to correct it. Where possible, the evaluation of the structures 'Before' and 'After' upgrade should be completed with monitoring of structures which have not been modified ('Control' structures) compared to upgraded structures ('Intervention' structures). This methodological approach is called BACI (Before-After-Control-Intervention) and is recommended (van der Grift et al 2013; van der Ree et al., 2015).

Several indicators can be used to measure benefits:

- Reduction in the rate of animal-vehicle collisions on the section of road.
- Reduction of large carnivore mortality on the section of road.
- Reduction of target species mortality on the section of road
- Number of target species crossing the structure per time unit, and frequency and minimum number of different individuals per target species using each structure.

While these indicators do not provide an evaluation of the positive impact that a wild-

Figure 8.17. Installation of the devices in underpasses to be monitored. The 4G wireless camera including a solar panel were installed. Photos by: Callisto; Cosmote; Minuartia.

life crossing has in enhancing the long-term viability of large carnivore populations, they may be considered a good 'proxy' of how far the goals of providing an increase of the road/railway permeability have been met. Genetic variability and gene flow analyses of target species should be also considered to provide long-term assessment of how effective a measure has been in enhancing wildlife use of existing crossing structures.

Innovative monitoring of wildlife use of structures and visualisation tool

An innovative, end-to-end wildlife monitoring solution including species identification and visualisation tools was applied within the LIFE SAFE-CROSSING project, to evaluate the use of underpasses before and after upgrading was undertaken. The technique was developed by COSMOTE and monitors the use of underpasses by wildlife, but also effectively assesses the nformation/data collected (photos, videos) and provides meaningful, automated results in the form of statistics, species categorization and alerting.

The solution comprises (Figure 8.18):

- 4G (wireless) battery-powered, ultra-low consumption cameras equipped with small and very efficient solar panels to enable long operation of up to more than more than a month without charge (Figure 8.18). A SIM card camera is also required to enable (a) automated uploading of snapshots/videos to a cloud infrastructure, (b) remote access to cameras for e.g., configuration purposes and playback and (c) alerting.

- A cloud infrastructure for automated camera content storage, processing and visualization through an intuitive web-portal (Figure 8.19).

- An innovative object/species detection and categorization tool based on Artificial Intelligence techniques. like Machine Learning and Deep Learning.

- A statistics extraction tool.
- Near-real time species alerting via push-notifications sent to a smartphone.

The devices were installed and validated at 45 underpasses along the highway A29, Eg-

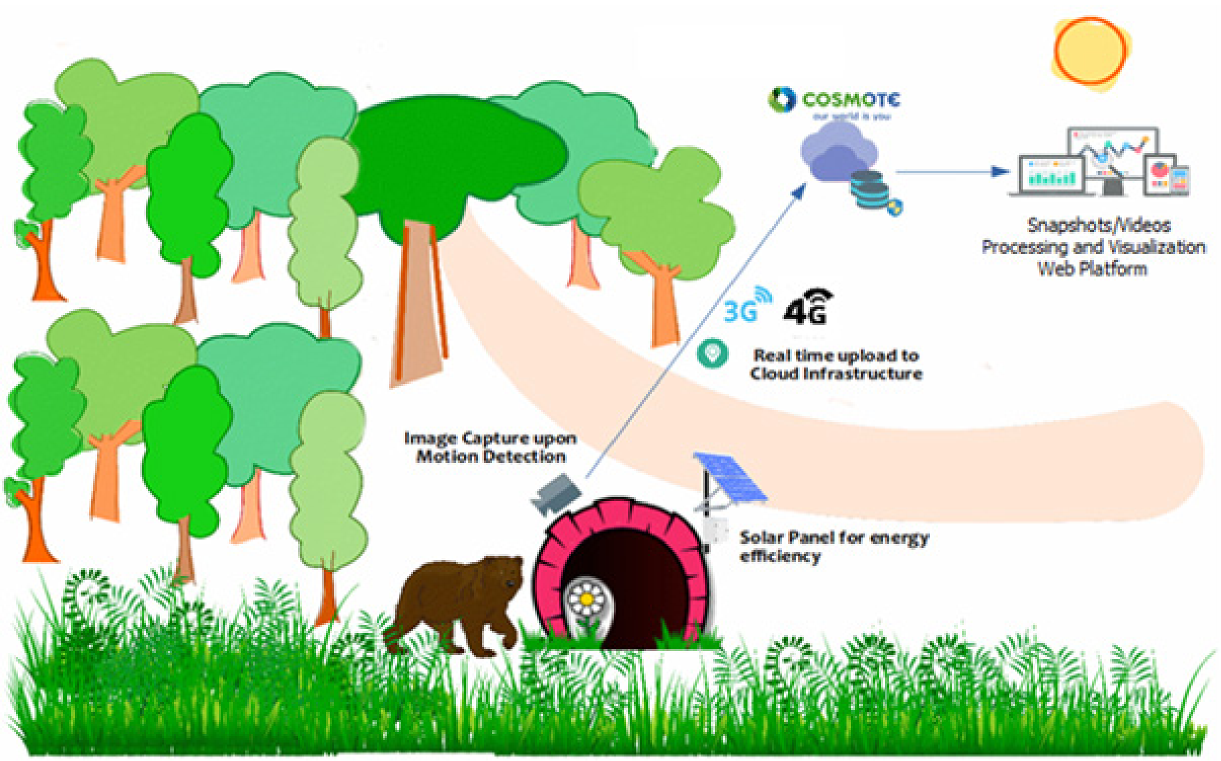


Figure 8.18. Architecture of the innovative solution applied to monitor wildlife use of crossing structures. Source: COSMOTE, LIFE SAFE-CROSSING

natia Odos, in north eastern Greece. From Spring 2019 to Spring 2020 more than 100,000 photos and videos were collected and processed and the use of the underpasses by Brown bear and other species was assessed. This information assisted in the identification of the appropriate upgrading actions to be undertaken in the structures to increase road permeability.

A video summarising the experience is available in https://www.youtube.com/watch?v=L67AWc0Ppu8&t=1s

Some monitoring technique features are listed below:

- Continuous (24x7) wildlife monitoring of underpasses, safeguarded by the use of ultra-low consumption batteries and solar powered wireless 4G cameras.

- Permanent access to camera' configurations, including PIR sensors on/off, PIR schedule, PIR sensitivity, video and audio recording, IR lights and others, and to camera features such as real-time video/audio single or multi-view, video/audio playback, battery usage, remaining battery (%), two-way audio communication, local awareness alert and others.

- Automated procedures for snapshot uploading via the 4G network and storage on a cloud infrastructure (Figure 8.20).

- Near-real time alerts for target species, such as Brown bear and others, with detection triggering push notifications to smartphones including a snapshot.

- Innovative tools for automatic near real time and offline detection of species passing through and automated categorization/storage of snapshots based on animal species (e.g., bear, fox, dog, sheep) and others, such as humans and vehicles.

- Snapshot availability via an intuitive, user-friendly web portal including underpass information and a search capability (Figure 8.19; http://193.218.97.145:8081/).

- Innovative tools for automatic statistics extraction which produce graphs for snapshots/day/week frequency of species registered in each underpass, and other details (Figure 8.21; http://193.218.97.145:8081/plots/).

The monitoring solution applied within the LIFE SAFE-CROSSING PROJECT combines low cost with ease of installation and has a notable reduction in the human resources required to manually process the huge number of snapshots and videos collected. It also brings other benefits, specifically that it is environmental-friendly i) using solar panels to charge the camera battery; ii) using rechargeable batteries instead of non-rechargeable batteries used in trail/trap cam-

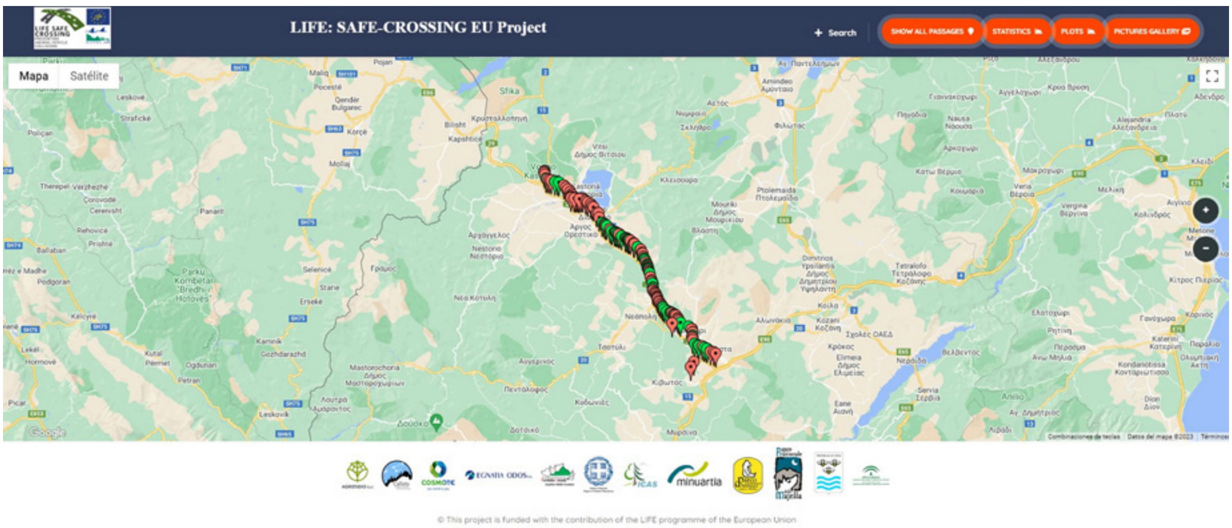


Figure 8.19. Installation of the devices in underpasses to be monitored. The 4G wireless camera including a solar panel were installed. Photos by: Callisto; Cosmote; Minuartia.

eras; iii) reducing the need for on-site visits to collect SD cards, because the information is automatically uploaded and stored in the cloud. The solution developed in Greece could be replicated in other countries, it requires just wireless 4G cameras with photovoltaic panels and SIM cards to guarantee connectivity with the internet network.

Figure 8.20. Snapshot visualizations provided by the platform. By: Callisto; COSMOTE; Egnatia Odos SA.

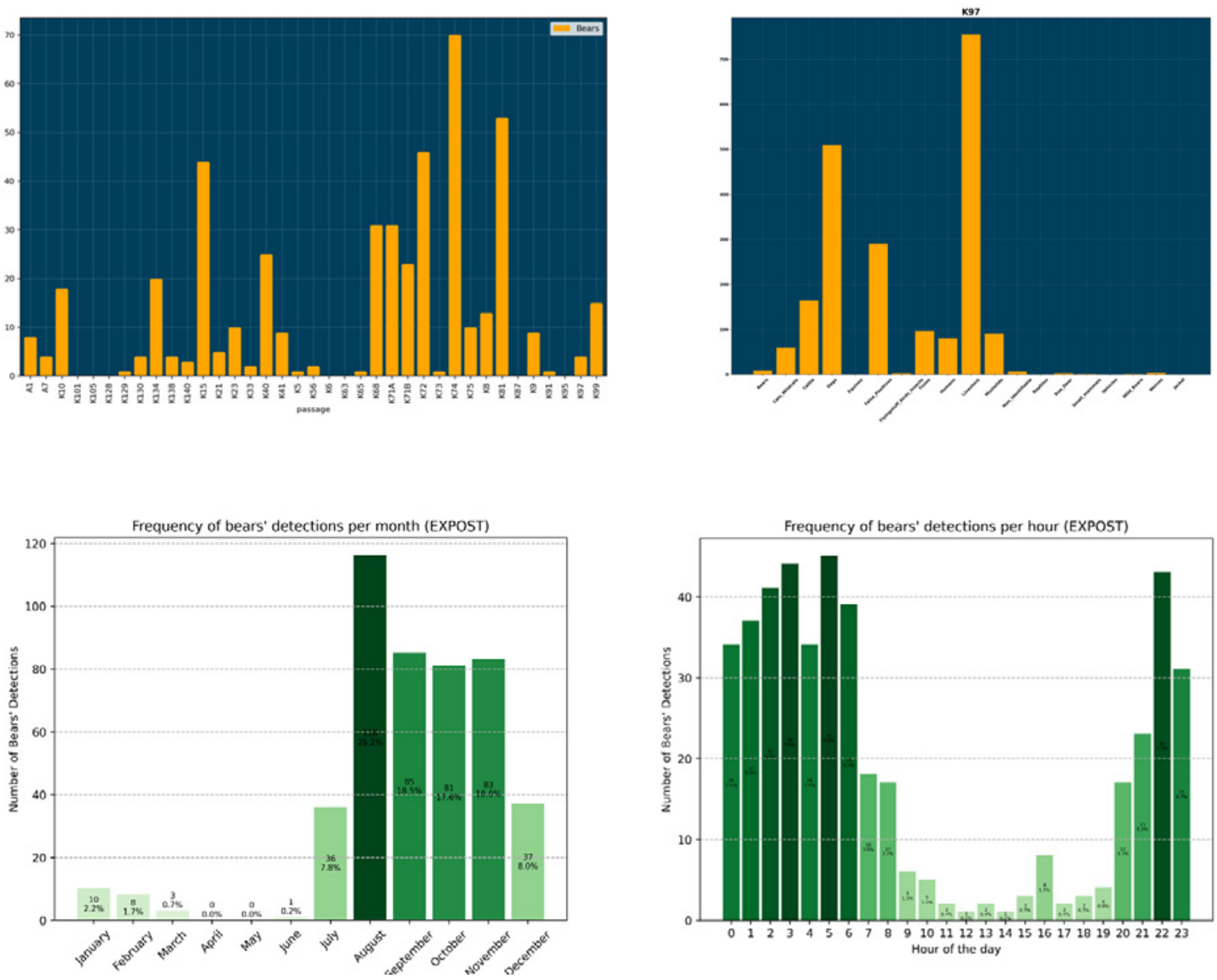


Figure 8.21. Examples of the automated ('zero-touch') statistics which can be obtained from the wild-life monitoring platform. Number of snapshots/detections per camera and day (A). Number of Brown bear crossings registered per underpass (B). Frequency of Brown bear detection in each underpass per month (C). Frequency of Brown bear detection per month (D). Frequency of Brown bear detection per each hour of the day. By: Callisto; COSMOTE; Egnatia Odos SA.

9

Governance and stakeholder involvement

9

Governance and stakeholder involvement

Cooperation between different stakeholders is vital for the design, application and monitoring of measures to reduce impacts of linear infrastructure on wildlife. Specifically, the solutions applied on roads to reduce risk of collisions with large animals (i.e. ungulates and large carnivores) as well as landscape fragmentation require the participation of multiple stakeholders. Infrastructure authorities and operators, Biodiversity managers, wildlife experts and other stakeholders at national, regional and local level, must cooperate in order to identify and apply effective solutions.

It is crucial that relevant authorities and stakeholders share 'know how' and best practice, to be replicated and expanded in the future. In fact, the reduction of the impact of roads and railways should not be limited to the installation of roadkill prevention tools, but it should include more ambitious initiatives, which can be achieved only with the full participation of all relevant stakeholders. Specifically:

- The implementation of defragmentation measures and their long-term maintenance requires **coordination with land planners and managers as well as local stakeholders.** It is necessary to establish synergies between all stakeholders managing infrastructures that generate fragmentation in a territory, as well as with local agencies and interested parties.

- Promoting awareness and communication between **infrastructure and biodiversity sectors, and to the public,** is fundamental in achieving the objectives of defragmentation and ecological restoration.
- Each project to improve existing transport infrastructure, to build new infrastructure or to carry out urban development in a territory is an **opportunity to contribute to habitat defragmentation and ecological restoration**. The inclusion in new projects, from their conception and design phase, of measures that favour defragmentation and minimise wildlife mortality risks is essential and efficient in cost-benefit terms.

Reducing the impact of roads on large carnivores which are specifically the target species of the LIFE SAFE-CROSSING project, it is of fundamental importance to adapt and/or upgrade roads and railways that are already under operation. This requires the involvement of many stakeholders, both from the field of infrastructure development (administrations and infrastructure operators/managers) as well as from the field of the management of the surrounding landscapes such as landowners, farmers and hunters, as well as biodiversity authorities.

Although Environmental Impact Assessments and corresponding legislation impose obligations for the preservation of biodiversity in the design of new infrastructures, the quality and extent to which this is taken into account to really minimize the impacts is still is strongly dependent on the awareness and willingness of the decision makers. This aspect calls for the strengthening of adequate communication addressed to key stakeholders.

However, the involvement of stakeholders, mainly public authorities, creates notable challenges which are often an obstacle to the proactive minimization of the infrastructure impacts. Therefore this chapter analyses the most important factors to take into account in order to achieve the support of stakeholders in actions to benefit biodiversity, and it tries to answer the following questions:

- Which are the key stakeholders to be involved, whose attention and support must be gained, and why are they important?
- What are the capacity gaps and roadblocks for effective action by stakeholders in minimising the impact of infrastructures?
- What are the most important aspects to actively gain the support of key stakeholders?

The information provided is partially based on the feedback provided by the participants of workshops held in the frame of the IENE International Conference on Ecology and Transportation (2022) and the BISON proiect 'Biodiversity and Infrastructure Synergies and Opportunities for European Transport Network' (101006661) development (2022).

Figure 9.1. Workshops undertaken in the frame of the LIFE Safe Crossing and BISON projects identified key stakeholders and barriers to be overcome to expand actions for defragmentation of roads and railways under operation. By: Minuartia; LIFE SAFE-CROSSING.

9.1 | Key stakeholders to be involved and their importance

A stakeholder is defined as an individual or group that has an interest in any decision or activity of an organisation. They can be divided into 'interest groups' and 'authorities'. According to the analysis made in the frame of the 'Exploitation and dissemination plan' produced by the BISON project (*** REF), the key stakeholders can be subdivided as follows,

Stakeholder group	Examples	Why they are important
EU and national level governmental bodies	EC level: Directorates General National level: Ministries; Environmental Agencies / Infrastructure management Agencies; Governmental Development Bodies	Provide adequate legal backgrounds Review policies Create international/national monitoring policies Create and manage funding mechanisms Provide authorizations
Regional and local governance bodies	Regional governments and agencies Municipalities	Create the local, practical legal basis Control over the implementation of legal requirements Create and manage funding mechanisms Provide authorizations
Infrastructure management companies and authorities	Road, railway management bodies (including authorities and operation companies)	Design, construct and install mitigation measures Provide permits for interventions on their road segments Implement monitoring schemes and provide data Fund mitigation interventions
Professionals involved in wildlife, landscape planning and management, infrastructure design, nature management.	Engineers/Architects Wildlife conservation professionals Landscape planners Constructors Professional associations	Undertake design and management projects Undertake defragmentation works Provide assessment and guidelines to governmental bodies and management authorities Cooperate in research studies
Academia and scientific community	Researchers Professors Students	Provide basic information and know-how Develop research projects Provide capacity building to professionals and new generations Contribute with volunteers to monitoring
Infrastructure users, NGOs and civil society	Drivers General public Conservationists Animal welfare groups Hunting and agricultural associations Other civil society association	Provide basic information and know-how Cooperate in research and management projects Provide capacity building to professionals Contribute with volunteers to monitoring

9.2 | Capacity gaps and roadblocks preventing effective stakeholder action

Main obstacles which have been identified as barriers which prevent authorities from applying measures to reduce the impact of transport infrastructure on biodiversity are: a lack of awareness, economic issues and a lack of political willingness.

The lack of awareness refers to both an insufficient consciousness of the importance of a healthy environment and biodiversity in general, and to scarce knowledge on the impact that transport infrastructure has on the environment. While persons involved in the planning and construction of roads are not generally trained in the specific field of ecology and wildlife conservation, low levels of awareness are also due to wildlife professionals lacking the capacity to effectively communicate the messages that should be conveyed. Addressing the communication gap between the fields of expertise (transport and ecology) and interests requires the application of necessary communication expertise to ensure the spread of key messages through all stakeholder groups. Moreover, raising awareness of the decline of biodiversity is necessary in order to emphasise the importance of decision-making stakeholders and practitioners including environmental aspects as an essential component to be included in their work from the initial steps of any infrastructure life cycle.

Shortfalls in communication also create a corresponding lack of necessary interest in decision-makers, resulting in low levels of political willingness to include the requirements of biodiversity and environmental conservation in planning and development of infrastructure, as well as in implementation of mitigation measures. Furthermore, governance structures often cannot facilitate and sometimes prevent the interlinking of such diverse topics as biodiversity conservation and infrastructure development, and therefore the legal background can generate a roadblock to fruitful cooperation, even in the presence of the awareness and willingness to do so.

The low awareness about biodiversity and also to a scarcity of financial resources necessary to implement measures that minimise the impact of infrastructures on the environment. Promoting biodiversity tends to be perceived as a problem with a high cost, which does not yield any social or economic benefit, whereas the ecosystem services and economic asset that biodiversity can provide is normally not taken into account. Evaluating the economic benefit of biodiversity is challenging due to a lack of clear and universally agreed indicators, and this is often a reason why cheaper options are chosen even if they have detrimental impacts on ecosystems and the services they provide to societies.

The Planning, design and operation of infrastructures really does provide huge opportunities not only to reduce impacts on the environment but also to benefit nature and people. However, this approach requires the serious involvement of and strong cooperation between decision makers, technical experts and stakeholders, taking into consideration all the potential social and economic benefits of protecting and restoring biodiversity.

9.3 | Aspects which actively gain key stakeholder support

Considering the afore-mentioned challenges, it is crucial to adopt the most effective tools to adequately communicate to decision makers in order to raise their interest in taking biodiversity into account when they develop and manage transport infrastructure. The following aspects have been identified as being crucial to reach this aim:

- Information campaigns should involve specifically trained experts avoiding involvement of interest groups who may be perceived as agenda-driven and lacking in sufficient communication skills.

- The most effective communication channels should be used according to the stakeholders to be reached. Using mass media in order to maximize the messages.

- The use of ambassadors (e.g. reputed persons, known professionals) and specifically attractive messages will raise the attention of the target groups.

- Information about the overlap between infrastructures and the environment should begin at an early stage, starting from primary school age.

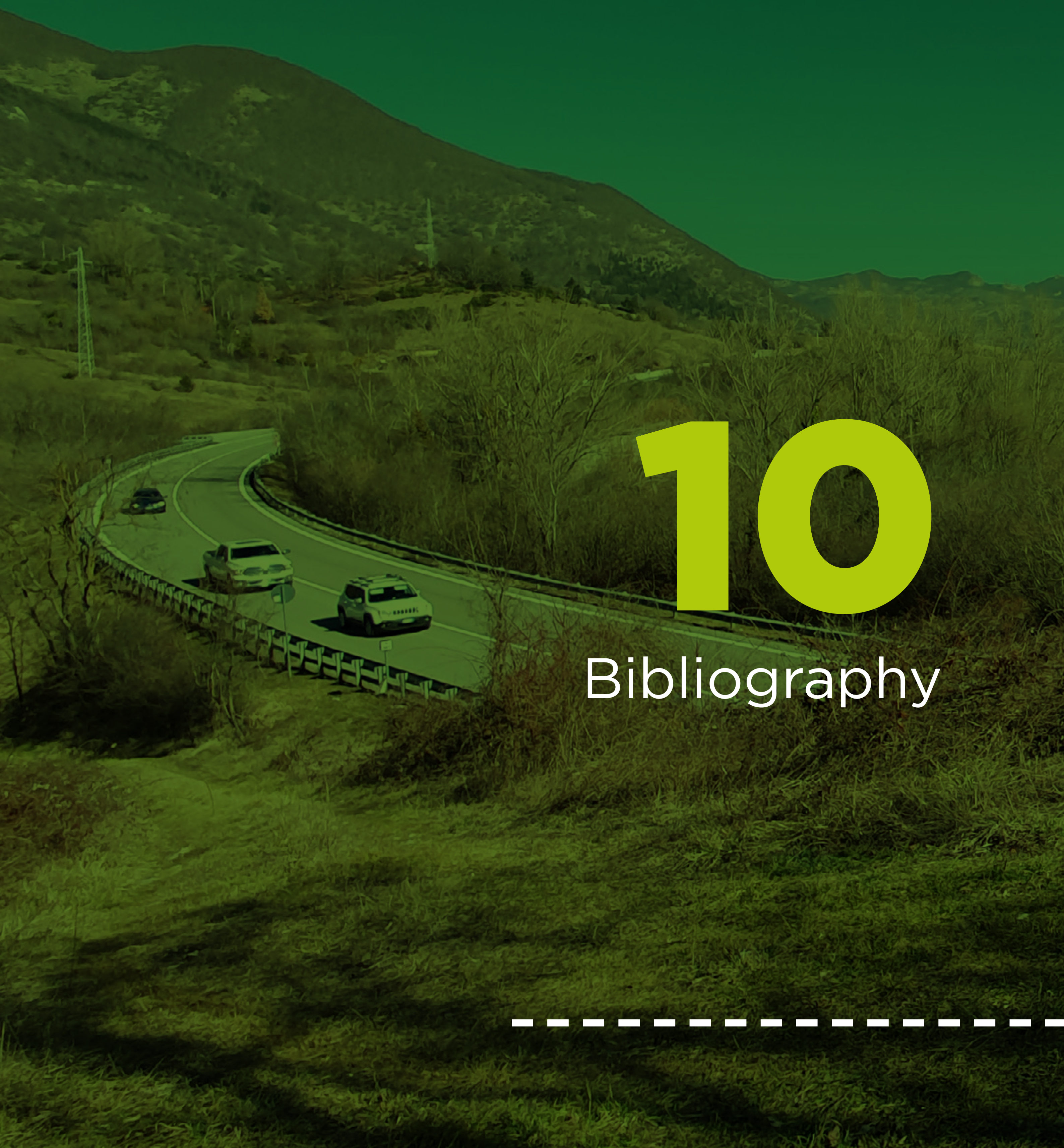
- Communication must always take into account language issues, in order to reach the biggest number of people.

- An easily accessible information basis and capacity-building tools should be provided

- Communication tools must be developed in a way that they can be easily updated.

- Training should be cross-sectoral, adapted to specific target groups, in order to convey different types of information in the most effective way.

10 Bibliography



10

Bibliography

Ascensão, F., & Mira, A. (2006). Factors affecting culvert use by vertebrates along two stretches of road in south Portugal. *Ecological Research, 22*, 57-66. https://doi.org/10.1007/s11284-006-0004-1

Ascensão, F., Clevenger, A., Santos-Reis, M., Urbano, P., & Jackson, N. (2013). Wildlife–vehicle collision mitigation: Is partial fencing the answer? An agent-based model approach. *Ecological Modelling, 257*, 36-43. https://doi.org/10.1016/j.ecolmodel.2013.02.026

Ascensão, F., Lucas, P. S., Costa, A., & Bager, A. (2017). The effect of roads on edge permeability and movement patterns for small mammals: a case study with Montane Akodont. *Landscape ecology, 32*, 781-790. https://doi.org/10.1007/s10980-017-0485-z

Balkenhol, N., & Waits, L. P. (2009) Molecular road ecology: exploring the potential of genetics for investigating transportation impacts on wildlife. *Molecular Ecology, 18*, 4151-4164. https://doi.org/10.1111/j.1365-294X.2009.04322.x

Benten, A., Hothorn, T., Vor, T., & Ammer, C. (2018b). Wildlife warning reflectors do not mitigate wildlife–vehicle collisions on roads. *Accident; Analysis and Prevention, 120*, 64–73.

Brunen, B., Daguet, C., & Jaeger, J. A. G. (2020). What attributes are relevant for drainage culverts to serve as efficient road crossing structures for mammals? *Journal of Environmental Management, 268*:110423. https://doi.org/10.1016/j.jenvman.2020.110423

Coulson, G., & Brender, H. (2020). Roadkill mitigation is paved with good intentions: a critique of Fox et al. (2019). *Australian Mammalogy, 42*, 122-130.

Cuperus, R., Canters, K. J., de Haes, H. A. U., & Friedman, D. S. (1999). Guidelines for ecological compensation associated with highways. *Biological Conservation, 90*(1), 0–51. https://doi.org/10.1016/S0006-3207(99)00007-5

Denneboom, D., Bar-Massada, A., & Shwartz, A. (2021). Factors affecting usage of crossing structures by wildlife – A systematic review and meta-analysis. *Science of the Total Environment, 777*:146061. https://doi.org/10.1016/j.scitotenv.2021.146061

Ditmer, M. A., Rettler, S. J., Fieberg, J. R., Iaizzo, P. A., Laske, T. G., Noyce, K. V., & Garshelis, D. L. (2018). American black bears perceive the risks of crossing roads. *Behavioral Ecology, 29*(3), 667–675. https://doi.org/10.1093/beheco/ary020

Forman, R. T. T., & Alexander, L. E. (1998). Roads and their major ecological effects. *Annual Review of Ecology and Systematics, 29*, 207-231.

Fox, S., & Potts, J. M. (2020). Virtual fence devices -a promising innovation: a response to Coulson and Bender (2019). *Australian Mammalogy, 42*, 131-133.

Fox, S., Potts, J. M., Pemberton, D., & Crosswell, D. (2019). Roadkill mitigation: trialing virtual fence devices on the west coast of Tasmania. *Australian Mammalogy, 41*(2), 205-211.

Grilo, C., Bissonette, J. A., & Santos-Reis, M. (2008). Response of carnivores to existing highway culverts and underpasses: implications for road planning and mitigation. *Biodiversity and Conservation, 17*, 1685–1699. https://doi.org/10.1007/s10531-008-9374-8

Grilo, C., Bissonette, J. A., & Santos-Reis, M. (2009). Spatial–temporal patterns in Mediterranean carnivore road casualties: consequences for mitigation. *Biological Conservation, 142*, 301-313. https://doi.org/10.1016/j.biocon.2008.10.026

Hilty, J., Worboys, G. L., Keeley, A., Woodley, S., Lausche, B., Locke, H., Carr, M., Pulsford I., Pittock, J., White, J. W., Theobald, D. M., Levine, J., Reuling, M., Watson, J. E. M., Ament, R., & Tabor, G. M. (2020). *Guidelines for conserving connectivity through ecological networks and corridors*. Best Practice Protected Area Guidelines Series No. 30. Gland, Switzerland: IUCN. https://doi.org/10.2305/IUCN.CH.2020.PAG.30.en.

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.

Jackson, N. D., & Fahrig, L. (2011). Relative effects of road mortality and decreased connectivity on population genetic diversity. *Biological Conservation, 144*, 3143-3148. https://doi.org/10.1016/j.biocon.2011.09.010

Jensen, A. J., Perrine, J. D., Schaffner, A., Brewster, R., Giordano, A. J., Robertson, M., & Siepel, N. (2023). Mammal use of undercrossings is influenced by openness and proximity to riparian corridors. *Wildlife Research, 50*, 495-506. https://doi.org/10.1071/WR21183

Kaczensky, P., Knauer, F., Krze, B., Jonozovic, M., Adamic, M., & Gossow, H. (2003) The impact of high speed, high volume traffic axes on brown bears in Slovenia. *Biological Conservation, 111*(2), 191-204. https://doi.org/10.1016/S0006-3207(02)00273-2

Ministerio de Agricultura, Alimentación y Medio Ambiente. 2013. *Desfragmentación de hábitats. Orientaciones para reducir los efector de las infraestructuras de transporte en funcionamiento*. Documentos para la reducción de la fragmentación de hábitats causada por infraestructuras de transporte, número 5. O.A. Parques Nacionales. Ministerio de Agricultura, Alimentación y Medio Ambiente. 159pp.

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. 258pp.

Minuartia. (2019). LIFE SAFE-CROSSING. ACTION A4. Technical report. *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*. 75pp.

Nevřelová, M., Lehotská, B., & Ružičková, J. (2022). Methodology of Wildlife Underpasses Attractiveness Assessment. *Ekológia (Bratislava), 41*(2), 172-182. https://doi.org/10.2478/eko-2022-0018

Psaralexi, M., Lazarina, M., Mertzanis, Y., Michaelidou, D.-E., & Sgardelis, S. (2022). Exploring 15 years of brown bear (*Ursus arctos*)-vehicle collisions in northwestern Greece. *Nature Conservation, 47*, 105-119. https://doi.org/10.3897/natureconservation.47.71348

Ramp, D., & Ben-Ami, D. (2006). The effect of road-based fatalities on the viability of a peri-urban swamp wallaby population. *The Journal of Wildlife Management, 70*, 1615-1624. https://www.jstor.org/stable/4128093

Rytwinski, T., & Fahrig, L. (2011) Reproductive rate and body size predict road impacts on mammal abundance. *Ecological Applications, 21*, 589-600. https://www.jstor.org/stable/29779685

Sawaya, M. A., Kalinowski, S. T., & Clevenger, A. P. (2014). Genetic connectivity for two bear species at wildlife crossing structures in Banff National Park. *Proceedings of the Royal Society B: Biological Sciences*, *281*:20131705. https://doi.org/10.1098/rspb.2013.1705

Smith, D. J., van der Ree, R., & Rosell, C. (2015). Wildlife crossing structures: An effective strategy to restore or maintain wildlife connectivity across roads. In: R. van der Ree, D. J. Smith, & C. Grilo (Eds.), *Handbook of road ecology* (1st ed., pp. 172–183). John Wiley & Sons. DOI:10.1002/9781118568170.

Smith, J. A., Duane, T. P., & Wilmers, C. C. (2019). Moving through the matrix: Promoting permeability for large carnivores in a human-dominated landscape. *Landscape and Urban Planning, 183*, 50-58. https://doi.org/10.1016/j.landurbplan.2018.11.003

Straka, M., Paule, L., Ionescu, O., Štofík, J., & Adamec, M. (2012). Microsatellite diversity and structure of Carpathian brown bears (*Ursus arctos*): consequences of human caused fragmentation. *Conservation Genetics, 13*, 153-164. https://doi.org/10.1007/s10592-011-0271-4

Taylor-Brown, A., Booth, R., Gillett, A., Mealy, E., Ogbourne, S. M., Polkinghorne, A., & Conroy, G. C. (2019). The impact of human activities on Australian wildlife. *PloS ONE, 14*(1), e0206958. https://doi.org/10.1371/journal.pone.0206958

van der Ree, R., Smith, D. J., & Grilo, C. (2015) *Handbook of Road Ecology* (1st ed.) John Wiley & Sons. DOI:10.1002/9781118568170.

Ważna, A., Kaźmierczak, A., Cichocki, J., Bojarski, J., & Gabryś, G. (2020). Use of underpasses by animals on a fenced expressway in a suburban area in western Poland. *Nature Conservation 39*, 1-18. https://doi.org/10.3897/natureconservation.39.33967

LIFE SAFE CROSSING
PREVENTING ANIMAL-VEHICLE COLLISIONS