BEST PRACTICE GUIDE

Solutions for mitigating the impacts of roads on animal communities

LIFE LINES
Linear Infrastructure Networks with Ecological Solutions

Life

Coordination of the edition

Graça Garcia, Luís G. Sousa, Pedro A. Salgueiro, João Craveiro, Nuno M. Pedroso, António Mira.

Contributions

André Oliveira, Carmo Silva, Sofia Eufrázio, Tiago Pinto.

Translation and text revision of the English version

Graça Oliveira.

Photography credits

Graça Garcia (GG), Luís Guilherme Sousa (LGS), Pedro A. Salgueiro (PAS).

Artwork

Infraestruturas de Portugal, SA (IP), Luís Guilherme Sousa (LGS), Neftalí Sillero (NS), Pedro A. Salgueiro (PAS).

Graphic design

Rui Belo

ISBN

978-972-778-230-7

Edition

Universidade de Évora

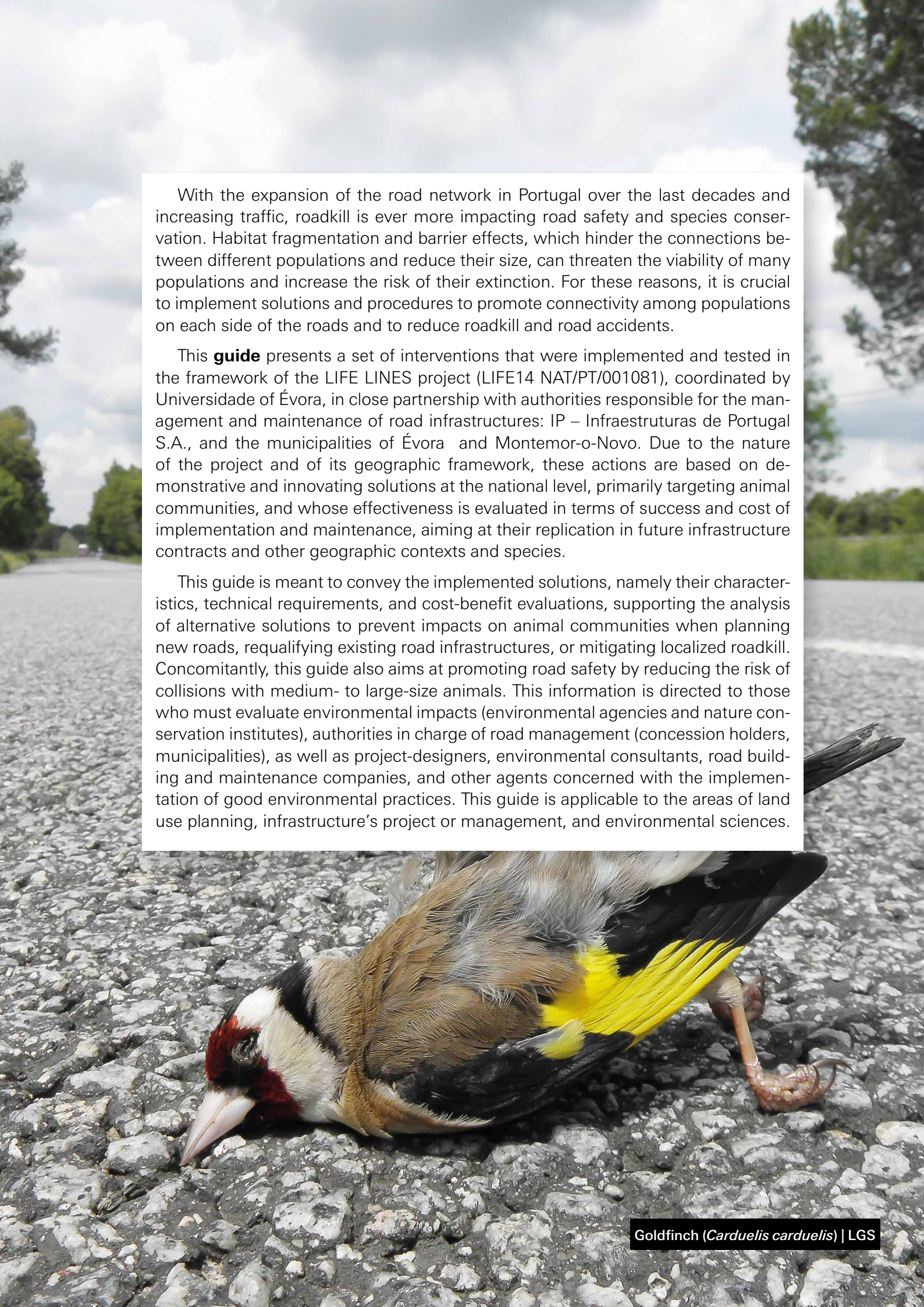
Citation:

Garcia G., Sousa L.G., Salgueiro P.A., Craveiro J., Pedroso N.M., Mira A. (2021). Best practice guide: Solutions for mitigating the impacts of roads on animal communities. LIFE LINES Project. Universidade de Évora. ISBN: 978-972-778-230-7.

With the expansion of the road network in Portugal over the last decades and increasing traffic, roadkill is ever more impacting road safety and species conservation. Habitat fragmentation and barrier effects, which hinder the connections between different populations and reduce their size, can threaten the viability of many populations and increase the risk of their extinction. For these reasons, it is crucial to implement solutions and procedures to promote connectivity among populations on each side of the roads and to reduce roadkill and road accidents.

This **guide** presents a set of interventions that were implemented and tested in the framework of the LIFE LINES project (LIFE14 NAT/PT/001081), coordinated by Universidade of Évora, in close partnership with authorities responsible for the management and maintenance of road infrastructures: IP – Infraestruturas de Portugal S.A., and the municipalities of Évora and Montemor-o-Novo. Due to the nature of the project and of its geographic framework, these actions are based on demonstrative and innovating solutions at the national level, primarily targeting animal communities, and whose effectiveness is evaluated in terms of success and cost of implementation and maintenance, aiming at their replication in future infrastructure contracts and other geographic contexts and species.

This guide is meant to convey the implemented solutions, namely their characteristics, technical requirements, and cost-benefit evaluations, supporting the analysis of alternative solutions to prevent impacts on animal communities when planning new roads, requalifying existing road infrastructures, or mitigating localized roadkill. Concomitantly, this guide also aims at promoting road safety by reducing the risk of collisions with medium- to large-size animals. This information is directed to those who must evaluate environmental impacts (environmental agencies and nature conservation institutes), authorities in charge of road management (concession holders, municipalities), as well as project-designers, environmental consultants, road building and maintenance companies, and other agents concerned with the implementation of good environmental practices. This guide is applicable to the areas of land use planning, infrastructure's project or management, and environmental sciences.



Goldfinch (*Carduelis carduelis*) | LGS

Barn-owl (*Tyto alba*) | UBC

Index

Purposes of the guide 3

The LIFE LINES project 6

Intervention area 6

Ecological impacts of road infrastructures 7

Planning, deployment and maintenance of the solutions 9

Solutions for road infrastructures 11

Types of solutions 11

Key to identify the solutions proposed in this Guide, according to the type of impacts 14

Interpretation of the solution sheets 16

Minimizing the impacts of roads on fauna – solution sheets 17

Culverts with dry ledges for terrestrial fauna 18

Specific tunnels for amphibians 20

Permanent concrete barriers and temporary canvas barriers for amphibians 22

Mesh barriers to elevate flight height 26

Fences with progressive mesh 28

Fences with additional L-shaped mesh 30

Deterring mesh for rabbits 32

Wildlife Warning Refletors 34

Deterrent ultrasound prototype to drive small mammals away from road verges 36

Amphibians warning road sign 38

Cost-benefit of interventions 40

Cited bibliography 42

Recommended bibliography 42

The LIFE LINES Project

Thousands of animals die every year in linear transport and energy infrastructures, either killed on roads or rails, or by electrocution or collision with medium- and high-voltage power lines. This increased mortality impacts the preservation of biological diversity, but there are solutions to minimize their effects.

The **LIFE LINES project – Linear Infrastructure Networks with Ecological Solutions** (LIFE14NAT/PT/001081) was developed to contribute to the creation of a **Green Infrastructure** that promotes **refugia for plants and animals**, and their safe **movement along the linear infrastructures**, ensuring ecosystem services and thus mitigating the negative impacts of those structures on biodiversity.

The project was coordinated by the Universidade of Évora and involves the following partners: Universidade de Aveiro, Faculdade de Ciências da Universidade do Porto, Municipalities of Évora (CME – Câmara Municipal de Évora) and Montemor-o-Novo (CMMN – Câmara Municipal de Montemor-o-Novo), Infraestruturas de Portugal S.A., MARCA – Associação de Desenvolvimento Local, and QUERCUS. LIFE LINES is also in close collaboration with GNR (Guarda Nacional Republicana), REN – Redes Energéticas Nacionais SGPS S.A. and E-REDES. The project focuses on the promotion and recovery of biodiversity in an area that is still well preserved but where a number of linear infrastructures might endanger some local populations of animals and plants.

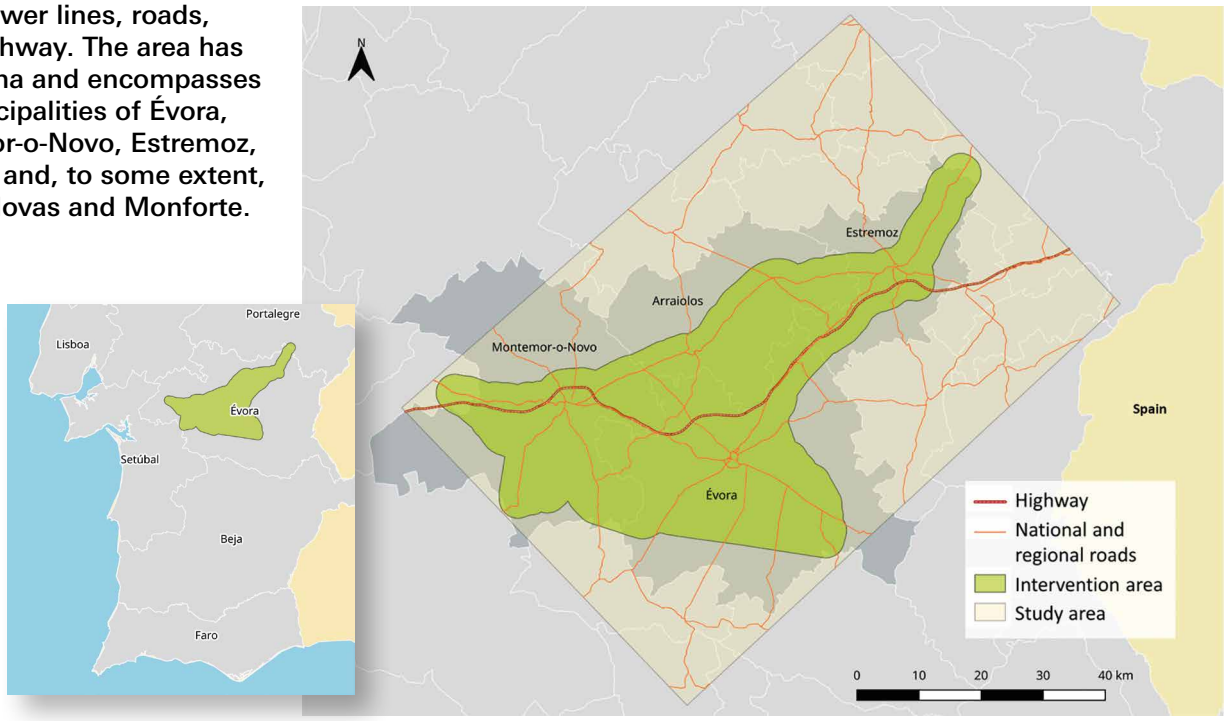
The linear transport infrastructures are one of the main subjects addressed in this project. Among many other actions, LIFE LINES deployed and tested several measures to minimize the impacts of roads, including the promotion of safe road passages, and mitigation of animal roadkill, and developed a National Fauna Roadkill Database and a mobile app to allow the active contribution of the public to data collection.

FIND OUT MORE AT
LIFELINES.UEVORA.PT

The intervention area of LIFE LINES is crossed by the main land transport corridor between Lisbon and Madrid. There is a high density of power lines, roads, and a highway. The area has 210,000 ha and encompasses the municipalities of Évora, Montemor-o-Novo, Estremoz, Arraiolos and, to some extent, Vendas Novas and Monforte.

2015-2021

Central Alentejo



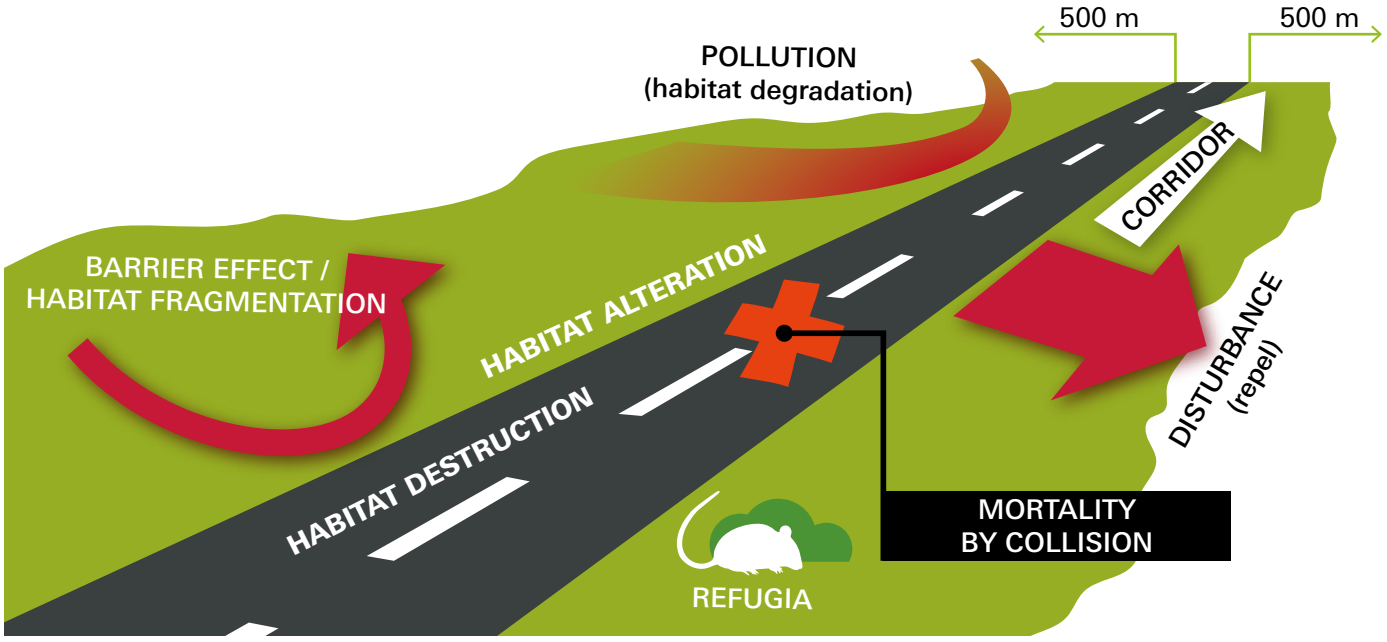
Objectives of the Project:

- Create corridors and refugia for biodiversity
- Promote landscape connectivity
- Implement a national database on wildlife roadkill
- Detect and control invasive vegetation
- Inform and raise public awareness about the impacts of linear infrastructures on biodiversity
- Reduce mortality by electrocution, collision, and roadkill

LIFE LINES
Linear Infrastructure Networks with Ecological Solutions

Ecological impacts of road infrastructures

Although animal roadkill is the most visible impact of roads, other factors are equally negative, or even worse, for animal and plant populations thriving in the vicinities of these infrastructures. Habitat destruction, resulting from the construction of the road, is the first impact. Then, there are the effects of the presence of the road, such as the barrier effect: traffic noise and lights scare and drive away the animals that live nearby, and the fences often present along the roads prevent some species from crossing. The pollution from exhaust gases, motor oil or fuel leaks, or even the garbage thrown away by drivers and passengers, degrade the surrounding area, sometimes reaching long distances through contamination of watercourses. However, roadsides can also represent refugia and means of dispersal for some animals, such as small mammals (mice and shrews) and butterflies. There can also grow native plants, thus increasing floristic diversity, especially where the surrounding habitat is less diverse, such as agricultural or intensively grazed lands.



Adapted from Seiler, 2002 [1]

Planning, deployment and maintenance of the solutions

The selection and implementation of the solutions described in this Guide should consider the steps indicated in the following Table namely the preliminary information, the relevant criteria to be considered, the requirements for their proper implementation and maintenance and the monitoring of its effectiveness.

Preliminary information	1. Identify sites of potential or confirmed roadkill, based on: • Mortality records (if the road already exists) • Occurrence maps of vulnerable / threatened species • Connectivity maps • Specific situations: – Watercourses with riparian vegetation • Nearby ponds (< 500 m) 2. Identify the species that are more liable to roadkill 3. Identify the characteristics of the site or of the road that might condition the interventions: • Geometrical design of road: Longitudinal and transversal profile, and sinuosity. • Permeability of the road (location of underpasses, overpasses and culverts, which might be used by the target species, as well as the distance between them, the presence of fences and their characteristics) • Flow regimes of the watercourses, whenever possible • Location of vegetation corridors and other habitats that favour the target species
Selection and planning of solutions	1. Select the adequate measures, according to the purpose of the intervention: • Prevent crossings / guide animals towards passages (barriers, fences) • Provide safe passages (underpasses / overpasses / culverts) • Discourage approach to roads (reflective devices; wire mesh for dissuading rabbit colonization, sound and ultrasound emitters) 2. Select the adequate measures, taking into consideration: • The target species and its ecology • The characteristics and permeability of the surrounding landscape • The characteristics of the infrastructure • The cost-benefit of the actions 3. Design and plan the solutions, taking the above identified needs and requirements into consideration: • Select the type of solution, the site to implement it, its specific characteristics, its extension/dimension and the most suitable materials • Elaborate the project (if applicable) 4. Identify the most appropriate period for the action, considering: • the seasonal meteorological conditions • species ecology • volume and seasonality of traffic (if the roads already exist)

Deployment of solutions	Deployment of the solutions must absolutely abide by the project and/or by the provided instructions, and be followed by experienced technicians who know the requirements of such solutions as well as the ecological precautions to be taken
Maintenance of solutions	1. Regularly check the state of the solutions, considering the durability of materials, the degradation caused by traffic, accidents, or extreme weather events (heavy rains, flooding), among others 2. Make the necessary repairments whenever they are damaged, and/or clean them from any accumulated debris 3. Regularly manage the vegetation so that it will not reduce the efficiency of the solutions
Monitoring / Adjustments	1. Monitoring of: • Effects on roadkill (change of patterns), and on the abundance and movement of animals in the surrounding area • Animal behaviour related with the implemented solutions 2. Evaluation of the effectiveness of the implemented solutions 3. Adjustment of the implemented solutions: • Identification of problems • Reversion or improvement of the solutions

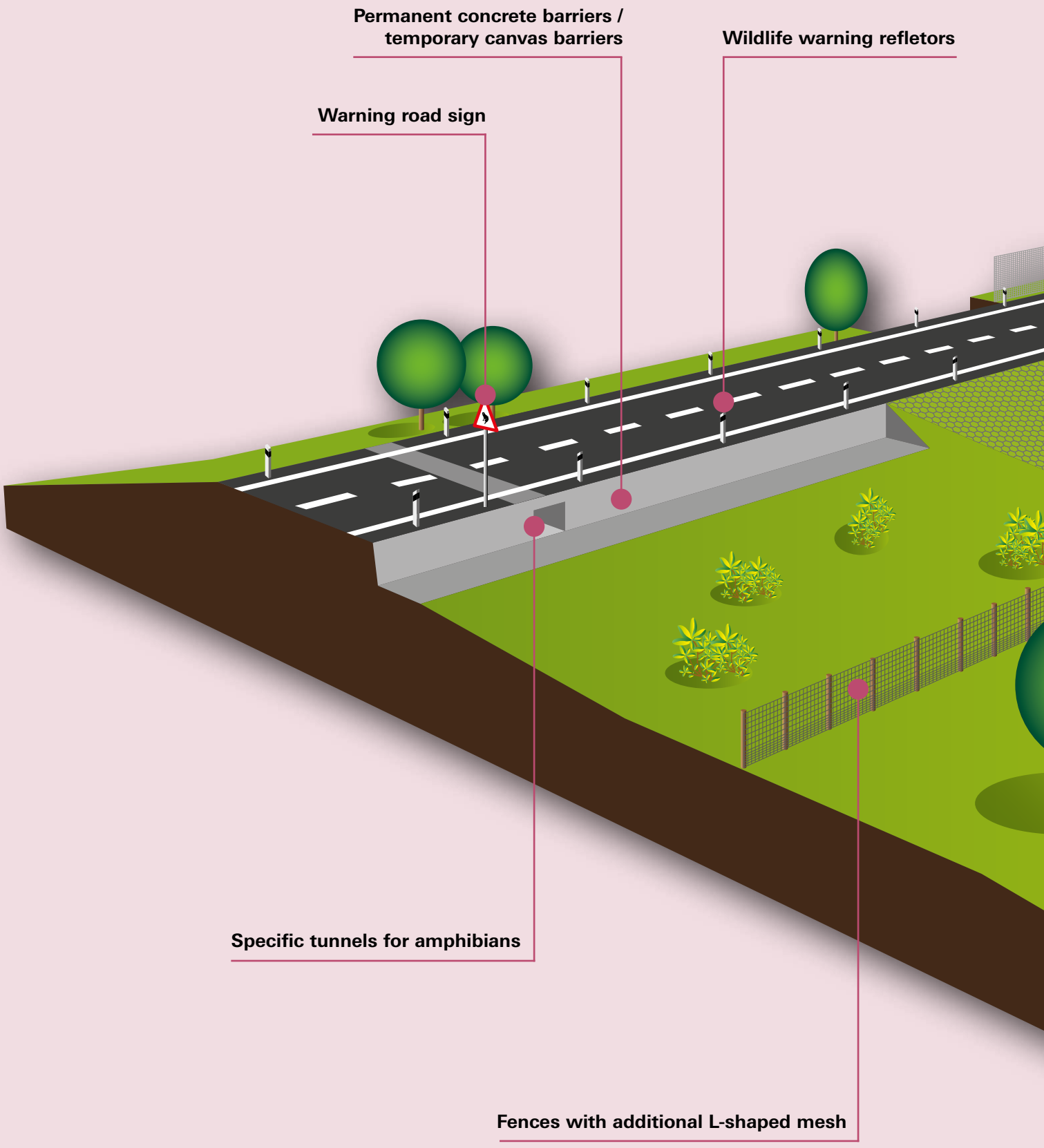
Solutions for road infrastructures

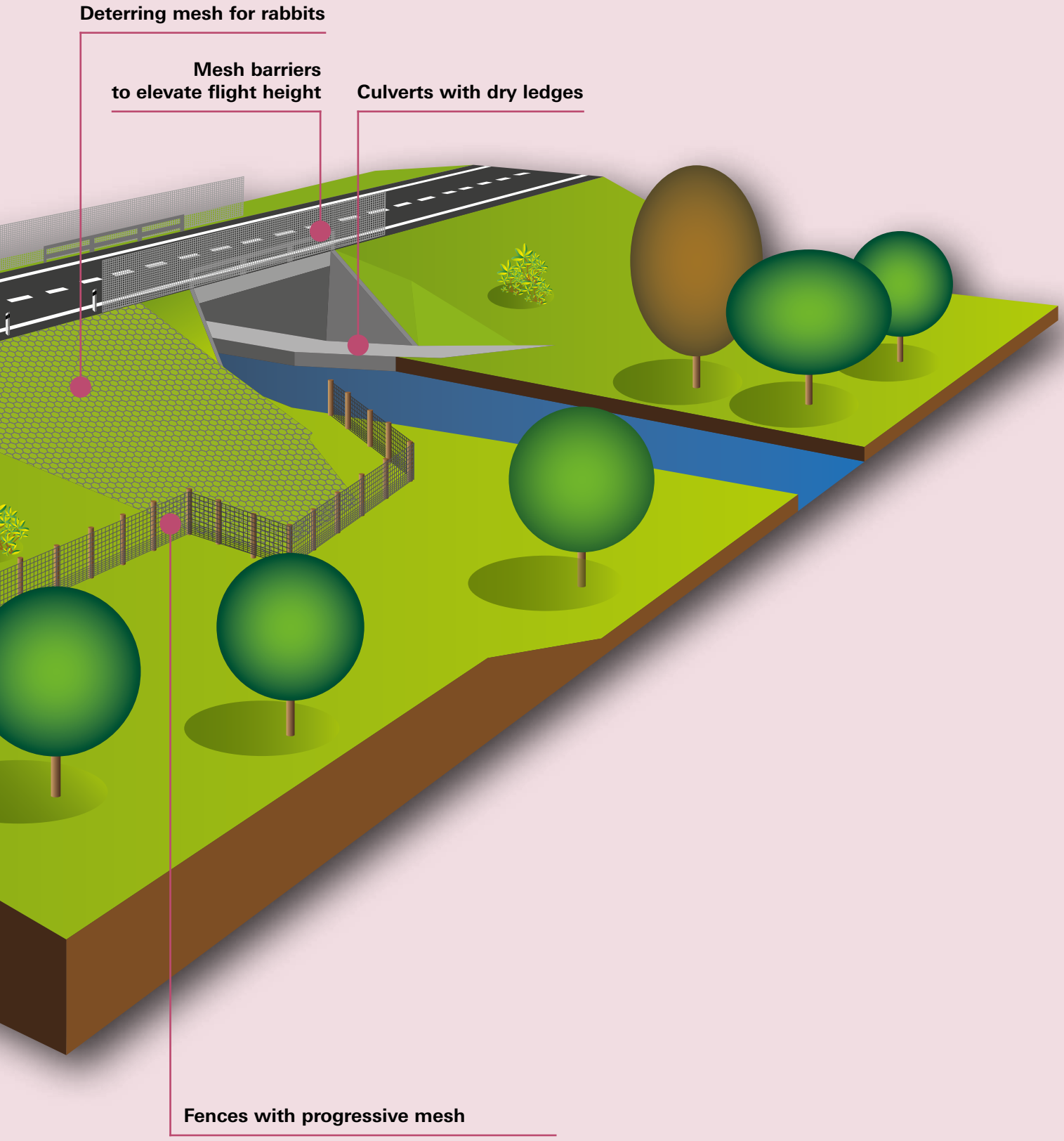
Types of solutions

The solutions described in this Guide can be classified into the following categories, according to the site and objectives of the action, and to the target animal groups.

<table>
<tr><th></th><th>Underpasses and Culverts</th><th colspan="2">Barriers and Fences</th><th>Deterring measures</th><th>Signalling</th></tr>
<tr><td>Amphibians</td><td>Tunnels for amphibians (P. 20)</td><td rowspan="2">Permanent concrete barriers (P. 22)</td><td rowspan="2">Temporary canvas barriers (P. 22)</td><td></td><td rowspan="2">Amphibians warning road sign (P. 38)</td></tr>
<tr><td>Small mammals</td><td rowspan="4">Culverts with dry ledges for terrestrial animals (P. 18)</td><td>Deterrent ultrasound prototype (P. 36)</td></tr>
<tr><td>Hedgehog</td><td rowspan="3">Fences with progressive mesh (P. 28)</td><td rowspan="3">Fences with additional L-shaped mesh (P. 30)</td><td rowspan="2"></td><td rowspan="3"></td></tr>
<tr><td>Carnivores</td></tr>
<tr><td>Rabbit</td><td>Deterring mesh for rabbits (P. 32)</td></tr>
<tr><td>Bats</td><td rowspan="3"></td><td colspan="2" rowspan="3">Mesh barriers to elevate flight height (P. 26)</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Passerines</td></tr>
<tr><td>Nocturnal birds-of-prey</td><td>Wildlife Warning Reflectors (P. 34)</td></tr>
</table>

The solutions can be focused to directly mitigate mortality, through the construction or installation of barriers that are more or less permeable to animal movement. These types of solutions are mainly represented by **Barriers and Fences**, but they also include a set of **Deterring Measures** aimed at specific groups of fauna, and therefore more selective, allowing the permeability of the road to other animals which, locally, do not jeopardise road safety or animal conservation. Since these solutions eventually aggravate the barrier effect of roads, they should be complemented with a set of measures that promote the safe passage of animals at specifically established zones offering adequate conditions for fauna, namely **Underpasses and Culverts**. When both mitigation or promotion actions are still ineffective, or where it is not possible to apply them on the short-term, **Signalling** must be implemented to warn drivers of road segments where road safety might be compromised by the crossing of animals.


Permanent concrete barriers / temporary canvas barriers
Wildlife warning refletors
Warning road sign
Specific tunnels for amphibians
Fences with additional L-shaped mesh


Deterring mesh for rabbits
Mesh barriers
to elevate flight height
Culverts with dry ledges
Fences with progressive mesh

Key to identify the solutions proposed in this Guide, according to the type of impacts

1	Solutions targetting the drivers, through road signs	Amphibians' warning road sign (pp. 38)
	Solutions to manipulate animal movements	2
2	Promote or facilitate crossing through safe passages	3
	Prevent the access of animals to dangerous zones, discouraging their presence or guiding them to safe passages	4
3	Adapt culverts (subjected to permanent or periodic flooding) for terrestrial animals (terrestrial mammals, *sensu lato*: carnivores, small mammals, hedgehogs, wild boars)	Dry ledges for terrestrial animals (pp. 18)
	Underpasses for semi-aquatic animals (amphibians)	Specific tunnels for amphibians (pp. 20)
4	Prevent crossings and/or redirect animals to safe passages	5
	Prevent or discourage the use of zones surrounding the road	9
5	Prevent crossings and/or redirect terrestrial or semi-aquatic animals	6
	Discourage flying animals to cross roads or promote crossings at safe heights	Mesh barriers to elevate flight (pp. 26)
6	Prevent crossings and/or redirect small- and medium-size terrestrial animals (carnivores, hedgehogs, wild boars, rabbits or hares)	7
	Prevent crossings of small-sized terrestrial and/or semi-aquatic species	8
7	General measures to redirect terrestrial animals of medium- and large-size to safe passages (carnivores, hedgehogs, wild boars, rabbits and hares)	Fences with progressive mesh (pp. 28)
	Specific measures to prevent crossing by small-sized terrestrial animals or with digging or fossorial behavioural, and to guide them to safe passages (small mammals, wild boars)	Fences with additional L-shaped mesh (pp. 30)
8	Temporary or adjustable measures to prevent crossings of small-sized terrestrial and/or semi-aquatic species (small mammals, amphibians)	Temporary canvas barriers (pp. 22)
	Permanent measures to prevent small-sized terrestrial and/or semi-aquatic species (small mammals, amphibians) from crossing	Permanent concrete barriers (pp. 22)
9	Prevent the establishment of burrowing species on road slopes	Deterring mesh for rabbits (pp. 32)
	Discourage the presence of species in areas close to the road	10
10	Dissuasive solutions based on visual signs	Warning reflectors (pp. 34)
	Dissuasive solutions based on sound	Ultrasounds to discourage the presence of small mammals (pp. 36)

Interpretation of the solution sheets

1. **Name of the solution**

2. **Target group:** groups of species for which the solution is designed.

3. **Ecological context:** specific ecological conditions and requirements of the target-groups that support and determine the implementation of the solution.

4. **Impact to minimize:** description of the impacts on biodiversity and on road safety.

5. **Technical considerations:** technical details and specificities related with the implementation of the solution (dimensions, materials).

6. **Maintenance requirements:** maintenance actions that are necessary after the implementation of the solution, and their periodicity.

7. **Complementarity:** associated measures that might be implemented, to increase the effectiveness of the main solution.

8. **Alternatives:** Other possible solutions for the same purpose.

9. **General effectiveness:** capacity of the solution to attain the objectives, based on the evaluation made during the LIFE LINES project.

10. **Evaluation:** according to the following criteria: (1) difficulty of implementation, in terms of human and logistics resources; (2) maintenance costs following implementation; (3) need to rehabilitate the solution, depending on how long it remains functional; (4) general cost of implementation, including the design process; (5) effectiveness to mitigate roadkill or to promote animal movements.

11. **Cost-benefit:** Weighing the average costs of implementation and maintenance relative to the general effectiveness of the intervention, according to five classes: **"Very favourable"** (dark-green), **"Favourable"** (light-green), **"Fair"** (yellow), **"Unfavourable"** (orange) and **"Very unfavourable"** (red). The higher the effectiveness and the lower the associated costs, the more favourable the solution.

12. **Schemes and photographs:** they show the details of the interventions, precautions when implementing them, and practical examples of deployment taken from the LIFE LINES project.

Interpretation of the solution sheets

CULVERTS WITH [1] EDGES FOR TERRESTRI[2]MALS

TARGET GROUP: terrestrial [2] strial mammals sensu lato: carnivores, small mammals, h[2] boars)

ECOLOGICAL CONTEXT: The [3] courses and associated vegetation are important corridors for animals, allowing the movement of many species across the landscape. The culverts under the roads reestablish water circulation, and have also the potential to facilitate animal movement between the two sides of the road without exposing them to roadkill. However, these passages can be flooded for long periods, thus compromising its use by most species [2]. The installation of dry ledges along the culverts, [3] water level, can increase the use of culverts by animals [3] vention requires previous information to evaluate its app[3]ances of success. In order to help selecting the culverts fo[3]ose, a preliminary hydrological study can be performed of the watercourse running in the culvert during flooding. This study must determine (1) the total number of days of the flooding, (2) the number of consecutive days of flooding, (3) the usual level of the water, and (4) the presence/absence of a dry strip of soil all along the culvert.

IMPACT TO MINIMIZE: r[4]-, medium- or large-sized animals; road accidents deriv[4]l; the barrier effect of road for animal movements.

TECHNICAL CONSIDERATIONS: The culvert should present headwalls, without catch basins which would represent traps for smaller animals. The lateral dry ledge should be at least 50 cm wide, levelled along all along the passage; in wider culverts, wider ledges can be considered, to increase their usefulness for larger animals. The right height should be above the usual water level inside the culvert, so that the ledge remains generally dry. [5]ledge can consist of a block of concrete extending all along [5]ttached to the walls of the structure), or of suspended pl[5]compromise the capacity and passage in such a way that th[5]and the durability of the ledge hydrodynamics of draining, on on[5]the other. The surface of the dry ledge can also be made of wood, soil or other natural materials such as sand, as long as they do not risk being removed by intense water flows. The surface should never be of metal. It is important to ensure an easy access to the dry ledges through entrance/exit ramps with smooth slopes (< 30º) and a surface with some degree of adherence. Steep gradients, steps and slippery surfaces should be avoided. The dry ledge should end on the adjacent dry terrain and not on a riverbed or ditch. If necessary, a landscape integration with vegetation corridors should be made to favour the movement of animals towards the passages, thus providing safety and refugia. For this purpose, the vegetation should be planted in an oblique way, forming a continuous corridor between the passage and the surrounding environment.

MAINTENANCE REQUIREMENTS: Minor, particularly for concrete ledges. In this case, the degradation occurs at the same rate as the hydraulic structure itself, [6]aintenance of the ledge will be included in culvert maint[6]aintenance. Any fences blockstructures might need a m[6]d by the landowners of the adjaing the culvert entrances, u[6]their removal requested. It is necescent areas, should be checked a[6]any vegetation that obstructs them.

COMPLEMENTARITY: This solution should always be complemented by the installation of a fence with progressive mesh (see pp.XX) to adequately guide the animals [7]passage, except in zones where it is not possible to install it[7]erence with traffic flow or impacts on the infrastructure[7]ter flows are permanent and the culverts are wide, the [7]of two dry ledges should be considered, one at each side [7]er channel. The regular mowing of the vegetation in 1.5 – 3 m strip adjacent to the road pavement can contribute to reduce the risk of roadkill since it increases visibility and allows longer reaction times, while preventing animals to approach the road.

ALTERNATIVES: Build [8]ges for animals or adapt existing underpasses for agricu[8]estry use.

GENERAL EFFECTIVENESS: The solution tested by the LIFE LINES project consisted of lateral concrete dry ledges. This is an effective way to promote connectivity, particularly in situations where torrential or permanent water flows occu[9]als, especially during periods of flooding and as compa[9]rvention numbers. However, number of crossings by ca[9]ich may be related to the short roadkill did not decrease si[9]oring time is needed to give aniperiod of monitoring. A larger [9]mals the necessary time to adapt its behaviour and start using the new structure in order to properly assess the efficacy of the solution in the long-term.

EVALUATION:

[10]

Intervention	Target group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness	Cost-benefit
Culverts with dry ledges	Terrestrial animals	●●●○○	●●○○○	●○○○○	●○○○○	●●●●○[1]	Favourable

[1] The effectiveness increases with the deployment of fences that guide animals from the vicinities to the passage.

COST-BENEFIT:

[11]

[12]

Example of the standard design details concerning a concrete dry ledge for fauna, showing the access ramp leading to a dry adjacent terrain. Source: IP.

View of the dry ledge and of the way it leads the animals to an adjacent dry terrain, in one of the culverts where this solution was implemented.

Building of the dry ledge and final aspect, in one of the culverts where this solution was implemented.

An Egyptian mongoose using the dry ledge of a flooded culvert.

18

19

Minimizing the impacts of roads on animal communities – solution sheets

CULVERTS WITH DRY LEDGES FOR TERRESTRIAL ANIMALS

TARGET GROUP: terrestrial animals (terrestrial mammals sensu lato: carnivores, small mammals, hedgehogs, wild boars)

ECOLOGICAL CONTEXT: The watercourses and associated vegetation are important corridors for animals, allowing the movement of many species across the landscape. The culverts under the roads reestablish water circulation, and have also the potential to facilitate animal movement between the two sides of the road without exposing them to roadkill. However, these passages can be flooded for long periods, thus compromising its use by most species [2]. The installation of dry ledges along the culverts, above the usual water level, can increase the use of culverts by animals, but this intervention requires previous information to evaluate its applicability and chances of success. In order to help selecting the culverts for this purppose, a preliminary hydrological study can be performed of the watercourse running in the culvert during flooding. This study must determine (1) the total number of days of the flooding, (2) the number of consecutive days of flooding, (3) the usual level of the water, and (4) the presence/absence of a dry strip of soil all along the culvert.

IMPACT TO MINIMIZE: roadkill of small-, medium- or large-sized animals; road accidents deriving from roadkill; the barrier effect of road for animal movements.

TECHNICAL CONSIDERATIONS: The culvert should present headwalls, without catch basins which would represent traps for smaller animals. The lateral dry ledge should be at least 50 cm wide, levelled along all along the passage; in wider culverts, wider ledges can be considered, to increase their usefulness for larger animals. The right height should be above the usual water level inside the culvert, so that the ledge remains generally dry. The dry ledge can consist of a block of concrete extending all along the passage (easier and more durable structure), or of suspended platforms well attached to the walls of the passage in such a way that they do not compromise the capacity and hydrodynamics of draining, on one hand, and the durability of the ledge considering its resistance to the flow intensity, on the other. The surface of the dry ledge can also be made of wood, soil or other natural materials such as sand, as long as they do not risk being removed by intense water flows. The surface should never be of metal. It is important to ensure an easy access to the dry ledges through entrance/exit ramps with smooth slopes (< 30°) and a surface with some degree of adherence. Steep gradients, steps and slippery surfaces should be avoided. The dry ledge should end on the adjacent dry terrain and not on a riverbed or ditch. If necessary, a landscape integration with vegetation corridors should be made to favour the movement of animals towards the passages, thus providing safety and refugia. For this purpose, the vegetation should be planted in an oblique way, forming a continuous corridor between the passage and the surrounding environment.

MAINTENANCE REQUIREMENTS: Minor, particularly for concrete ledges. In this case, the degradation occurs at the same rate as the hydraulic structure itself, therefore maintenance of the ledge will be included in culvert maintenance actions. Other materials and hanging structures might need a more frequent maintenance. Any fences blocking the culvert entrances, usually placed by the landowners of the adjacent areas, should be checked and their removal requested. It is necessary to clear the culvert entries of any vegetation that obstructs them.

COMPLEMENTARITY: This solution should always be complemented by the installation of a fence with progressive mesh (see pp.XX) to adequately guide the animals to the passage, except in zones where it is not possible to install it due to interference with traffic flow or impacts on the infrastructure When the water flows are permanent and the culverts are wide, the implementation of two dry ledges should be considered, one at each side of the water channel. The regular mowing of the vegetation in 1.5 – 3 m strip adjacent to the road pavement can contribute to reduce the risk of roadkill since it increases visibility and allows longer reaction times, while preventing animals to approach the road.

ALTERNATIVES: Build specific passages for animals or adapt existing underpasses for agricultural and forestry use.

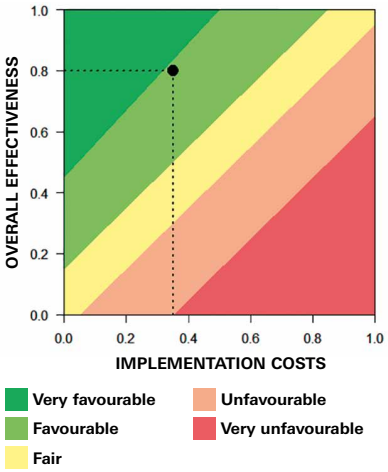
GENERAL EFFECTIVENESS: The solution tested by the LIFE LINES project consisted of lateral concrete dry ledges. This is an effective way to promote connectivity, particularly in situations where torrential or permanent water flows occur; a 21.1% increase was observed in the number of crossings by carnivore mammals, especially during periods of flooding and as compared to pre-intervention numbers. However, roadkill did not decrease significantly which may be related to the short period of monitoring. A larger monitoring time is needed to give animals the necessary time to adapt its behaviour and start using the new structure in order to properly assess the efficacy of the solution in the long-term.

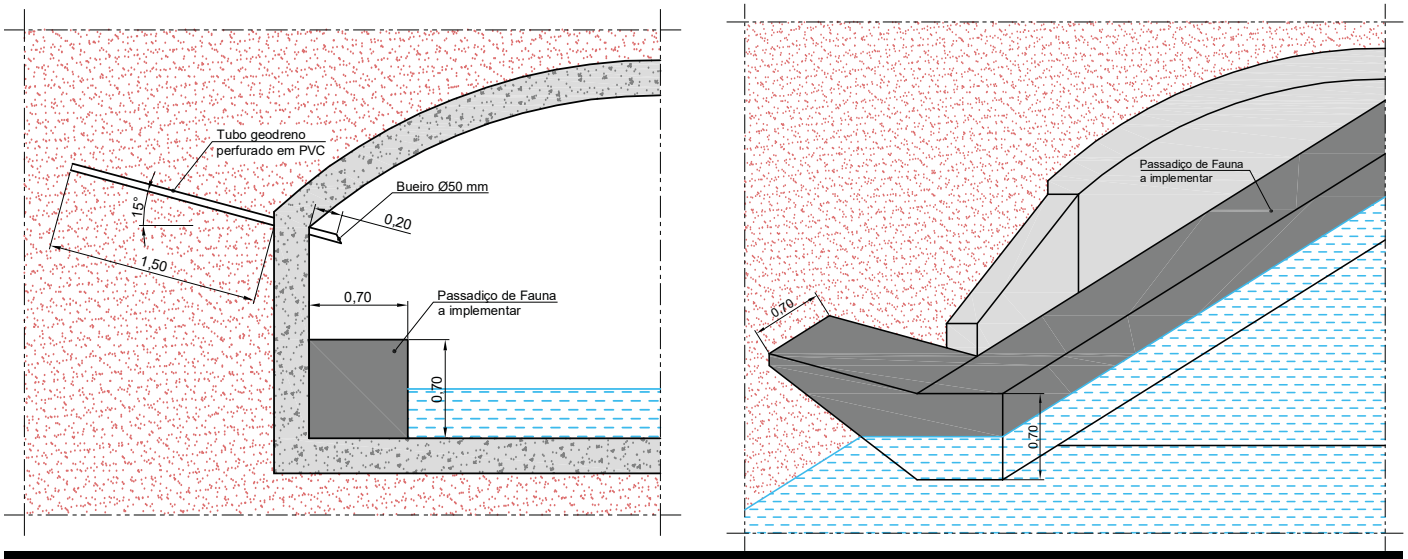
EVALUATION:

Solution	Target Group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness	Cost-benefit
Culverts with dry ledges	Terrestrial animals	●●●○○	●●○○○	●○○○○	●○○○○	●●●●○[1]	Favourable

[1] The effectiveness increases with the deployment of fences that guide animals from the vicinities to the passage.

COST-BENEFIT:





Example of the standard design details concerning a concrete dry ledge for fauna, showing the access ramp leading to a dry adjacent terrain. Source: IP.

View of the dry ledge and of the way it leads the animals to an adjacent dry terrain, in one of the culverts where this solution was implemented.

Building of the dry ledge and final aspect, in one of the culverts where this solution was implemented.

An Egyptian mongoose using the dry ledge of a flooded culvert.

SPECIFIC TUNNELS FOR AMPHIBIANS

TARGET GROUP: amphibians.

ECOLOGICAL CONTEXT: installing barriers is a practical solution to prevent amphibians from crossing the roads and avoid roadkill (see pp. 22), but it constrains the seasonal processes of dispersal and migration. By associating tunnels with such barriers, it is possible to direct the amphibians towards safe areas, thus greatly reducing the risk of roadkill. There are prefabricated structures for this purpose, with suitable characteristics for this animal group, such as those used in the LIFE LINES project; these present Climate openings or climate slots the surface to allow the passage of rain water, air circulation and light, offering favourable moisture conditions for amphibians.

IMPACT TO MINIMIZE: reduce roadkill and the road barrier effect.

TECHNICAL CONSIDERATIONS: The tunnel should have a height and a width of 40 – 100 cm. Some studies point to dimensions of 100 x 60 cm or of 100 cm diameters for circular passages; tunnels longer than 20 m should be larger (200 x 150 cm or 200 cm diameter). The embankment slopes need to be high enough to allow the tunnel installation and, in the case of tunnels with climate openings, the surface must be levelled with the road. The entries of these tunnels should be prepared to integrate complementary structures such as specific barriers (see pp. 22), avoiding empty spaces or bumps that might be climbed by the animals. The tunnels should be slightly inclined (2 – 3 %) to allow water drainage and thus avoid long periods of flooding that would hinder their use by some species of amphibians and other small fauna. The presence of natural substrate inside the tunnels might encourage their use by some species of amphibians [3], but its application should consider the risk of being flushed away by water. Some authors suggest the promotion of oblique plant hedges to direct the animals to the intervention zone and act as shelter [4], but near the barriers and tunnel entries vegetation should be kept low, to facilitate the movement of animals. Amphibian's crossings might occur along stretches of roads with some hundreds of meters. Therefore, several passages should be installed to encompass the whole length of the road where such crossings occur, with a maximum distance of 100 m between them.

MAINTENANCE REQUIREMENTS: To ensure the functionality of the structure, the passages should be checked before the Autumn rains, to remove any obstructions to animal movement (plants, debris, soil). The presence of these tunnels might require a more frequent maintenance of the road due to the development of irregularities on the pavement, which is particularly relevant in roads with high volume of traffic and high traffic speeds.

COMPLEMENTARITY: These passages should be implemented in association with barriers (see pp. 22) that lead the animals towards them.

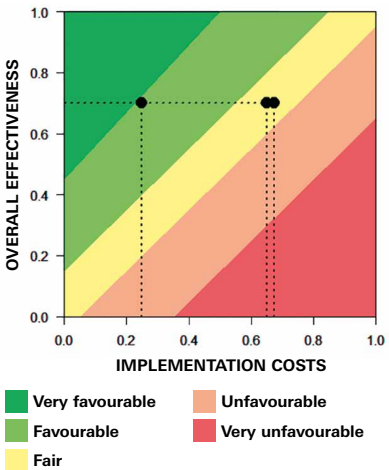
ALTERNATIVES: The culverts that re-establish the watercourses under the roads can be adapted for this purpose, as long as they have good accesses at their extremities, and no catch basins that may act as traps for amphibians. It is also important that they are not permanently flooded in the periods when these animals are more active (Autumn and Spring). This is a cheaper solution, easier to implement and with less impact on road traffic. However, the spatial distribution of these structures along the road varies considerably, and might not coincide with the sections where higher amphibian roadkill occurs, or be too far apart (more than 100 m). In this case, the culvert should be complemented with new passages (specific tunnels for amphibians, or concrete culverts), and the connection between the passages and the barriers should not allow amphibians to climb. When using existing culverts, it must be ensured that no steep slopes or other limitations prevent their use by amphibians.

GENERAL EFFECTIVENESS: While monitoring LIFE LINES' solutions, several species of amphibians were seen using the different types of passages (amphibian tunnels and adapted culverts). However, it is difficult to ascertain crossing movements, and no accurate estimate of the number of animals that used the tunnels was possible.

EVALUATION:

Solution	Target Group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness	Cost-benefit
Installation of new culverts	Amphibians	●●●●●	●●○○○	●○○○○	●●●●●	●●●◕○	Fair
Specific tunnels	Amphibians	●●●●●	●●◕○○	●○○○○	●●●●●	●●●◕○	Fair
Adaptation of existing culverts	Amphibians	●○○○○	●●○○○	●○○○○	●○○○○	●●●◕○	Fair

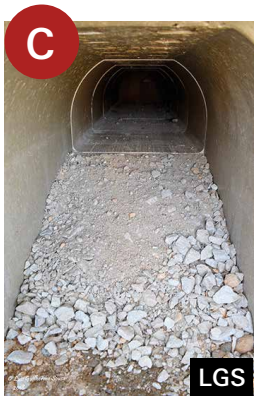
COST-BENEFIT:



Adaptation of a rectangular culvert in the framework of the LIFE LINES project, by creating an entrance ramp and connecting it to the guiding barriers.

Adaptation and integration of a circular culvert with a permanent concrete barrier.

Works to implement permanent concrete barriers guiding animals towards the culvert.



Installation phases of a specific tunnel for amphibians: (A) placement of the crossing pipes, with heavy machinery, (B) entry/exit of the passage during levelling of its first segment with the road, (C) detail of the placement of natural substrate inside the tunnel, and (D) final aspect of the passage, integrated in the roadbed and complemented with the permanent concrete barrier.

PERMANENT CONCRETE BARRIERS AND TEMPORARY CANVAS BARRIERS FOR AMPHIBIANS

TARGET GROUP: amphibians

ECOLOGICAL CONTEXT: Due to their mobility, amphibians are an easy group to redirect because when they find an obstacle, they try to find a way around. At road stretches where amphibian crossing is most probable, the installation of specific barriers for amphibians might be justified, to divert the animals into safe underpasses. Depending on the objective, barriers can be temporary or permanent, according to the material they are made of. Permanent barriers of concrete are a resistant, durable and easy to maintain solution; temporary fences, made of canvas, for example, can be installed just during certain critical periods (e.g., migration season) and then removed and placed elsewhere.

IMPACT TO MINIMIZE: prevent amphibian roadkill, as well as reduce the risk of traffic accidents caused by slippery pavement due to the accumulation of dead animals on the road where mass migrations take place.

TECHNICAL CONSIDERATIONS: The barriers must be installed along and on both sides of the road, and extend about 500 m to each side of the corridor defined for amphibian movement, guiding the animals towards the entrances of the tunnels (or other suitable underpasses). The barriers should be connected to the passage wing-walls to ensure the same protection height. The concrete barriers installed by the LIFE LINES project have an innovating design: they are L-shaped, made of concrete, with a smooth surface. The vertical side is 40 cm high and slightly bent away from the road, to hamper climbing or jumping over. For the same reason, the bent wall was thoroughly polished, and the vegetation within 50 cm around was kept short. When dealing with species of high jumping ability, some studies recommend a height of 60 cm [5]. For some species (e.g., newts) that are able to climb walls by means of cohesion adherence, an overhanging shoulder bended away from the road should be considered at the top of the barriers. The bottom of these barriers, strong enough to support the structure, should be 10-15 cm high and be buried. Barriers should be installed on the lower part of the road embankment slope or along the ditches at the base of the road excavation slope, depending on the road profile. Barrier extremities should be U-shaped, to prevent amphibians from passing to the other side of the road. Vegetation should be kept short within 50 cm around the barriers, so that they are visible to the drivers and thus avoid accidents, while preventing animals from climbing over and reaching the road. For drivers' safety, areas with barriers should be signalled.

Temporary barriers are built with an iron structure covered by canvas. Before installation, the ground should be cleaned and any obstacles removed (e.g., trunks, stones, vegetation); then a small groove where the barrier will be placed must be excavated. The barrier has three components: (1) a supporting structure made of two iron bars crossing each other, with a ring at each extremity; (2) a 1 m wide canvas (green or white), associated with pairs of rings (30 cm apart) every 2 to 3 m; and (3) 55 cm-long iron poles. The iron structure should be bent into a C-form, with 50 cm of height, 25 cm of width and 30 cm of length. The canvas will wrap this structure in such a way that the rings coincide with the iron structure. Then, the poles will hold the canvas to the iron structure and to the ground. The barrier should be well stretched and, after the installation, the part touching the ground should be covered with the soil that was previously dug up. The barriers should be installed starting from the entrance of the amphibian passages, to ensure they are adequately aligned with them. At these places, particular care must be taken to avoid breaches between the canvas and passages, through which the animals can access the road. To preserve the structure and not disturb the traffic, the barrier should be placed at least 2 m far from the road pavement whenever possible. The temporary barriers can be a cheap solution, easier to install than the concrete barriers, and offer the possibility of reutilization, in the same place or elsewhere.

MAINTENANCE REQUIREMENTS: In both cases, the space around the barriers must be cleared of vegetation at least twice a year, in September, before the Autumn migrations, and in March, when the Spring migrations take place; and whenever the growth of the vegetation justifies it. The bottom of the barriers should also be kept free of soil, to prevent the vegetation from establishing there. Due to the shape of the temporary barriers, more vegetation cleanings might be necessary, to ensure that the amphibians are not able to climb the plants growing along the barrier and do not reach its top. The integrity of the structure should be checked at least once a year, preferably after vegetation clearing to facilitate the detection of any possible problems. If damages are detected, they should be repaired.

COMPLEMENTARITY: The implementation of barriers should be associated with culverts suitable for amphibians, or with the installation of specific tunnels for this group, depending on the extent of the intervention.

ALTERNATIVES: Several types of barriers have been used for amphibians, but not all of them are adequate. Vertical barriers made of compact and smooth materials should be chosen, because they make climbing more difficult (small mesh fences are not suitable for this purpose). The installation of a prominent top or a mid-wall longitudinal ridge may discourage climbing even more. Concave barriers hinder the movement of amphibians along them.

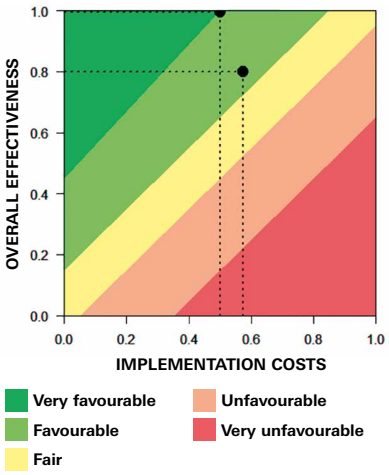
GENERAL EFFECTIVENESS: Several individuals of almost all the species were observed moving alongside the barriers. In rare occasions, juveniles were seen trying to climb the barrier, but none was seen reaching the road. The use of barriers allowed, in some cases, to reduce by 100% the number of amphibians on the road, in the area of intervention.

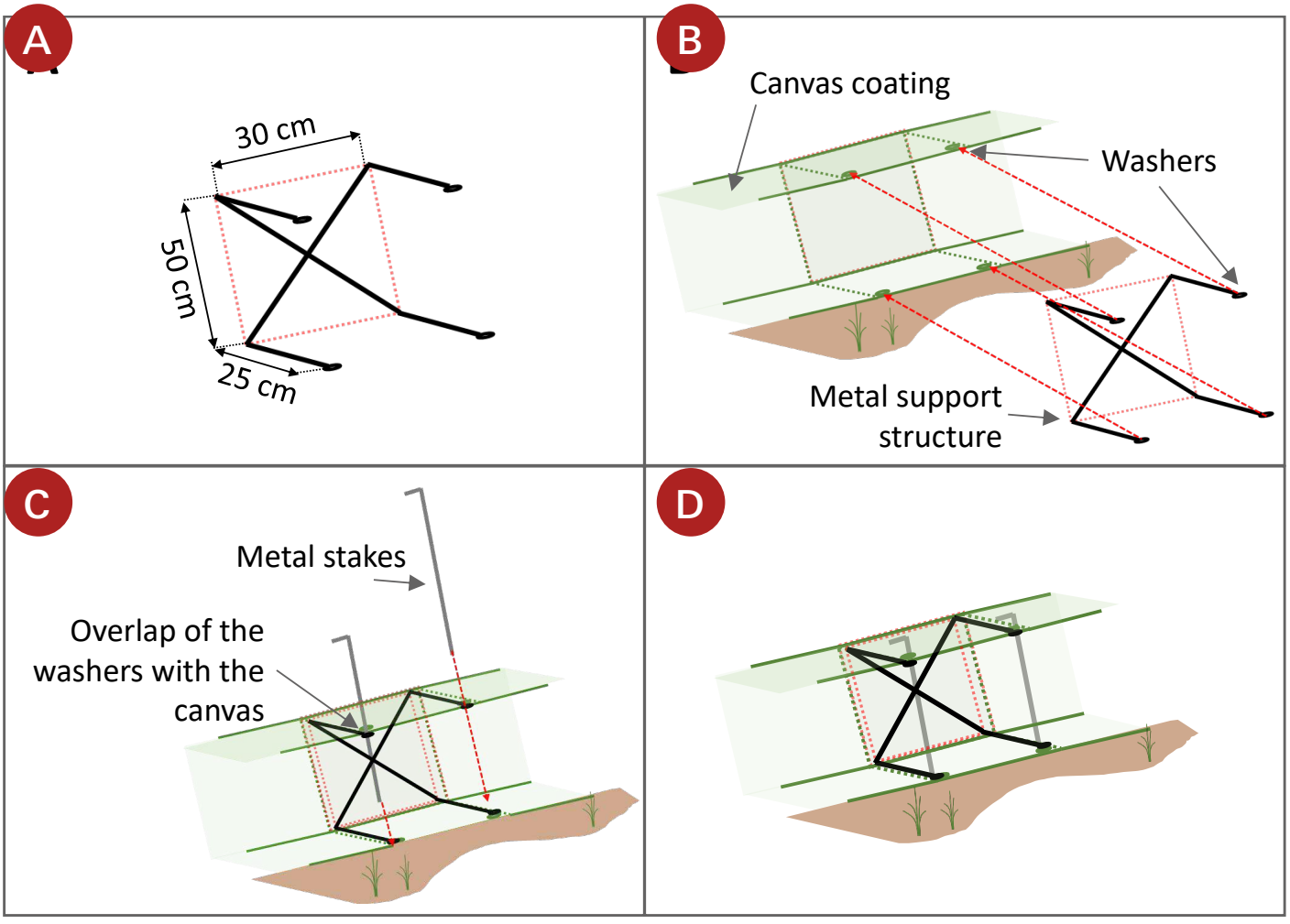
EVALUATION:

Solution	Target Group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness	Cost-benefit
Permanent concrete barriers	Amphibians	●●●●○	●●●○○	●○○○○	●●○○○[1]	●●●●●	Very favourable
Temporary canvas barriers	Amphibians	●●○○○	●●●●○[2]	●●●●○	●○○○○	●●●●○	Favourable

[1] Increases with the length of the interventioned segment of road. The values considered for the evaluation vary between 400 m and 2 km, with a minimum of 100 m to each side of the passage, on both sides of the road.
[2] Depends on the growth speed of the vegetation. In areas of higher moisture, where plants grow faster, more vegetation cuttings may be necessary.

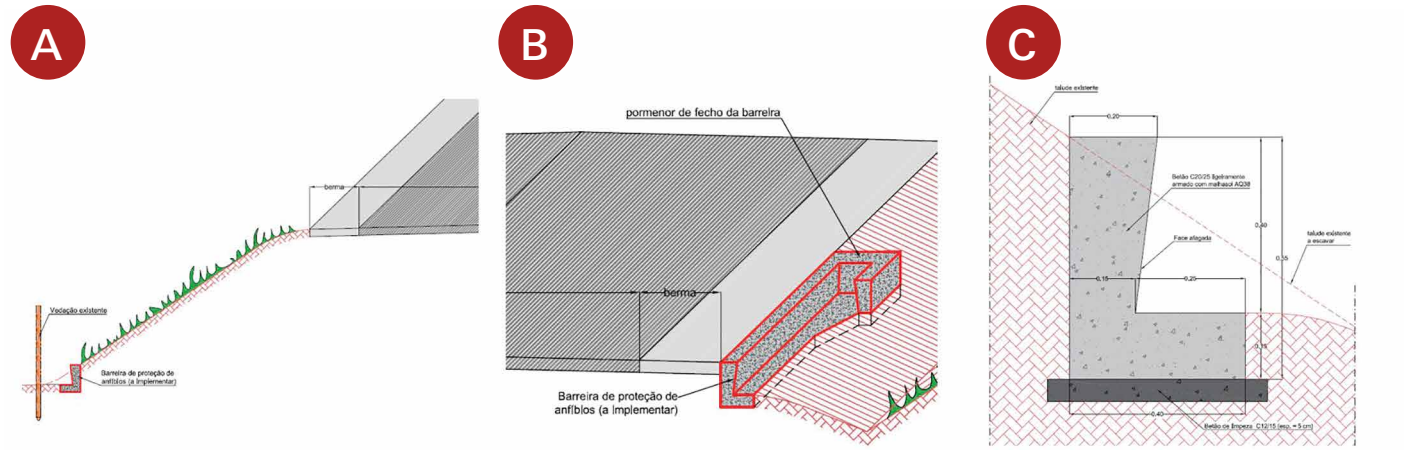
COST-BENEFIT:





Steps of installation of a temporary canvas barrier: (A) setting the iron structure, (B) placement of the canvas in a C-position and of the iron support inside it, ensuring that the rings of both components are aligned, (C) inserting the poles through these rings and fixing the canvas to the ground, and (D) final aspect of the installed barrier.

Installation of the temporary canvas barrier in the framework of the LIFE LINES project: (A) placement of the support structure, and (B) final aspect of the installed barrier.



Project of concrete barrier for amphibians at road EN114. (A) Standard cross profile, (B) detail of the barrier closure in U-shape, and (C) cross-cut of the L-shaped piece, with a total height of 55 cm and a slight inclination of the wall towards the outer side of the road (Source: IP).

Installation of the permanent concrete barriers on the road verges.

Examples of permanent concrete barriers for amphibians and details of their installation: (A) permanent concrete barrier well connected with the passage structure, preventing the amphibians from reaching the road; (B) U-shaped extremities; (C) integration of the barriers in the road embankment; (D) barriers directing amphibians to adapted culverts; and (E) barriers directing amphibians to specific tunnel entrance.

MESH BARRIERS TO ELEVATE FLIGHT HEIGHT

TARGET GROUP: Flying species (passerines, nocturnal birds-of-prey, bats).

ECOLOGICAL CONTEXT: The flying species are one of the groups most affected by roadkill. It is also a group for which the planning of mitigating measures is more complex, due to the plasticity of their movements and behavioural differences. Feeding places, refugia and territories nearby roads, together with low flight altitudes, typical of some species, are factors of risk of wildlife-vehicles collision. In roadkill records, passerines, owls and bats stand out, and all of them have different habits and mortality peaks. The installation of mesh barriers on both sides of the road prevents many of these species from crossing the road in segments of higher risk, forcing the animals to fly higher and thus cross the road above the height of most vehicles.

IMPACT TO MINIMIZE: Mortality by collision with vehicles.

TECHNICAL CONSIDERATIONS: The barriers must be 3 – 5 m high above the carriageway, and in roads with high truck traffic they should be over 4 m. They must be installed, in parallel, on both sides of the road. To increase their safety and resistance, and have the least visual impact to drivers, the barriers must consist of wire mesh and thus wind-permeable. The mesh size opening must be, around 1-2 cm and the diameter of the wire should be at least of 2 mm, preferably light-coloured in order to be well seen by the different species. For better stability, horizontal bracings should be contemplated to join the vertical posts, with the necessary clearance to allow the fixation of the net ensuring that it is well fixed and stretched. If the barrier is placed on bridges, viaducts or other crossing structures, the distance between posts should be adjusted to allow the connection with the safety guard rails. For greater safety, it is advisable to install guard rails along the barrier, so the barrier placement must take into account the spacing required for the guard to deform.

MAINTENANCE REQUIREMENTS: A periodical checking should be made (at the beginning of Spring and by the end of Summer), to evaluate the need for repairs before the critical periods when the most significant movements of flying species occur.

COMPLEMENTARITY: A possibility (still experimental) is to connect the two barriers with cross cables[6], which seem to prevent some species of bats from overflying the barrier and from crossing the road close to the carriageway.

ALTERNATIVES: The bibliography suggests the implementation of natural barriers created from shrub or tree lines. This solution depends on the region and can take a long time to be effective. Additionally, it might require a more frequent maintenance. It also implies an increased risk of fire in some areas, and thus be incompatible with legally supported municipality plans for forest protection against fire (Decree Law 124/2006 of 28 June and subsequent modifications), which might require large gaps between tree crowns and limit shrub heights near roads. The acoustic barriers, used to reduce traffic noise in the surrounding areas, can additionally contribute to force birds to fly higher. However, the transparent ones might become traps if birds cannot see them, and collision with these structures is often an additional cause of mortality associated with roads. To avoid this impact, the use of non-transparent barriers is recommended but, if this is not possible, they should be coloured (contrasting with landscape colours) or present vertical stripes [7].

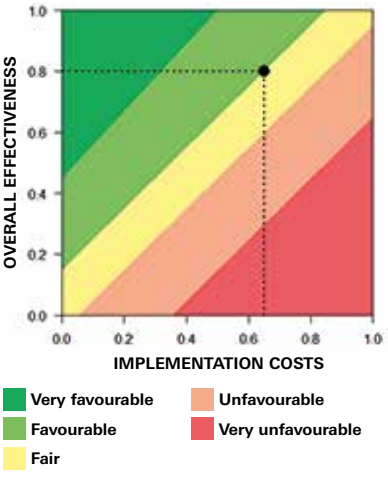
GENERAL EFFECTIVENESS: Under the LIFE LINES project about 400 m of 3 m-high wire mesh barriers were installed along two segments of a national road, and one segment of a municipal road. A reduction of 69.2% was recorded in bat mortality, and of 55.5% of passeriform mortality. During the year of monitoring, no owl roadkill was found, but due to the usually low annual mortality numbers, the effectiveness of the solution regarding this group can only be evaluated after a longer period.

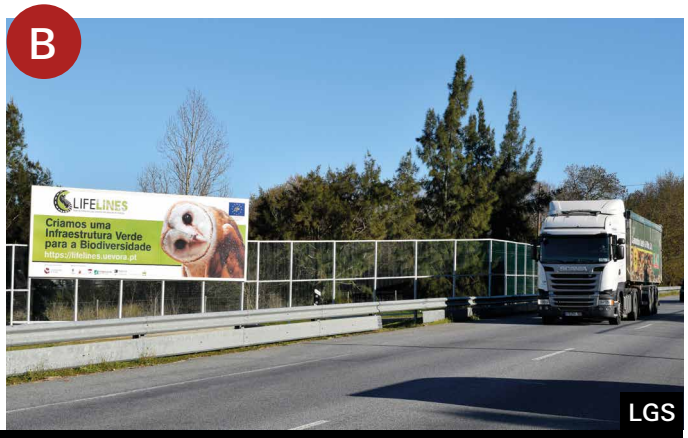
EVALUATION:

Solution	Target Group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness	Cost-benefit
Mesh barriers to elevate flight height	Flying species	●●●●●[1]	●●●●●	●●●●●	●●●●●[1]	●●●●●	Favourable

[1] increases with the length and height of the fence (higher fences might imply more complex requirements).

COST-BENEFIT:





Examples of wire mesh barriers installed during the project: (A) municipal road 529; and (B) national road 114.

Details of the 3 m-high barriers implemented on the national road 114 road, made of rectangular-section metallic posts (RHS 80x60x3 cm) inserted in the foundation and topped by plastic caps, 2 m apart, that support a galvanised wire mesh welded and plasticized with PVC/polyester, with a 19 x 19 mm of diameter and a wire diameter of 2 mm.

FENCES WITH PROGRESSIVE MESH

TARGET GROUP: medium- and large-size mammals.

ECOLOGICAL CONTEXT: Medium- and large-size mammals are greatly affected by roads' barrier effect and the risk of roadkill. The presence of these animals on the road is also a safety hazard for drivers. The target group includes ecologically diverse and highly mobile species, that can occur in very different habitats. Fencing will limit their access to the road and guide them towards safe points for passage, such as culverts and underpasses for agricultural and forestry use. Although the lands adjacent to the roads are often fenced (for cattle control), such fences are generally not suitable for wild mammals since the mesh aperture is not small enough to effectively act as a barrier.

IMPACT TO MINIMIZE: roadkill of medium- and large-sized animals; traffic accidents caused by the presence of animals on the roads.

TECHNICAL CONSIDERATIONS: The fences should be 1.60 m high (in areas of red deer occurrence, they should be higher than 2.20 m) with progressive wire mesh, whose basal mech aperture is small (preferably ≤ 5 cm) and becomes gradually larger towards the top. The fence should be partly buried and well stretched, so that no gap remains between the mesh and the ground (in areas with wild-boars, the mesh should be buried 20 cm deep, at least, or an additional L-shaped mesh should be installed, see pp. 30). Moreover, the fence should surround the culverts and underpass entrances in an oblique way, to guide the animals to these passages. If this is not possible, the fence should end next to the passage extremity ensuring that no breach is left, through which the animals could reach the road. Other possible accesses to the road should be considered, such as ditches or access gates, which should be complemented with mesh or other materials to prevent animals from using them to reach the road. The mortality of birds and bats can also be caused by the barbed wire, so this type of wire should be avoided, particularly in areas where species of conservation interest occur.

MAINTENANCE REQUIREMENTS: The fence should be checked every 6 months, or when there is a high number of roadkill in the fenced segment of the road. Any detected damage should be immediately repaired. The ditches should be regularly cleaned from accumulated debris.

COMPLEMENTARITY: The fences should guide the animals towards culverts and underpasses (which might need intervention, see pp. 18), to provide animals with safe passages to cross the road, maintaining the connectivity between the two sides of the road. In zones of abundant small-sized or digging species, the fences can be complemented with L-shaped mesh (see pp. 30). In non-fenced roads, the implementation of fences close to the culverts should be considered, extending at least 250 m to each side of its entrances, in order to guide the animals in the vicinities. If there are rabbit burrows on road sides, a rabbit-deterring mesh can also be implemented (see pp. 32).

ALTERNATIVES: Acoustic or light devices (see warning reflectors, pp. 36) that warn the animal of an approaching vehicle, thus driving the animal away from the road. This solution is less effective as a barrier. In the case of climbing species, fences can be adapted by presenting a bent top, leaning to the opposite side of the road. When no fences can be used, the regular mowing of the vegetation should take place within 1.5 – 3 m of each road side, to reduce roadkill by increasing the visibility and therefore the reaction time of drivers, as well as to keep the animals further away from the road.

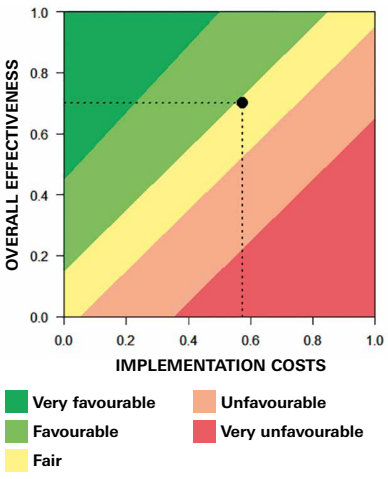
GENERAL EFFECTIVENESS: In the framework of the LIFE LINES project, the fences were installed in association with culverts, to guide the animals to those passages. The few recorded monitoring data (mesofauna roadkill are occasional events in short periods of time) do not indicate differences in mortality, relative to control monitoring areas. However, in the culverts where both fences and dry ledges were installed, a considerable increase of crossings by carnivore mammals (18.3%) was observed, particularly of genets (34.9%) and weasels (58.8%) compared to the numbers recorded before their implementation.

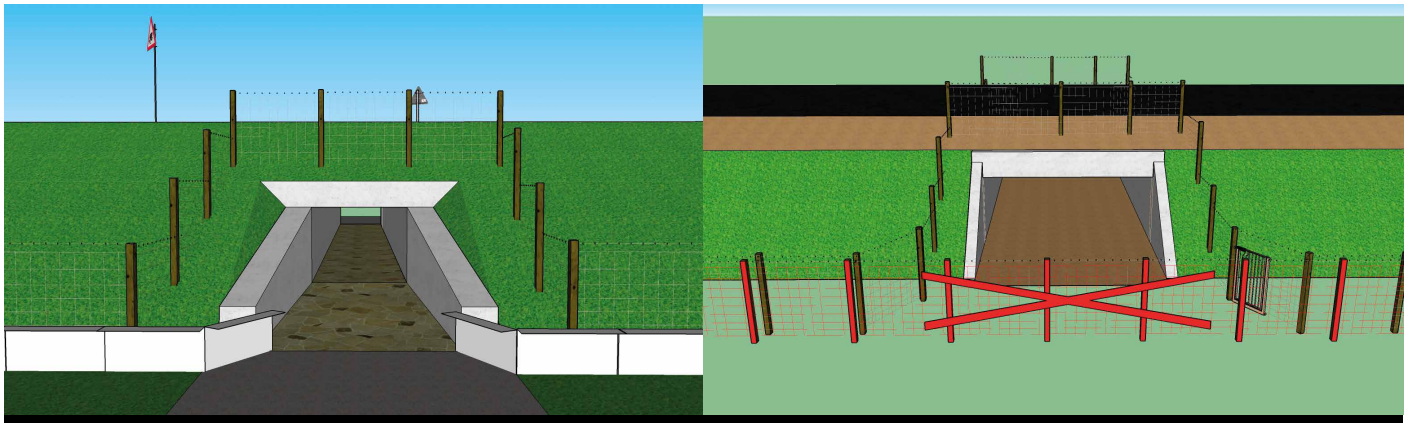
EVALUATION:

Solution	Target Group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness	Cost-benefit
Fences with progressive mesh	Medium- and large-size mammals	●●●○○	●●●○○	●●●●○	●●○○○[1]	●●○○○	Fair

[1] increases with the length of the road segment where the intervention takes place. The values considered for this evaluation vary between 2 and 20 km.

COST-BENEFIT:





Schematic installation of fences next to culverts: (A) the fence is placed around the culvert entrances, not hindering its use by animals, and extends along the road verges, guiding the fauna towards the passage; (B) private land fences closing the culverts entrances prevent animals from using it, and alternatives should be discussed to increase their permeability or to remove them.

Examples of fences contouring the upper part of culverts, thus leaving their entries accessible.

Examples of incorrect installation of fences: (A) gap between the fence and the passage wall; (B) fence placed in front of the culvert, with pallets hindering access to it.

FENCES WITH ADDITIONAL L-SHAPED MESH

TARGET GROUP: wild boars, small mammals, other digging or fossorial animals.

ECOLOGICAL CONTEXT: Conventional fences or fences with progressive mesh might not be effective barriers to small-sized species or digging or fossorial species. However, if they are complemented with L-shaped mesh their effectiveness increases for such species, guiding them towards safe crossing places. This kind of solution makes excavation under the fence more difficult because its bottom is buried and it has a smaller mesh aperture, thus reducing the range of species able to pass through it.

IMPACT TO MINIMIZE: animal roadkill, traffic accidents due to the presence of animals on roads (wild boars).

TECHNICAL CONSIDERATIONS: The L-shaped mesh should have a very small aperture (1-2 cm in diameter), be attached to the external side of the fences' posts (i.e., away from the road), and be bent into an L, with 50 cm erected above the ground and 50 cm lying flat on the ground. This base should be buried to a 10 cm depth, covered with well compacted soil or concrete. The "bent" zone might be reinforced with a steel cable to ensure that it stays straight and in place.

MAINTENANCE REQUIREMENTS: The mesh should be checked every 6 months, or whenever high animal mortality rates occur on the concerned segment of road. During the regular cutting of the vegetation, special caution is recommended not to damage the mesh. Any detected damage should be repaired.

COMPLEMENTARITY: This solution serves as complement to road fences (see pp. 28).

ALTERNATIVES: Canvas can be used instead of wire mesh where there is a high mortality of amphibians. This alternative is less durable and is not effective for digging animals.

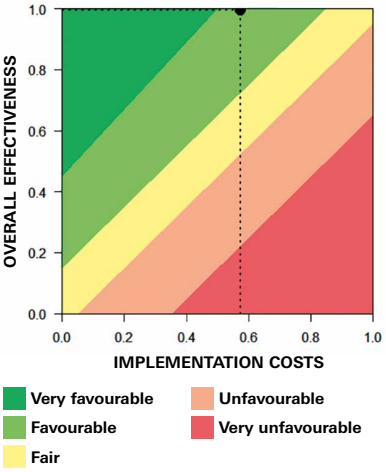
GENERAL EFFECTIVENESS: In the framework of the LIFE LINES project, the L-shaped mesh was installed along 16 km, on both sides of the road. A reduction of 90.8% was recorded in the mortality of carnivore mammals, thus proving its efficiency for this group.

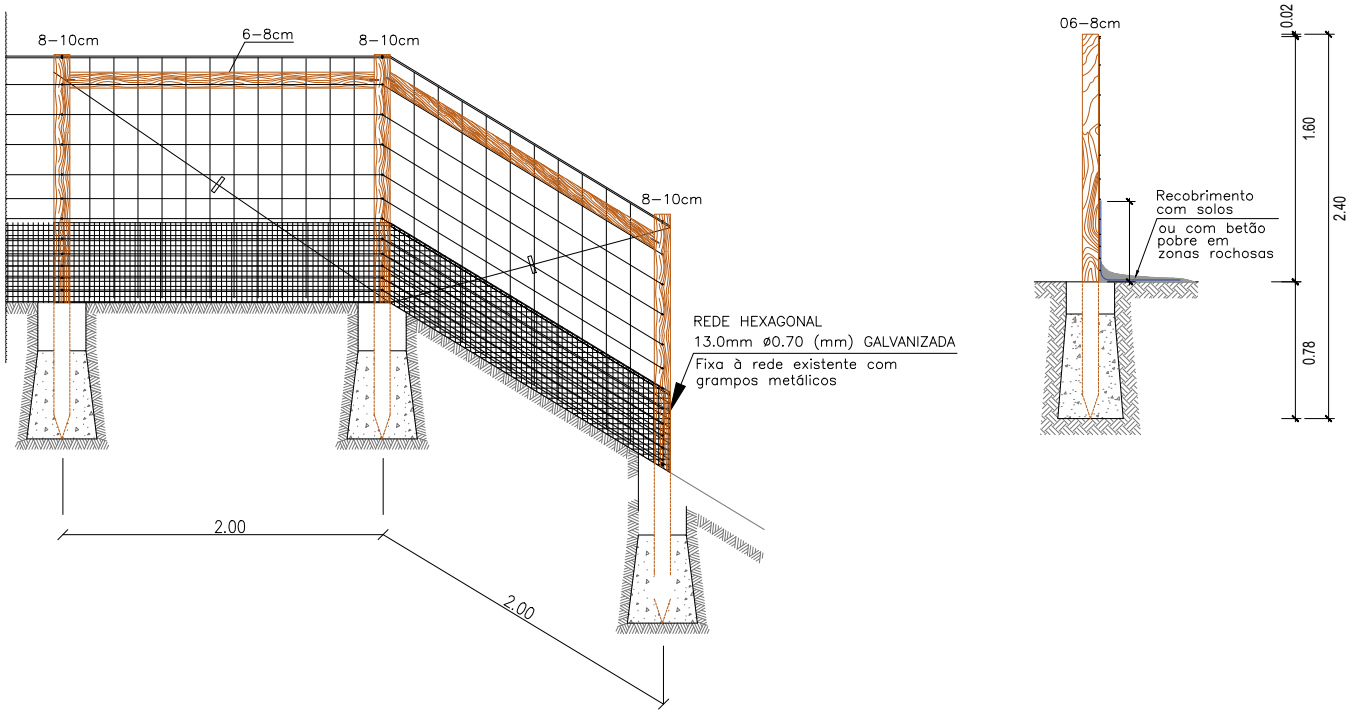
EVALUATION:

Solution	Target Group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness	Cost-benefit
Fences with additional L-shaped mesh	Mammals, in general	●●●○○	●●●○○	●●●●○	●●○○○[1]	●●●●●	Favourable

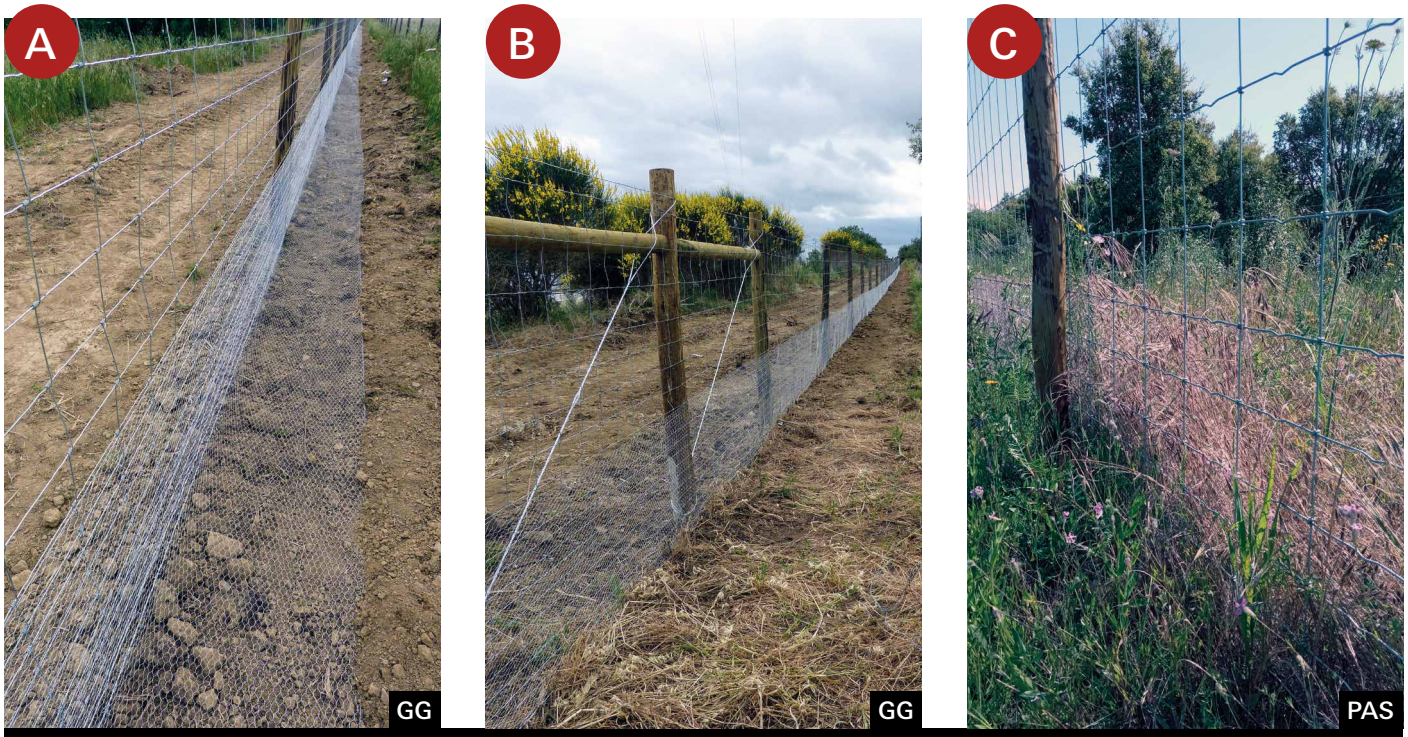
1 – increases with the length of road segment subjected to the intervention. The values considered for the evaluation range between 2 and 20 km.

COST-BENEFIT:





Schematic representation of the design of an L-shaped mesh attached to a fence. The galvanized mesh is hexagonal with a small aperture (13. 0 mm), attached to the fence with metallic gramps. The base is bended and The base is covered with soil or concrete in rock zones.



Installation of a fence with additional L-shaped mesh at the road IP2, in the framework of the LIFE LINES project: (A) attachment of the additional mesh to the fence; (B) cover and compaction of the soil at the base; (C) final aspect of the L-shaped mesh.

DETERRING MESH FOR RABBITS

TARGET GROUP: rabbits.

ECOLOGICAL CONTEXT: Rabbits have colonial habits and a high reproductive rate. When they build their burrows under the roadslopes they might compromise their integraty and even cause instability of the road platform. Being so close to the road, these animals are often victims of roadkill. Moreover, the high abundance of prey on road verges might attract predators and scavengers to the roads and thus increase the risk of roadkill for these species too. The installation of a wire mesh covering the roadslope prevents the rabbits from building their warrens there, and reduces the frequency of their approach to the road, hence reducing the risk of roadkill.

IMPACT TO MINIMIZE: fauna roadkill; traffic accidents caused by the presence of animals on the road, instability of roadslopes.

TECHNICAL CONSIDERATIONS: The vegetation (herbs and shrubs) should be cut prior to the installation of the wire mesh, and any existing rabbit colonies removed. The rabbit-type mesh or any other with a mesh aperture size smaller than 3-4 cm, made of galvanized steel, should be fixed to the ground and cover the whole road slope, from the road verge to the road fence or road expropriation limit. It should extend along at least 500 m to each side of the road segment where burrows are present, on both sides of the road or, ideally, along all the segment of road that is conducive to the presence of rabbits, to avoid rabbit colonization in the areas adjacent to the mesh. Along the road slope, the mesh strips should be stapled to one another to avoid gaps between them; the borders of each mesh should be well stretched and well attached to the ground, preferably by burying to a 15-20 cm depth to avoid it being lifted up. If trees or large shrubs are present, the mesh should be cut around the trunks, well-adjusted to avoid its loosening.

MAINTENANCE REQUIREMENTS: The team in charge of mowing and cutting of vegetation should be informed about the areas of intervention to avoid damaging the mesh during their work. Mowing and cutting can be performed normally, as long as some care is taken in handling the machinery. The mesh should be checked after mowing and cutting of vegetation and any damage repaired.

COMPLEMENTARITY: None.

ALTERNATIVES: The fences with progressive mesh complemented with L-shaped mesh limit the access of rabbits and of their predators to the road, but are not full alternatives to prevent rabbits from colonizing the road slopes.

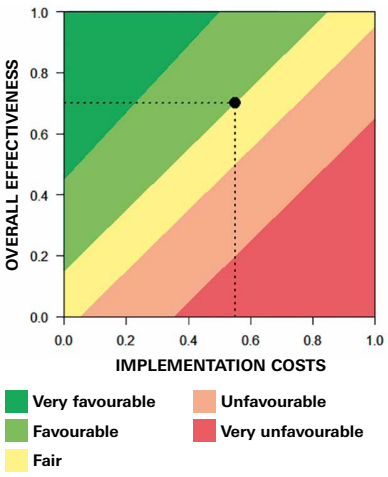
GENERAL EFFECTIVENESS: In the framework of the LIFE LINES project, 2000 m of deterrent mesh for rabbits were installed, on the slopes of two 500 m-segments of national road 4. The monitoring data shows there was a rapid reduction of mortality in those road segments, but the reduction of the populations of this species at national level cannot be ignored. Therefore, the effectiveness of this solution to reduce roadkill remains uncertain.

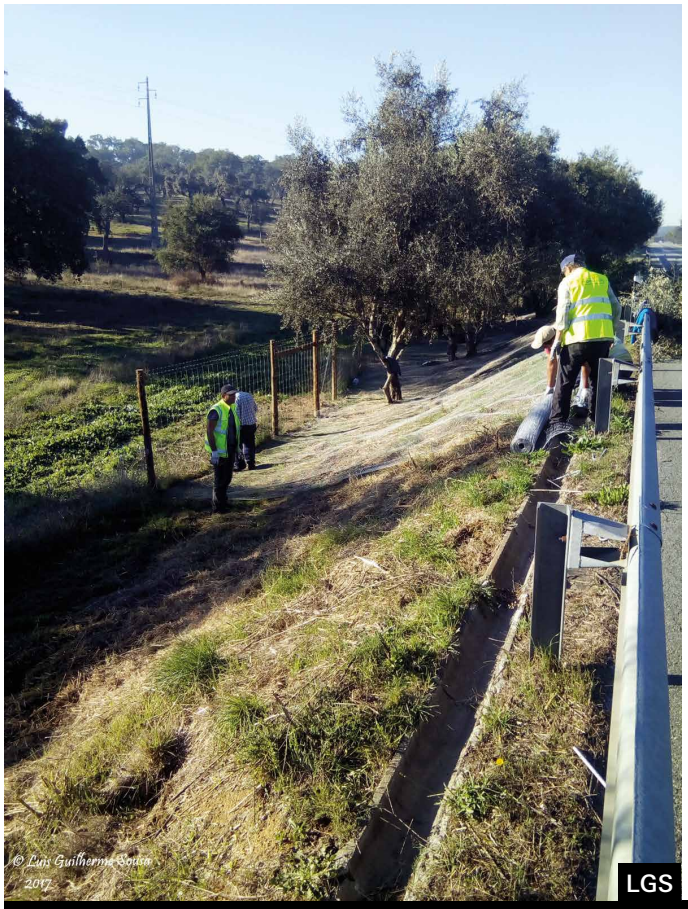
EVALUATION:

Solution	Target Group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness	Cost-benefit
Deterrent mesh for rabbits	Rabbits	●●○○○	●●●○○	●●●●○	●●○○○	●●●○○[1]	Favourable

[1] the action was effective to prevent the installation of new rabbit burrows in the monitored road slopes, but this effect cannot be dissociated from the generalized reduction of rabbit populations across all country.

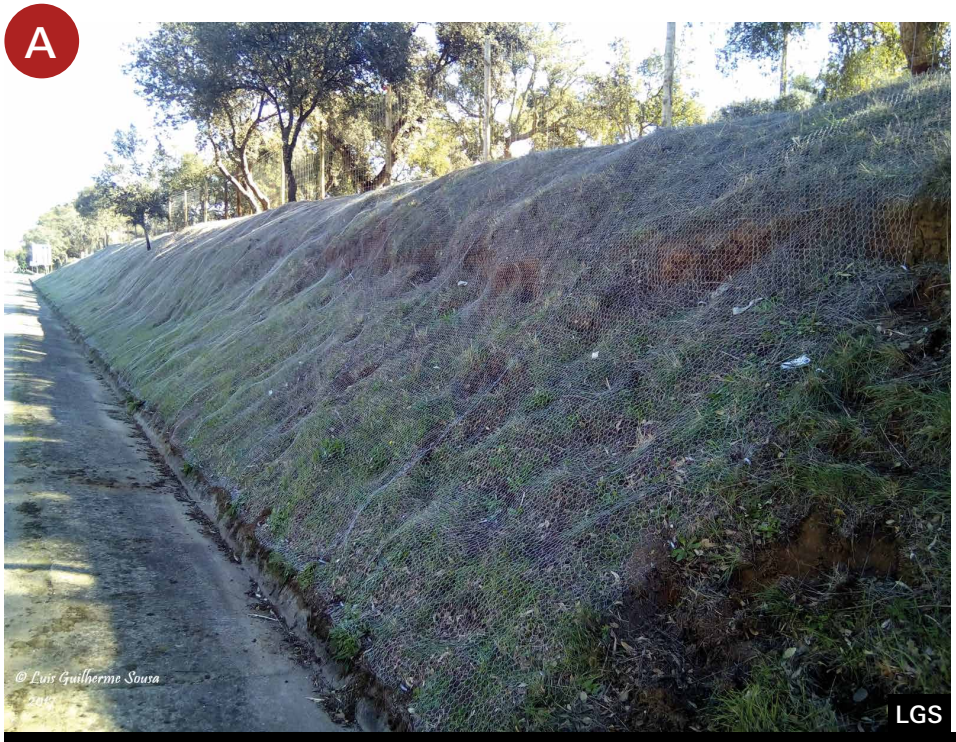
COST-BENEFIT:





Installation of a deterrent mesh for rabbits on the road slopes of national road 4, Évora district.

A



B

(A) Final aspect of the installed deterrent mesh for rabbits, and (B) detail of the placement of the mesh next to a tree trunk to prevent rabbits from passing through.

WILDLIFE WARNING REFLETORS

TARGET GROUP: nocturnal birds-of-prey.

ECOLOGICAL CONTEXT: Nocturnal birds-of-prey (owls, little owls and Eagle owls) are the birds presenting the highest roadkill values because they use the vicinities of roads as hunting areas or as territorial limits. Particularly during the dispersal period, juveniles get too close to the roads, greatly exposing themselves to collisions with vehicles. The use of warning reflectors, which redirect the lights of approaching vehicles to the road surrounding zones, is a solution already applied to other groups (ungulate and carnivore mammals), with inconsistent results [7,8]. However, it had never been used for nocturnal birds-of-prey before.

IMPACT TO MINIMIZE: roadkill of nocturnal birds, traffic accidents caused by the presence of the animals.

TECHNICAL CONSIDERATIONS: There are different types of warning reflectors that redirect light to three different directions, according to the road profile: forward, upwards, and downwards. The two former types are best suited for nocturnal birds-of-prey. If the road is at the same level as the surrounding area or on a smooth embankment, the reflector should redirect the light straight ahead, with no inclination. If the road slopes are higher than the road the reflector should redirect light upwards. The adequate positioning of the reflectors should be ensured, as well as their stable support, such as that provided by road delineators and guard rails delineators). They should be placed 25 m apart from each other, alternating between the two sides of the road, i.e., each reflector should be placed in the middle of the section gap between two reflectors on the opposite side of the road.

MAINTENANCE REQUIREMENTS: An annual inspection should be made, along with other road works. The vegetation should also be managed to avoid compromising the correct dispersion of the light.

COMPLEMENTARITY: This solution can be complementary to the installation of mesh barriers to elevate flight height, thus increasing the intervention area at a lower cost.

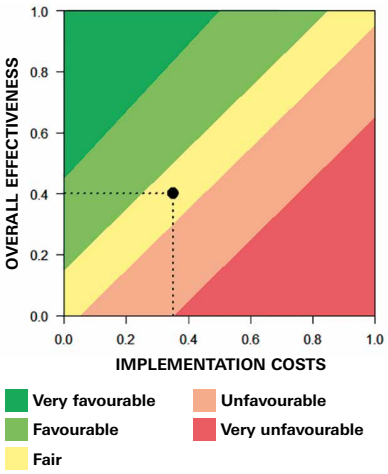
ALTERNATIVES: Mesh barriers to elevate flight height can be alternatives (see pp. 26). However, these require higher technical skills and costs, and are generally applied in relatively short segments of road. Warning reflectors allow a more extensive application and are more adequate when mortality occurs over long segments of road rather than concentrated on well-defined spots.

GENERAL EFFECTIVENESS: In the framework of LIFE LINES, 100 wildlife warning reflectors were installed along a 1200 km-long segment of road in national road 4, 25 m apart from each other. Since nocturnal birds-of-prey roadkill are occasional events in short periods of time due to the wide vital areas of these species, the volume of data recorded so far is still not enough to evaluate the effectiveness of this measure; only after gathering a long-term monitoring recording will be possible to make such an evaluation.

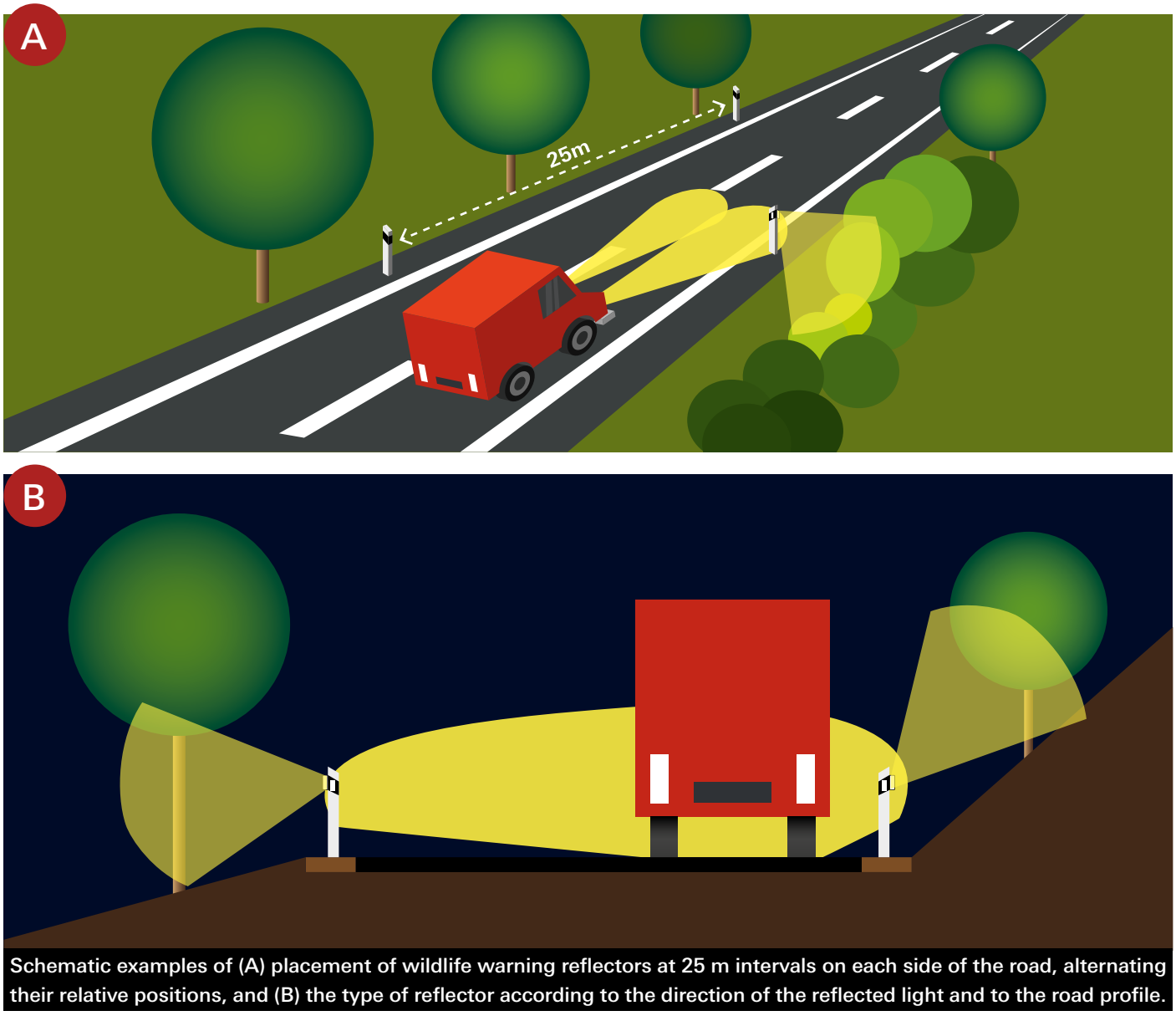
EVALUATION:

Solution	Target Group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness	Cost-benefit
Wildlife warning reflectors	Nocturnal birds-of-prey	●○○○○	●●○○○	●●●○○	●○○○○	●●○○○	Fair

COST-BENEFIT:



Wildlife warning reflector attached to a road delineator.



Schematic examples of (A) placement of wildlife warning reflectors at 25 m intervals on each side of the road, alternating their relative positions, and (B) the type of reflector according to the direction of the reflected light and to the road profile.

DETERRENT ULTRASOUND PROTOTYPE TO DRIVE SMALL MAMMALS AWAY FROM ROAD VERGES

TARGET GROUP: small mammals (preys of the nocturnal birds-of-prey).

ECOLOGICAL CONTEXT: The marginal zones of roads provide suitable habitats for many animal species, namely small rodents, particularly where the surrounding areas are not able to provide such habitats due to intensive agriculture or grazing. On the other hand, the presence of prey close to the roads attracts predators which, under certain circumnstances (e.g. traffic) become more exposed to roadkill. For example, the tawny owl generally uses roads as territorial limits and roadsides as hunting areas. This proximity to the roads can represent a problem for this species, which is one of the birds-of-prey most affected by roadkill.

IMPACT TO MINIMIZE: roadkill of nocturnal birds-of-prey by discouraging the presence of small mammals in the marginal zones of roads; traffic accidents caused by the presence of the animals.

TECHNICAL CONSIDERATIONS: The prototype consists of an emitter of ultrasounds of continuously changing frequency (between 20 and 32 KHz) and with a maximum intensity of 120 dB. The ultrasounds are emitted at variable time intervals, previously established, so that small mammals do not get used to them. The expected range of influence of the ultrasounds is 30 m. The battery box should be buried in the road verges and the emitter should remain on the surface. The existence of alternative habitats in the surrounding area to host the small mammals scared away by the device should be considered.

MAINTENANCE REQUIREMENTS: The battery must be weekly replaced. A more intensive maintenance should be made during periods of heavy rainfall. Mowing and cutting the verge vegetation must be performed with caution, to avoid damaging the external parts of the prototype.

COMPLEMENTARITY: None.

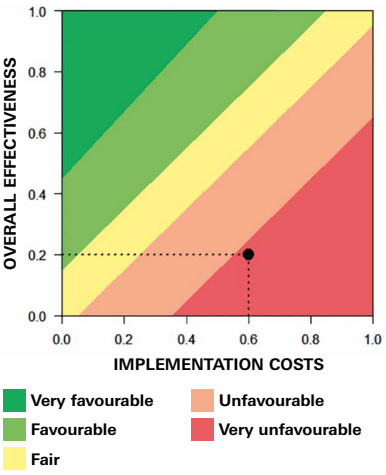
ALTERNATIVES: Since the goal is to reduce roadkill of nocturnal birds-of-prey, additional solutions for that same purpose can be implemented, such as the installation of mesh barriers to raise flight height or wildlife warning reflectors.

GENERAL EFFECTIVENESS: The prototypes to drive small mammals away from road verges were tested on two sites along national roads. Although a significant reduction was recorded in one of them, the results are not coherent, so the effectiveness of this solution remains uncertain.

EVALUATION:

Solution	Target Group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness	Cost-benefit
Deterrent ultrasound prototype	Small mammals	●○○○○	●●●●●	●●●●●	●○○○○	●○○○○	Unfavourable

COST-BENEFIT:



Placement of a prototype on a road verge to drive small mammals away.

AMPHIBIANS WARNING ROAD SIGN

TARGET GROUP: amphibians.

ECOLOGICAL CONTEXT: The amphibians are one of the groups most affected by roadkill: 35% of all the roadkill vertebrates. The species of this group make dispersal or migration movements to reproduction areas after the first Autumn rains, and these movements may last until Spring. Moreover, amphibians use the road as a feeding zone or to find mates. Under favourable conditions, they might occur in large numbers within a short distance. The warning road signs are meant to warn drivers about possible dangerous situations. For larger wild animals, sign A19b – Animais selvagens (wild animals) is generally used. However, this sign does not specify the groups of fauna that drivers must pay attention to. Therefore, for more specific species, this sign is insufficient. On the 20th of April 2020, two new animal alert road signs were enforced: A19c – Lince-ibérico (iberian lynx) and A19d – Anfíbios (amphibians), added through the Regulatory Decree n.º 6/2019, which alters the Traffic Signage Regulations, approved by the Regulatory Decree n.º 22-A/98, of 1 October. The sign concerning amphibians indicates that "the road can be crossed by amphibians" (mainly during nights with temperatures higher than 10 °C and slight to moderate rain), warning the drivers of the risk of occurrence of large numbers of amphibians on the road in rainy nights, as well as possibly impaired adherence of the wet pavement, thus leading the driver to drive more carefully and to reduce speed. But this sign also aims at protecting the amphibians, one of the groups most vulnerable to this kind of impact, with high mortality rates on roads, not only by roadkill but also by the high speed of vehicles, which can kill nearby amphibians by barotrauma, i.e., destruction of internal organs by sudden changes of pressure.

IMPACT TO MINIMIZE: mortality of amphibians during the migration of large numbers of individuals; traffic accidents due to slippery pavement resulting from the accumulation of skins of dead amphibians on the wet pavement.

TECHNICAL CONSIDERATIONS: It must comply with the rules of installation of road signs. They should be placed in segments of the road where crossing by large numbers of amphibians is highly probable; such zones should be ascertained by recording of numerous amphibians' roadkill, or through knowledge of the migratory routes of the species, that justify their application.

MAINTENANCE REQUIREMENTS: Periodical checking of the sign condition. Due to its novelty, it has often been stolen or vandalised; it should be replaced as soon as possible.

COMPLEMENTARITY: It can be used as a complement in zones where solutions to mitigate amphibians' mortality have been implemented.

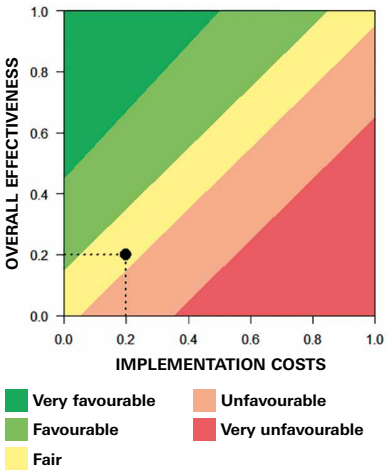
ALTERNATIVES: Solutions to actively mitigate amphibians' roadkill (barriers with tunnels/culverts, see pps 20 and 22).

GENERAL EFFECTIVENESS: In the framework of LIFE LINES project, the signs installed on the roads were poorly effective, and no reduction of amphibians' roadkill was observed. The effectiveness of this solution largely depends on external factors such as the driver's behaviour, how visible the animals are on the road, and even how intense the mass migrations are. However, this solution has several advantages such as being a quick and simple solution (as an alternative to others that are lengthy to design and execute) and can be used temporarily (the sign can be installed only during critical periods, thus becoming a more efficient warning for drivers).

EVALUATION:

Solution	Target Group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness	Cost-benefit
Warning road sign	Amphibians	●○○○○	●○○○○	●○○○○	●○○○○	●○○○○	Fair

COST-BENEFIT:



Sign A19b – Animais selvagens
(wild animals)

Sign A19c – Lince-ibérico
(Iberian lynx)

Sign A19d – Anfíbios
(amphibians)

Amphibians' warning road sign (Sign A19d – Amphibians), at national road 114 road, Évora.

Cost-benefit of interventions

The criteria and conditions on which the assessment of each solution was based are presented below, together with a summary table of the assessment of each solution.

	●○○○○	●●○○○	●●●○○	●●●●○	●●●●●
Difficulty of implementation in terms of human and logistics resources	No design is required, only simple adaptations of existing structures; the implementation does not require particular skills nor substantial human resources.	No design is required and the execution is not particularly demanding though it might require a significant number of non-specialized human resources or some specialised.	A simple design is needed, involves construction works. It might require some heavy machinery or complex technicities, requiring a significant number of human resources, including some skilled ones.	It requires a complex design, involves a complex execution, mobilizing numerous skilled human resources. It requires heavy machinery and involves demanding technicities.	It requires a complex design and execution, involving demanding technicities and numerous skilled human resources. It requires heavy machinery. It involves the total or partial transverse cutting of the road.
Maintenance costs after the intervention	It requires very little maintenance (< once a year).	It requires little maintenance (once a year).	It requires a more frequent (e.g., twice a year) or extensive maintenance	It requires frequent (3 - 4 times a year), and/ or more demanding maintenance.	It requires very demanding and frequent maintenance (≥ 6 times a year).
Need for rehabilitation determined by the period during which it remains functional	Durable and functional solution on the long-term, with little need of repair.	Durable and functional solution on the long-term, that might need repair every 5-10 years.	Durable and functional solution on the medium-term, needing repair every 2-5 years.	Non-durable solution, requiring frequent repair (every 1-2 years).	Non-durable solution, requiring very frequent repair (> once a year).
General cost of implementation, including the design process when applicable	< 50 000 €	50 000 – 100 000 €	100 000 – 150 000 €	150 000 – 200 000 €	> 200 000 €
Effectiveness in mitigating mortality or in promoting animal movements	Null effectiveness; the results do not meet expectations, no changes in animal behaviour or decreased mortality are observed.	Poorly effective solution; a slight effect is detected in species behaviour or mortality but not independent of external factors (e.g., populational fluctuations).	Modest effectiveness; some, though not significant effect on changes in the behaviour of species or in mortality.	Effective solution, meeting the expectations by changing species' behaviours or decreasing mortality, but not effective for all the species of the target group.	Very effective solution, beyond the expectations; clear and significant effect in changing species' behaviour and considerably decreasing mortality.

Solution	Target Group	Difficulty of implementation	Maintenance costs	Need for rehabilitation	General cost	Effectiveness		Cost-benefit
Underpasses and culverts								
Culverts with dry ledges	Terrestrial animals	●●●○○	●●○○○	●○○○○	●○○○○	●●●●◐[1]		Favourable
Installation of new culverts	Amphibians	●●●●●	●●○○○	●○○○○	●●●●●	●●●○○		Fair
Specific tunnels	Amphibians	●●●●●	●●●○○	●○○○○	●●●●●	●●●○○		Fair
Adaptation of existing culverts	Amphibians	●○○○○	●●○○○	●○○○○	●●●●●	●●●○○		Favourable
Barriers and fences								
Permanent concrete barriers	Amphibians	●●●●○	●●●○○	●○○○○	●◐◐○○[2]	●●●●●		Very favourable
Temporary canvas barriers	Amphibians	●●○○○	●●●●◐[3]	●●●●○	●○○○○	●●●●○		Favourable
Mesh barriers to elevate flight height	Flying species	●●●●◐[4]	●○○○○	●●●○○	●●●●◐[4]	●●●●●		Favourable
Fences with progressive mesh	Medium to large-size mammals	●●●○○	●●●○○	●●●●○	●◐◐○○[5]	●●●○○		Fair
Fences with additional L-shaped mesh	Mammals in general	●●●○○	●●●○○	●●●●○	●●◐◐○[5]	●●●●●		Favourable
Dissuasive measures								
Deterring mesh	Rabbits	●●○○○	●●●○○	●●●●○	●●○○○	●●●◐○[6]		Favourable
Wildlife warning reflectors	Nocturnal birds-of-prey	●○○○○	●●○○○	●●●○○	●○○○○	●●○○○		Fair
Deterrent ultrasound prototype	Small mammals	●○○○○	●●●●●	●●●●●	●○○○○	●○○○○		Unfavourable
Signalling								
Warning road sign	Amphibians	●○○○○	●○○○○	●○○○○	●○○○○	●○○○○		Fair

[1] the effectiveness increases when guiding fences are also installed around the passages.

[2] increases with the length of the road segment subjected to the intervention. The values considered for the evaluation vary between 400 m and 2 km, with a minimum of 100 m to each side of the passage, on both sides of the road.

[3] depends on the growth speed of vegetation. In more humid areas, where the vegetation grows faster, more frequent cuttings might be needed.

[4] increases with the length and height of the barrier (higher barriers might involve more complex requirements).

[5] increases with the length of the road segment subjected to the intervention. The values here considered varied between 2 km and 20 km.

[6] the action was effective to prevent the installation of new rabbit burrows in the monitored road slopes, but this effect cannot be dissociated from the generalized reduction of rabbit populations across all country.

CITED BIBLIOGRAPHY

[1] Seiler A (2002). Effects of Infrastructure on Nature. In: Trocmé M, Cahill S, De Vries JG, Farrall H, Folkeson L, Fry G, Hicks C, Peymen J (Eds.) (2003). COST 341 – Habitat Fragmentation due to transportation infrastructure: The European Review, pp. 31-50. Office for Official Publications of the European Communities, Luxembourg.

[2] Craveiro J, Bernardino J, Mira A, Vaz PG (2019). Impact of culvert flooding on carnivore crossings. Journal of Environmental Management 231: 878-885.

[3] Lesbarrères D, Lodé T, Merilä J (2004). What type of amphibian tunnel could reduce road kills? Oryx 38:220–223.

[4] Ministerio de Medio Ambiente (2006). Prescripciones Técnicas para el diseño de pasos de fauna y vallados perimetrales. Documentos para la reducción de la fragmentación de habitats causada por infraestructuras de transporte, número 1. O.A. Parques Nacionales. Ministerio de Medio Ambiente. 108 pp. Madrid.

[5] Woltz HW, Gibbs JP, Ducey PK (2008). Road crossing structures for amphibians and reptiles: informing design through behaviour analysis. Biological Conservation 141:2745–2750.

[6] CEDR (2016). Bat mitigation measures on roads – a guideline. CEDR, Brussels, 52 pp.

[7] Iuell B, Bekker GJ, Cuperus R, Dufek J, Fry G, Hicks C, Hlaváč V, Keller VB, Rosell C, Sangwine T, Tørsløv N, Wandall B le Maire (Eds.) (2003). COST 341 – Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions. KNNV Publishers, 180 pp.. ISBN:90 5011 186 6

[8] Rytwinski T, Soanes K, Jaeger JAG, Fahrig L, Findlay CS, Houlahan J, et al. (2016). How effective Is road mitigation at reducing roadkill? A meta-analysis. PLoS ONE 11(11): e0166941.

RECOMMENDED BIBLIOGRAPHY

Ascensão F (2005). Ecologia de Estradas - Análise de estudos sobre a mortalidade de vertebrados por atropelamento e o uso de passagens hidráulicas por vertebrados. Dissertação para a obtenção de grau de mestre em Biologia da Conservação, Universidade de Évora.

Barrientos R, Bolonio L (2008). The presence of rabbits adjacent to roads increases polecat road mortality. Biodiversity and Conservation, 18: 405-418.

Borda de Agua L, Barrientos R, Beja P, Pereira H (2017). Railway Ecology. SpringerLink

CEDR (2016). Procedures for the Design of Roads in Harmony with Wildlife. Final Report. CEDR, Brussels, 19 pp.

CEDR (2016). Procedures for the Design of Roads in Harmony with Wildlife. Cost-effective maintenance to support the ecological functions of roads. CEDR, Brussels, 49 pp.

CEDR (2016). Procedures for the Design of Roads in Harmony with Wildlife. Maintenance Handbook. CEDR, Brussels, 52 pp.

EuroNatur (2010). TEWN Manual. Recommendations for the reduction of habitat fragmentation caused by transport infrastructure development. EuroNatur Foundation, Radolfzell, 135 pp.

ICNB (2008). Manual de apoio à análise de projectos relativos à implementação de infraestruturas lineares. Instituto da Conservação da Natureza e Biodiversidade. Relatório não publicado. Lisboa, 65pp. Available at: http://www2.icnf.pt/portal/pn/biodiversidade/ordgest/aa/resource/doc/man-infra-lin

Ministerio de Medio Ambiente y Medio Rural (2008). Prescriciones técnicas para el seguimento y evaluación de la efectividade de las medidas corretoras del effecto barrera de las infraestructuras de transporte. Documentos para la reducción de la fragmentación de habitats por infraestructuras de transporte, número 2. O.A. Parques Nacionales. Ministerio de Medio Ambiente, Madrid, 138 pp.

Ministry of Agriculture, Food and the Environment (2016). Technical prescriptions for wildlife crossing and fence design (2nd edition, revised and expanded). Documents for the mitigation of habitat fragmentation caused by transport infrastructure, number 1. Ministry of Agriculture, Food and the Environment. 124 pp. Madrid.

O'Brien EJ, Tschan G, Wansink D, Puky M (2016). Design of roads in harmony with wildlife. Transportation Research Procedia 14: 509 – 517

O'Brien E, van der Grift E, Elmeros M, Wilson-Parr, Carey C (2018). Call 2013: Roads and Wildlife The Roads and Wildlife Manual. CEDR, Brussels, 123 pp.

Rosell C, Álvarez, G, Cahill S, Compeny R, Rodriguez A, Seiler A (2003). COST 341. La fragmentación del habitat en relación com las infraestructuras de transporte en España. O.A. Parques Nacionales. Ministerio de Medio Ambiente, Madrid, 317 pp.

Rosell C, Velasco Rivas J (1999). Manual de prevenció i correcció dels impactes de les infraestructures viàries sobre la fauna. Documents dels Quaderns de Medi Ambient, 4. Generalitat de Catalunya, Departament de Medi Ambient. Barcelona.

Sétra (2011). Bats and road Transport Infrastructure. Threats and preservation measures. Sétra Information Notes 91. 22pp.

Van der Ree R, Smith DJ, Grilo C (eds.) (2015). Hanbook of Road Ecology. John Wiley & Sons, West Sussex, 522 pp.

The LIFE Programme is a EU's funding instrument created to contribute to the implementation, updating and development of EU environmental and climate policy and legislation by co-financing projects with European added value.

The LIFE Nature and Biodiversity sub-programme supports projects that aim at the conservation and restoration of threatened natural habitats and to protect species of prioritary conservation in the EU, as well as innovating and demonstration projects on the conservation of biodiversity.

LIFE LINES (LIFE14 NAT / PT/ 001081) – Linear Infrastructures Networks with Ecological Solutions – is co-funded up to 60% by the UE LIFE Programme – Nature and Biodiversity, with a total budget of 5,540,485 €, and duration from August 2015 to May 2021.

LIFE LINES
Linear Infrastructure Networks with Ecological Solutions

Project contacts:

Email | info.lifelines@uevora.pt

Website | https://lifelines.uevora.pt

Facebook | www.facebook.com/lifelinesconservation

Vimeo | https://vimeo.com/user48795863

Co-financier:

LIFE-LINES (LIFE14 NAT / PT / 001081) Linear Infrastructure Networks with Ecological Solutions 60% co-financed project by the LIFE - Nature and Biodiversity Program of the European Commission

Coordinating beneficiary:

UNIVERSIDADE DE ÉVORA

Associated beneficiaries:

U.PORTO FACULDADE DE CIÊNCIAS UNIVERSIDADE DO PORTO

universidade de aveiro theoria poiesis praxis

Câmara Municipal de Évora

MONTEMOR | O | NOVO câmara municipal

Infraestruturas de Portugal

marca montemor-o-novo

Quercus

Collaborators:

REN

E-REDES