



Received: 28-05-2026
Accepted: 07-07-2026

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

The Place and Role of Animal Ecoducts in the Modern Road Infrastructure

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DOI: <https://doi.org/10.62225/2583049X.2026.6.4.6634>

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Abstract

Protecting biodiversity means conserving the variety of life on Earth (species, genes, ecosystems) in order to maintain the natural balance, ensure vital resources (clean air, water, food), and protect us from disease, preventing the extinction of species caused by human activities (pollution, deforestation) through conservation measures and sustainable use of resources, in order to guarantee a healthy future for the planet and humanity. This scientific paper was written by the authors in a logical and elegant manner, with the aim of presenting the place and role of animal ecoducts in modern road infrastructure. In this way, those interested can learn about both the legislation and specialized literature governing this field, as well as the importance of biodiversity in Europe and Romania. The paper also

includes chapters on the importance of road transport infrastructure in the European and Romanian context, types of wildlife migration, connectivity between different types of habitats, types of ecoducts currently in existence and used for animal migration between areas and biodiversity interrupted by road or rail transport routes (roads, highways, railways, etc.), the state of adaptation of Romania's transportation infrastructure to environmental requirements regarding wildlife crossings and then reports on a case study of road accidents involving motor vehicles and wild animals, presenting the most effective methods, techniques, and installations for protecting wild animals in road traffic. At the end of the scientific article, the authors' conclusions on the subject are presented.

Keywords: Road Infrastructure, Ecoduct, Motor Vehicle, Road, Highway, Animal, Nature, Passages, Green Routes

1. Introduction

From the need for greener and cooler cities, with vegetation that absorbs rainwater and reduces the effects of heat islands, to protecting wildlife by building animal ecoducts, the discussion covers a wide range of concrete solutions that can restore the connections between people and nature. Animal ecoducts are not only a road safety solution, but also one that responds to the urgent need to protect biodiversity. The fragmentation of natural habitats seriously affects wildlife, limiting its access to food and mates, increasing inbreeding, and exposing it to additional risks (disease, climate change, lack of resources) ^[1]. They are structures that allow animals to safely cross highways and other man-made barriers. The most general term used is "wildlife crossing" and can include: tunnels, viaducts, bridges and overpasses, amphibian tunnels, fish ladders, aqueducts, and green roofs ^[2]. The construction of ecoducts for animals, whether domestic or wild, to cross road infrastructure plays an essential role in maintaining ecological connectivity in areas where infrastructure separates entire areas. These well-designed and correctly positioned structures can repair, at least partially, the disruption caused by modern road infrastructure, contributing to the conservation of key species and the balance of ecosystems, of which humans are also a part. Even though the number of wild animals using them has not been counted, and in some areas locals say they have never seen bears or wolves, "green passages" are considered effective in reducing the impact that highways have on the environment. Today, wildlife crossings have become a common feature of highways that cross protected natural areas. Some "bear tunnels", as they have often been called, have served both as passageways for wild animals and as a means of stabilizing the land ^[3]. The crossings also help prevent collisions between vehicles and animals, accidents that result in injury or death to animals, as well as injury to humans or property damage. Authorities report that accidents between vehicles and animals in the United States result in \$8 billion in damage annually. Ecoducts are not just simple bridges, but miniature ecosystems covered with native vegetation, stones, and logs to mimic the natural habitat, and are essential for maintaining genetic flow between animal populations isolated by road infrastructure.

2. Literature review and legislation

2.1 Literature Review

The history of ecoducts began around the 1950s in France, with the first bridges dedicated to helping animals cross roads, a solution that evolved to reduce habitat fragmentation and human-wildlife conflicts, especially in areas such as South India, where natural arch bridges were built for macaques.

The first ecoducts and early development:

- France (1950s): The first ecoduct structures appeared in France, marking the beginning of recognition of the need to allow wildlife to safely cross road infrastructure;
- Netherlands: The concept was quickly adopted and perfected in the Netherlands, a country that has become a European leader, currently having over 600 such structures for various species, from badgers to deer. It is also home to the world's longest ecoduct, Natuurbrug Zanderij Crailoo, which measures over 800 meters;

India (2000): a notable example is the Arch Bridge in the Anamalai Tiger Reserve, built for macaques in response to numerous road accidents, demonstrating a locally adapted approach.

Evolution and purpose:

- Initially: These were often simple bridges or arched passages, but they have evolved into complex structures, including passages under roads (viaducts) and over them (ecoducts);

The main goal is to reconnect habitats fragmented by roads, allowing animals to move around for food, reproduction, or migration, thereby reducing traffic mortality and the impact on biodiversity.

Global expansion (1980–2000):

- North America: In the 1980s, Canada began a long-term study in Banff National Park, constructing over 40 structures that reduced collisions with animals by over 80%.

United States: the first passages appeared in Florida in the 1950s, but large-scale construction only began at the end of the 20th century and the beginning of the 21st century.

The modern context: today, ecoducts are an important component of road infrastructure planning, although their implementation varies, being influenced by economic factors and species-specific effectiveness.

History in Romania:

- Although large infrastructure developed later, Romania has begun to integrate these structures into recent motorway projects by aligning environmental legislation with European Union requirements;
- In 2019, Romania's first ecoduct was completed in Brănișca, on the Lugoj-Deva section of the A1 highway;

Major projects are underway for 2025-2026, such as the "complex ecoduct" on section 3 of the Sibiu-Pitești highway (Cornetu-Brezoi area) and the famous "bear tunnels" on the Margina-Holdea lot.

In the Romanian dictionary, we did not find the term ecoduct, which shows that this term (word) is new, not yet introduced into the multitude of words existing in the context; however, in the Dexonline version, under point 1.5, we found the term *passage*, *crossing* [4]. In the same online dictionary, we looked up the word *duct*, which means *channel*, *conduct*, *tube* [5]. Associated with the word *eco* [6], from the same online dictionary, added in front of the first

two, respectively three words mentioned above, we would define it as *ecopass*, *ecopassage*, *ecocanal* (*ecological canal*, *ecoconduct*, *ecotube*), that is, a means of access, passage, or crossing over certain obstacles (access roads, railways, roads, highways, etc).

2.2 Legislation

Car accidents caused by wild animals are a complex legal issue, and managing them requires a clear understanding of the legal framework.

Applicable legal framework [7]:

Hunting Law no. 407/2006 and Government Decision no. 3/2023 establish the conditions under which compensation may be granted for damage caused by hunting fauna. Art. 13 para. (1) of the law provides for compensation for damage caused by species in Annexes 1 and 2, but the actual liability is regulated by art. 13 para. (7) and detailed in Government Decision no. 3/2023.

According to these provisions, liability for car accidents involving wild animals is distributed as follows:

- The road administrator is responsible if there are no "Beware of Animals" signs on the road section.
- The driver is responsible if such signs are present.

Art.13 of Law No. 407/2006 [7]:

"(1) Compensation shall be granted for the damage and/or harm caused by specimens of fauna species of hunting interest, included in Annexes No. 1 and 2."

The same art.13 establishes in paragraph (7) that: "(7) Compensation for damages caused as a result of traffic accidents involving specimens of the fauna species of hunting interest included in annexes no. 1 and 2 shall be borne by the road administrator, if "beware of animals" signs are not installed, or by the driver of the vehicle in the event of the existence of this sign."

In the same register, art.8 paragraph (4) of GD no. 3/2023 provides that [7]:

"(4) Civil liability for damages resulting from traffic accidents involving specimens of the fauna species of hunting interest included in Annexes 1 and 2 to Law 407/2006, as subsequently amended and supplemented, is established as follows: a) the responsibility of the road administrator, if signs with the inscription "beware of animals" are not installed; b) the responsibility of the driver of the vehicle, if this sign exists; if the driver of the vehicle is also its owner, no compensation is granted."

3. The importance of biodiversity

The importance of biodiversity lies in ensuring vital resources (food, water, clean air), maintaining ecological balance, regulating climate, preventing disease, and supporting economies through ecosystem services, providing resilience to natural and human systems in the face of environmental change, from the genetic to the ecosystem level.

The ecological benefits of biodiversity:

- Ecosystem stability*: A greater variety of species makes an ecosystem more resistant to disturbances, such as climate change or disease, ensuring its functioning;
- Climate control*: Diverse ecosystems, such as forests, help absorb carbon dioxide, a key factor in mitigating climate change;
- Water and soil purification*: Plants and microorganisms contribute to water filtration and soil fertility maintenance;

- *Pollination:* Insects, birds, and other animals are essential for pollinating plants, including agricultural cultures.

The economic and social benefits of biodiversity:

- *Food:* The diversity of plants and animals provides a wide range of food for the population;
- *Medicines:* Many medicines are derived from plant and animal species, with biodiversity acting as a natural "pharmacy";
- *Tourism and recreation:* Rich ecosystems attract eco-tourism, contributing to local economies;
- *Resources:* Wood, fibers, and fuels are just a few of the resources that nature provides us with.

Human impact on biodiversity:

- Human activities such as deforestation, pollution, and intensive agriculture are the main causes of biodiversity loss;
- The disappearance of a species can affect the entire ecosystem and, implicitly, the services it provides us.

Why it is important to protect biodiversity:

- To maintain the natural balance and quality of our lives;
- To ensure resources for future generations;
- To reduce the impact of climate change;
- To prevent the spread of disease.

The European territory, as well as the Romanian one, is rich in biodiversity. It is concentrated in forest habitats, plains with extensive pastures, and wetlands.

4. Europe's Biodiversity

Europe's biodiversity encompasses the vast variety of species (animals, plants, fungi, microorganisms) and ecosystems (forests, rivers, seas, mountains, wetlands) on the continent, from common to rare species, all interconnected through essential ecosystem services such as pollination, water purification, and climate regulation. but it is facing decline due to climate change, pollution, habitat loss, overexploitation, and invasive species.

Composition:

- *Genetic diversity:* Genetic variations within a species, essential for adaptation;
- *Species diversity:* The number of different species of animals, plants, insects, etc. living in Europe;
- *Ecosystem diversity:* The variety of habitats, from boreal forests in the north to the Alps, Mediterranean areas, and coastal wetlands.

Key Ecosystems:

- *Forests:* Diverse, ranging from temperate deciduous to boreal coniferous;
- *Wetlands:* Marshes, peat bogs, deltas, crucial for water filtration;
- *Seas and oceans:* The Mediterranean Sea, the Baltic Sea, the Black Sea, with unique marine ecosystems;
- *Mountains:* The Carpathians, the Alps, the Pyrenees, with species adapted to high altitudes;
- *Agricultural landscapes:* rural areas with specific species (birds, insects) dependent on traditional agriculture.

European biodiversity, although rich, is in sharp decline due to habitat loss, pollution, climate change, and invasive species, but the European Union has an EU Biodiversity Strategy for 2030 [8], focused on protecting at least 30% of land and sea, restoring ecosystems, and creating an ecological network, in the context of the European Green Deal [9].

Current situation:

- *Drastic decline:* Wildlife species, habitats, and populations are rapidly declining, even though Europe covers only a small part of the planet's land mass. The European Environment Agency has warned in recent reports (2025) that biodiversity continues to decline due to unsustainable production and consumption patterns, particularly in the food system;
- *Main threats:* Overexploitation of natural resources, climate change, pollution, overexploitation, invasive species, and soil biodiversity loss are the major risk factors identified for 2026;
- *Main factors:* Climate change, habitat destruction, pollution, and invasive species contribute to this loss;
- *Economic impact:* it is estimated that biodiversity loss could cost the European economy up to €1.1 trillion annually if conservation targets are not met.

EU strategy for 2030:

- *Key initiatives and strategies:* Remains the central pillar in 2026, aiming to transform at least 30% of Europe's land and marine areas into protected areas;
- *Nature Restoration Law:* In 2026, Member States are under pressure to implement recent agreements that impose mandatory measures to restore degraded ecosystems, including agricultural areas and rivers;
- *Protection network:* Legal protection of 30% of the EU's territory and waters, with ecological corridors;
- *Nature restoration:* An ambitious plan to repair degraded ecosystems;
- *Concrete measures:* Commitments to combat illegal wildlife trade and support post-pandemic ecological recovery.

Importance: the strategy is part of the European Green Deal and aims to increase resilience to future crises.

Challenges: reports (such as the one from Greenpeace) highlight the devastating losses and the inaction of the authorities, despite EU commitments.

Financial support and programs:

- *LIFE Program:* The Nature and Biodiversity subprogram offers co-financing of up to 75% for conservation projects;
- *Biodiversa+:* The European Partnership for Biodiversity is running the "BiodivConnect" call for proposals from 2025 to 2026, focusing on restoring ecosystem connectivity [10];
- *EU financing:* Member States are encouraged to access the funds specifically allocated to biodiversity for 2026 and 2027 to avoid losing them.

Monitoring and events in 2026:

- *Major conferences:* ESP Europe 2026 is scheduled for 2026, bringing together experts to discuss ecosystem services and sustainable management of natural resources in Europe;
- *Reporting:* Member States, including Romania, must report progress in accordance with the new sustainability reporting standards (ESRS), which now include clear indicators for biodiversity.

5. Romania's Biodiversity

Romania's biodiversity is one of the richest in Europe, thanks to its unique geographical position (between five biogeographical regions, with the Danube and the Carpathian Mountains), hosting a wide variety of plant (over 3,700) and animal (over 33,000) species, including key areas

such as the Danube Delta, alpine pastures, and caves, although it faces threats such as habitat loss, pollution, and climate change, requiring conservation efforts to maintain vital ecosystem services.

Romania's territory (especially the Carpathian Mountains area) is very rich in biodiversity. Part of the BioREGIO Carpathians project, a study conducted between 2011 and 2013 (Appleton *et al.* 2014) focused on forest, grassland, and wetland habitats describes nine types of forest habitats, six main ecological groups of high natural value grasslands containing 38 types of vegetation, and seven simplified ecological groups of wetland habitats.

Key characteristics:

- *Biogeographical variety*: 5 of Europe's 11 biogeographical regions are found in Romania, contributing to a wide variety of habitats;
- *Importance of the Danube*: Romania has the largest part of the Danube Delta, a unique wetland area that is crucial for aquatic species and birdlife;
- *The Carpathian Mountains*: A significant part of the Carpathians, home to rich wildlife (bears, wolves, lynxes), is located in the country;
- *Species*: Over 3,700 plant species and 33,000 animal species have been identified.

Protected areas:

- The network of protected areas (Natura 2000 sites) includes national parks (e.g., Retezat, Piatra Craiului) and reserves, protecting diverse habitats, from virgin forests to wetlands.

Amenințări:

- *Loss and fragmentation of habitats*: Due to urbanization, intensive agriculture, and deforestation;
- *Pollution*: Of water and soil, originating from industry and agriculture;
- *Climate change*: Alteration of environmental conditions, impacting species.

Importance:

- *Provides ecosystem services*: Clean air, drinking water, pollination, pest control, food resources;
- *Tourism potential*: Rich nature attracts eco-tourism.

Conservation:

It includes the management of protected areas, ecosystem restoration, and climate change adaptation strategies, with public involvement in protection efforts.

Romania still has relatively significant areas of virgin and quasi-virgin forests. These represent natural capital of inestimable scientific and cultural interest, not only for Romania, but also at European and even global level. Semi-natural secondary grasslands are habitats for the richest communities of plant species, including a large number of endemic species.

In terms of animal species, Romania has a significant population of large carnivores. At the top of the food pyramid, large carnivores are key elements in the ecological relationships that govern Romania's natural environment. They are indicator species for habitat quality, but especially for the functionality of relationships between elements of natural ecosystems.

Other large mammals, especially herbivores, also play an important ecological role and are closely linked to the presence of large carnivores. The most common ungulates in Romania are roe deer, wild boar, and red deer; in the alpine and mountainous areas, the chamois is also found.

The importance of other animal groups in the Carpathians

should not be overlooked: birds, reptiles, amphibians, fish, and invertebrates.

6. The importance of transportation infrastructure

Transport infrastructure is the backbone of European integration in 2026, facilitating economic cohesion and the achievement of climate goals.

Transport infrastructure is crucial for a country because it connects production and consumption, facilitates trade (domestic and international), supports economic development, creates jobs, reduces social inequalities, promotes tourism, improves the safety and efficiency of mobility, ensures access to essential services (work, education), and increases global competitiveness, being practically the backbone of a modern and functional society.

6.1 The European context

European transport infrastructure is crucial for economic and social cohesion, facilitating the free movement of goods, people, and services, stimulating trade and regional development, integrating national markets, and promoting sustainability objectives (transition to sustainable transport, digitization) and combating climate change by creating modern and efficient corridors.

Detailed importance generalized for all EU countries:

- *Economic growth*: Connects production, consumption, and logistics centers, reducing transport costs and increasing the competitiveness of businesses;
- *Regional integration*: Removes physical barriers, creating a functional single market and facilitating the mobility of citizens between Member States;
- *Sustainability and the environment*: Investments in rail, smart road, and other sustainable transport infrastructure are essential to achieving the EU's climate goals;
- *Regional development*: Major infrastructure projects (TEN-T corridors) aim to modernize and develop less connected regions, reducing disparities;
- *Security and accessibility*: Ensures rapid access to services, education, and jobs, improving quality of life and social cohesion;
- *Innovation*: Supports the introduction of new solutions (electric vehicles, intelligent transport systems, digitization) for a more efficient and secure system;

Examples of projects:

- *Trans-European transport networks (TEN-T)* – high-speed rail corridors, highways, waterways, ports, airports;
- *Modernization projects*: EU-funded to transform Europe into a logistics hub.

6.2 The Romanian context

Transport infrastructure in Romania is crucial for economic development, regional connectivity, and European integration, facilitating trade, tourism, citizen mobility, and access to markets by modernizing road, rail, and river networks (Danube, Danube-Black Sea Canal) and ports, although it remains an area with deficits that require major investments in TEN-T networks.

In addition to the detailed importance at European level, which we specified in subchapter 3.1, to which Romania adheres by fully adapting its environmental legislation to European legislation, we mention that there are areas rich in biodiversity and important ecological corridors at the macro-

regional level, as our country is crossed by transport infrastructure corridors that are part of the Trans-European Transport Network (TEN-T). TEN-T plays a crucial role in ensuring the free movement of passengers and goods within the European Union. It includes all modes of transport and carries approximately half of all passenger and freight traffic. One of the important objectives in creating an intermodal network is to ensure the most appropriate mode of transport is chosen for each stage of the journey. The construction of the Trans-European Transport Network is a major factor in stimulating the economic competitiveness and sustainable development of the European Union, contributing to the implementation and development of the Internal Market, as well as to increased economic and social cohesion. The development of TEN-T involves the interconnection and interoperability of national transport networks, as well as access to them.

The two main corridors crossing Romania (Core TEN-T) are the East/Eastern Mediterranean Corridor and the Rhine-Danube Corridor. The East/Eastern Mediterranean Corridor connects the German ports of Bremen, Hamburg, and Rostock through the Czech Republic and Slovakia, with a branch through Austria, further through Hungary, through the Romanian port of Constanța, the Bulgarian port of Burgas, with a connection to Turkey, to the Greek ports of Thessaloniki and Piraeus, with a connection through the "Motorway of the Sea" to Cyprus. It includes railways, roads, airports, ports, rail-road terminals, and the inland waterways of the Elbe River. The main sector with heavy traffic is the Timișoara-Sofia railway line. The Rhine-Danube Corridor connects Strasbourg and Mannheim via two parallel axes in southern Germany, one along the Main and Danube rivers, and the other through Stuttgart and Munich, with a branch to Prague and Zilina, to the Slovak-Ukrainian border, through Austria, Slovakia, and Hungary, to the Romanian ports of Constanța and Galați. It includes railways, roads, airports, ports, rail-road terminals, and the inland waterway system of the Main River, the Main-Danube Canal, the entire course of the Danube downstream from Kelheim, and the Sava River.

Romania is not in a favorable position in terms of transport infrastructure. Compared to European countries such as Hungary or Portugal, the indicator of km of motorway per 1,000,000 inhabitants is 31 in Romania, compared to 137 in Hungary and a significant difference from Portugal, which has an indicator of 249 (World Bank, 2015). On the other hand, it is worth noting the lack of motorways in the areas with the lowest standard of living in Romania, which are also some of the poorest areas in the European Union. The lack of motorways is a major obstacle to job creation and investment in these areas. It is therefore absolutely necessary to step up efforts to ensure the conditions for the optimal implementation of infrastructure projects and to minimize congestion.

With an extensive network of Natura 2000 sites covering approximately a quarter of the country's territory, it is expected that most future infrastructure projects will intersect with Natura 2000 sites, which largely overlap with other types of protected natural areas.

There are already cases where failure to adequately address environmental issues at the design stage has led to delays in the implementation of infrastructure projects. The integration of environmental aspects into sectoral policies has received increasing attention in recent years, but there is

still a need to improve the harmonization of the two sectors by aligning political agendas, objectives, and instruments and through collaboration between specialists.

7. Types of migration (movement) of wild animals

The types of migration (movement) of wild animals can be classified into several categories [11]:

a) *An animals daily movements* within its territory are carried out in search of food, shelter, or mates, but also to defend its territory. Most often, animals travel long distances every day—wolves travel 23 km, lynxes 7 km, and deer 10–12 km.

b) *Seasonal migrations* are movements of a population in response to seasonal variations, including the amount of food available, safety, or reproductive behavior. They are common in birds, but are also reported in other animal groups: insects, crustaceans, fish, amphibians, reptiles, and mammals.

c) *The dispersal of young individuals to new territories*, usually different from those of their parents. There is a difference between the dispersal capacity of the two sexes; for example, in mammals, males have a greater dispersal capacity, while in birds, females are often the ones who set out for new territories.

d) *The dispersal of adult animals* is usually used to search for new food resources or mates for reproduction.

The dispersal capacity and migrations of animals influence their distribution range, the size and genetic structure of populations and, hence, the biodiversity of a region as a whole.

8. Connectivity between different types of habitats

When planning new transport infrastructure, it is necessary to ensure connectivity for populations of all species typical of the given habitat, as well as for species that would use this habitat as a connecting area. This requires answers to three main questions:

- *What kind of wildlife passages (with what parameters) should we build?*

There is already sufficient experience with the use of overpasses and underpasses by different animal species in Europe and other parts of the world;

- *What should be the density and location of such wildlife passages?*

This is reflected in the number of passages in each category and the location where they should be built. Safe animal passages with transport infrastructure are costly constructions, so it is generally necessary to determine the minimum number of passages that can prevent or minimize the negative consequences of population fragmentation. However, this is a very complicated question from a biological point of view (it is difficult to determine the number of individuals that migrate in order to prevent genetic isolation). The effectiveness of the measures implemented in relation to the funds spent is always an important consideration. Although environmental effects are often difficult to calculate in monetary terms, cost-benefit analysis principles (including factors such as the reduction of human accidents in traffic or adaptation to phenomena caused by climate change) can be used for this purpose. It is convenient for practical reasons to establish general recommendations that prevent population fragmentation and, at the same time, are realistic in terms of the amounts invested (these recommendations are listed below together

with individual habitats).

- *How should wildlife passages be integrated into the landscape/terrain to ensure their functionality?*

This question partly overlaps with the two previous questions, but emphasizes local conditions (whether natural or man-made), which must always be taken into account. This means that for each new construction plan, a comprehensive analysis of all potentially impacting factors and their cumulative effects in the given area must be prepared. The most important factors to be assessed are: management of surrounding land (e.g., agriculture, forestry and water management, mineral extraction, industrial or housing development, etc.). It is necessary to mention the essential role of spatial planning and the consideration of reliable information about future development plans in the area, because even a perfectly designed wildlife passage in a well-chosen location would not be effective if the movement corridor is later blocked by unforeseen developments.

In order to achieve sufficient permeability of the animal transport infrastructure, it is recommended, first of all, to check whether the elements initially proposed in the route planning can also be used for other purposes. In particular, canals, bridges over watercourses, and infrastructure planned over forest or field roads offer opportunities to adapt these elements so that they can also serve as wildlife passages. It is often feasible to achieve very good results simply by slightly extending the parameters of the elements. This type of solution is always much cheaper than building special passages.

9. Types of wildlife crossings used in road transport infrastructure

It is very important to note that shared use by wildlife and humans highlights the risk that sensitive species, such as large carnivores, may not accept these wildlife passages. Therefore, at the intersection of infrastructure with the known movement corridor of large mammals, the preferred solution is a special wildlife passage (for wildlife only).

The following structures are considered suitable for multifunctional utility:

A. Overpasses: These are "green" bridges covered with vegetation that recreate the natural habitat of the area.

B. Landscape bridges, (Fig 1): Very wide structures (over 50 m) that allow entire ecosystems to pass through, of which:

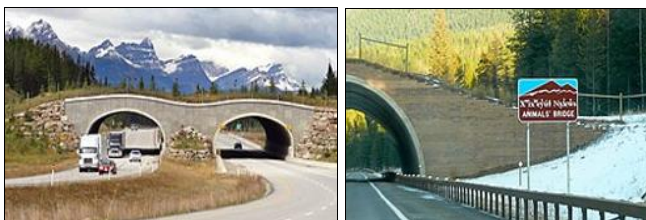


Fig 1: Landscape bridges

- *Ecoducts for large mammals, (Fig 2):* Specially designed for bears, deer, or wolves, offering wide visibility. They are also known as *ecoducts* or *wildlife passages* and are structures, often green viaducts/bridges or tunnels/underpasses, built over or under roads/railways to allow large animals (deer,

bears, wolves) to safely cross habitats fragmented by human infrastructure, thus reducing road accidents and genetic isolation. The largest ones in Romania are currently under construction. Their aims: *road safety* by reducing collisions between vehicles and wild animals; *biodiversity conservation* by maintaining connectivity between habitats, preventing genetic isolation of populations; *facilitating migration* by allowing herds and other large species to move between feeding, breeding, and wintering areas.



Fig 2: Ecoducts for large mammals

- *Bridges or tunnels for small animals.* They are smaller structures adapted for rodents or reptiles. The literature defines small animal ecoducts as specially designed structures, such as tunnels, bridges, underground passages, or even "canopies" under trees, that allow mammals, amphibians, insects, and other creatures to safely cross roads, railways, or other human barriers, connecting fragmented habitats, preventing road accidents, and conserving biodiversity, often being integrated with natural vegetation.

Types of ecoducts for small animals: *tunnels*, (Fig 3): Underground passages adapted for hedgehogs, otters, badgers, rodents, or even amphibians; *bridges* and *footbridges* (underground or above ground): structures that directly cross obstacles, used for various species; *channels/passages* alongside watercourses: for aquatic or semi-aquatic animals (otters, frogs); *cables/suspension bridges*: "canopies" for squirrels and monkeys to cross over roads; *green roofs/ecological corridors*: entire areas of vegetation that form passageways.

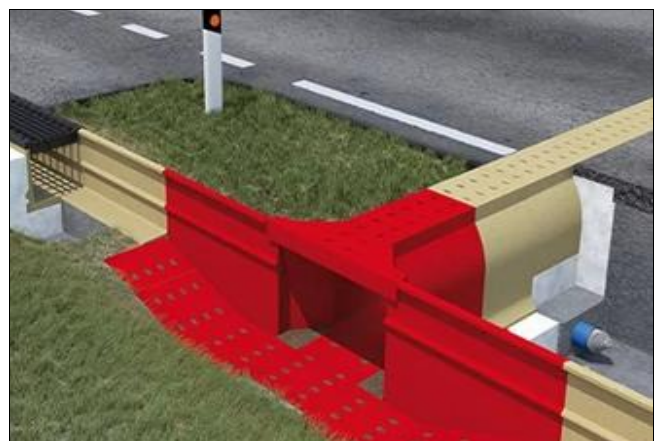


Fig 3: Tunnels for amphibians and other small animals [12]

Their importance: *Combating habitat fragmentation*: they connect habitat areas, allowing migration and genetic flow; *accident prevention*: they reduce collisions between cars and animals, protecting both wildlife and humans; *species conservation*: they ensure access to food, water, and breeding sites.

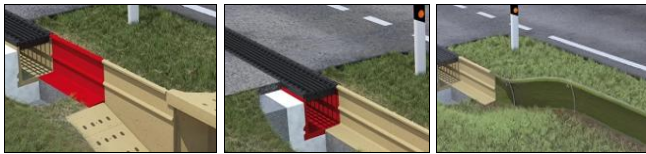


Fig 4: Systems, fixed guide channels, and mobile ACO PRO panels for directing the flow of small animals toward passage tunnels ^[12]

Fig 4 shows the systems, fixed guide channels, and ACO PRO mobile panels for directing the flow of small animals toward the passage tunnels, while Fig 5 shows the ACO PRO climate tunnels designed for the migration of these animals.

ACO PRO climate tunnels, designed for the migration of small animals, have the following characteristics ^[12]:

- Can be installed near or at floor level;
- Highly accepted by amphibians and small animals due to optimal climatic conditions (humidity, temperature, ventilation, smell, light);
- Load class D 400, according to SR EN 1433;
- Ventilation openings: 32 x 58 mm, arranged in pairs, 8 pairs per meter;
- Material: polymer concrete.

C. Underpasses:

- *Amphibian tunnels*, (Fig 5): Small concrete or metal passages located under roads, essential during seasonal migrations to breeding areas;

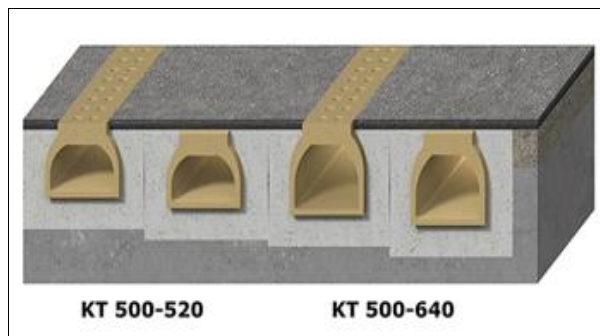


Fig 5: ACO PRO climate tunnels for small animal migration ^[12]

- *Passages that pass under infrastructure*, (Fig 6): Preferred by species seeking shelter or more enclosed environments;



Fig 6: Underground ecoducts

- *Wildlife viaducts*, (Fig 7): Sections of road suspended on high pillars, leaving the natural ground untouched below;



Fig 7: Crab crossing on Christmas Island, Australia ^[20]

- *Water flow ecoducts*: Tunnels that also include a watercourse, facilitating the passage of semi-aquatic mammals such as otters;

D. Specialized structures:

- *Fish passages*: Systems of "stairs" or channels that bypass dams to allow migration along rivers. These are hydraulic structures designed to allow fish to overcome artificial barriers (dams, thresholds, intakes) during their migration along rivers, restoring connectivity between upstream and downstream sectors in order to maintain the health of the aquatic ecosystem. There are various types, ranging from bypass channels to ladders with pools and slots.

How it works: *Restores fish migration*: Allows fish to swim upstream to spawn or downstream, overcoming man-made obstacles.

Types of fish passages: *bypass channels (artificial rivers)*: Bypass the barrier through a new channel with a flow similar to the natural one; *slotted steps (basins)*: a series of small basins, interconnected by slots or openings, which reduce the difference in level between basins, allowing fish to "jump" from one to another; *specialized technical passages*: more complex solutions, adapted to each specific river.

Their importance: *species protection*: they save aquatic species from isolation in river sections, helping them to survive; *ecosystem health*: they maintain the ecological connectivity of the river, which is essential for biodiversity.

- *Suspension bridges (Canopy crossings)*: Ropes or mesh tunnels stretched between trees for arboreal animals such as squirrels (Fig 8);



Fig 8: Squirrel bridge in Nutty Narrows, Washington, USA and in The Hague, Netherlands ^[20]

- *Bat bridges*, (Fig 9). They are tall structures that serve as landmarks for echolocation, helping bats cross roads without descending into the flow of road traffic;



Fig 9: Green passages for bats and butterflies

- *Tunnels for small mammals* (otters, hedgehogs, badgers): Designed for small terrestrial species;
- *Green Structures* (Green Roofs/Grassland Ecoducts), (Fig 9): Vegetation-covered areas integrated into infrastructure for butterflies, insects, and birds. Bat passages (or walkways for bats or other birds) are ecological structures created to facilitate their safe passage over major obstacles, such as highways, to reduce traffic-related mortality, being open to the sky (uncovered, unlike passages for terrestrial mammals), allowing free flight and maintaining habitat connectivity. These are essential for protecting bat populations, which are vulnerable to physical barriers and human impact.

Main purpose: *Ecological connectivity*: They allow bats to move between feeding grounds and shelters without having to cross dangerous roads; *reduction of mortality*: they reduce the number of bats hit by cars.

How they look and work: *overhead structures*: these are often extensions or adaptations of existing wildlife passages, but they can also be specific, taller structures, partially covered with vegetation to provide camouflage and facilitate flight; *strategic positioning*: they are located in areas where bats are frequently observed flying (flight corridors), for example, above highways, in areas with insect-rich habitats (forests, wetlands).

10. The state of adaptation of Romania's transportation infrastructure to environmental requirements regarding wildlife crossings

Romania's road infrastructure has adapted to environmental requirements regarding wildlife crossings (green corridors/animal bridges), shifting from ignoring them to the mandatory inclusion of wildlife crossings in feasibility studies and technical designs, particularly for highways built with European funds. This change was driven by the need to protect habitat connectivity in the Carpathians and reduce traffic accidents. Adaptările principale și exemple concrete:

- A1 Sibiu–Pitești Highway (Section 3): One of the most spectacular wildlife crossings, over 300 meters long and approximately 100 meters wide, is being built here in the Căineni–Racovița area (Olt Valley). It will cross over National Road 7, the railroad tracks, and the Olt River, restoring the ecological corridor between the Făgăraș, Cozia, and Căpățâni Mountains;
- Lugoj–Deva Highway (A1): The first "dedicated" above-ground wildlife crossings were installed on this section, including guide fences to direct animals toward the crossings;
- A8 Highway Târgu Mureș–Târgu Neamț (Unifications

Highway): Environmental NGOs have called for eight dedicated wildlife crossings to ensure passage for large mammals (bears, wolves, lynx), based on transnational connectivity studies;

Construction technologies:

Ecoducts are designed as composite structures (metal and concrete), covered with vegetation native to the area to mimic the natural habitat and reduce stress on animals as they cross.

Integrated environmental measures:

1. **Best practice guidelines:** Specific guidelines for road infrastructure have been developed in collaboration with ANANP (the National Agency for Protected Natural Areas) and NGOs to prevent habitat fragmentation;
2. **Environmental studies (DNSH):** Projects under the PNRR (National Recovery and Resilience Plan) must comply with the "Do No Significant Harm" (DNSH) principle, which requires the inclusion of wildlife crossings;
3. **Ecological design:** Identifying critical animal crossing points using GPS and surveillance cameras prior to design, in order to locate crossings in areas of highest usage.

11. Motor vehicle accidents involving wild animals. Methods, techniques, and installations for protecting wild animals in road traffic: Case study

We searched the literature and specialized websites for statistics on road accidents involving motor vehicles and wild animals over the last 10-20 years and found that there are no comprehensive statistics, but the data indicate a significant increase in road accidents involving wild animals in Romania, with over 600 incidents reported in a year and a half (in 2021), and at the European level, the phenomenon has increased by 20-25% in the last 5 years, reaching about 250 million large animals involved annually, although the figures are based on extrapolations.

Here is what some electronic sources found on the website present to us in the absence of centralization:

- *Constant increases:* The number of incidents in Romania is increasing, showing that wild animals are increasingly ending up on the roads;
- *European phenomena:* At European level, it is estimated that 250 million large animals are involved in accidents each year, a third of which are wild, and the phenomenon has increased by 20-25% recently;
- *Local reports:* In 2021, drivers reported over 600 incidents in a year and a half, but official figures are difficult to obtain.

We note that the difficulties in centralizing this data were caused by the lack of a robust national data collection system, and the figures are extrapolated from local/regional studies, as the authorities do not have complete data.

Of all animals involved in road accidents, approximately one third are wild animals that end up on roads during their normal movements in search of food, water, shelter, or breeding grounds. Studies conducted in this regard at European level show that accidents involving wild animals have increased by 20-25% in the last 5 years. But what are the reasons for the increase in the number of accidents/incidents involving wild animals, given that populations are still declining? The truth is still unknown. It is not yet known whether the data I have given you is

correct. These are, in fact, only extrapolations from local and specific research, reported for the whole of Europe. In reality, the figures may be slightly different ^[13].

In 2026, accidents involving animals remain a major challenge for road safety in Romania, against the backdrop of an increase in the number of incidents reported in recent years.

Applicable legal framework in Romania: *Hunting Law no. 407/2006* and *Government Decision no. 3/2023* establish the conditions under which compensation may be granted for damage caused by hunting fauna. Art. 13 para. (1) of the law provides for compensation for damage caused by species in Annexes 1 and 2, but the actual liability is regulated by art. 13 para. (7) and detailed in *Government Decision no. 3/2023*.

According to these provisions, liability for car accidents involving wild animals is distributed as follows:

- The road administrator is responsible if there are no "Beware of Animals" signs on the road section.
- The driver is responsible if such signs are present.

Road ecology is already a well-represented discipline of ecology in scientific journals, books, and conferences. Research in the field of road ecology began in 1925, when Dayton Stonner (1883-1944), an American zoologist, documented 225 cases of vertebrates from 29 species killed by collisions with motor vehicles during a 1,000 km trip in Iowa, USA. Roads and other linear transport infrastructure are a major cause of habitat loss, degradation, and fragmentation. Globally, in 2011, Rodney van der Ree and colleagues reported 750 million cars traveling on 50 million kilometers of public roads, and the road network appears to be expanding in China, India, Eastern European countries, and Latin America ^[11].

The particularities of Romania: Romania has very large wild animal populations compared to other European countries and, as such, incidents and road accidents involving them should probably be more numerous. These populations and the areas they occupy, in km², are shown in Fig 10. However, no one really knows how serious the situation is, but we can all certainly observe when traveling many kilometers by car that the number of wild animal carcasses we see on the side of the road is very high: foxes, rabbits, and ferrets are often scattered, in a sinister manner, on the sides of the roads. In addition to the fact that these creatures suffer or are killed as a result of being hit by a car, there is also the other side of the problem, namely that these accidents can also cause us material or personal damage. Accidents involving bears, deer, roe deers, wild boars, badgers, etc. can cause significant damage to vehicles and/or even people, and in some cases these accidents can even be fatal. Other times, incidents do not involve large animals destroying cars, but small creatures that are barely noticed by drivers, such as frogs, lizards, snakes, and other small vertebrates that are systematically run over as they move to feeding or breeding areas ^[13].

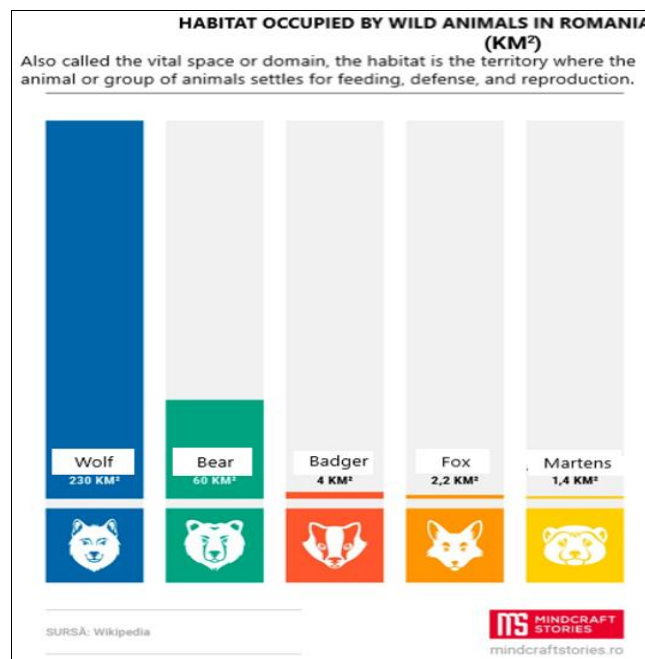


Fig 10: Habitats occupied by wild animals in Romania (km²) in 2022 ^[11]

The number of car accidents involving animals in Romania is on the rise, with drivers able to obtain compensation if they can prove that the road did not have warning signs. The procedure involves alerting the authorities (112), documenting the accident (photographs, witnesses), and submitting a claim to the local council within 48 hours, followed by an assessment of the damage by a commission, in accordance with *Government Decision 3/2023*.

Data and trends (2025-2026):

- **Frequency:** At European level, approximately 250 million large animals are involved in road accidents every year, with the phenomenon increasing by around 25% in recent years;
- **Species involved:** The most common wild animals involved in collisions on national roads and motorways are bears, deer, wild boars, and foxes;
- **Risk areas:** The incidence is highest in rural areas and near natural habitats, especially after the time change or during the winter holidays, when wildlife activity increases.

Legal aspects and compensation:

- **Liability:** Drivers can claim compensation from CNAIR or road administrators if the accident occurred on a section of road that was not properly marked with warning signs ("Beware of animals");
- **Insurance:** Damage caused by wild animals is covered by CASCO insurance. RCA insurance does not provide compensation to the vehicle owner in these cases, unless there is a legally identified party at fault (e.g., the owner of a domestic animal);

- **Legislation 2026:** New state protocols for managing domestic animals involved in accidents are under discussion, aiming to eliminate current legislative gaps.

Procedure in case of an accident according to Romanian police recommendations:

- **Frequency:** at European level, approximately 250;
- **Safety:** stop immediately, turn on your hazard lights, and secure the area;
- **Reporting:** call 112 to report the incident, even if there are no human casualties;
- **Monitoring:** you can use platforms such as Ro-Wildlife (Zăgan) ^[13], to report the location of the incident, thus helping to map dangerous areas.

What to do immediately after an accident in Romania according to the law:

1. **Secure the accident site:** Pull over to the right, turn on your hazard lights, stay in the car (the animal may be frightened/aggressive);
2. **Call the single emergency number in Romania, 112:** Notify the Traffic Police. They will take charge of the situation and may also alert Animal Protection, depending on the animal;
3. **Documentation:** Take photos (road, signs, damage, our injuries/those of our passengers);
4. **Request for information:** If someone stops, ask for their contact details;
5. **Contact your insurer:** File a claim for damages (if you have comprehensive insurance or if compensation is available from the authorities).

Compensation from Romanian authorities (for wild animals):

- a) **Obligation:** Drivers of damaged vehicles may be compensated by the Romanian state (CNADNR/CNAIR) if there were no warning signs for wild animals in the area of the accident;
- b) **Request:** We submit a written request to the mayor's office/administrative-territorial unit within 48 hours;
- c) **Findings:** A commission appointed by the insurer will investigate the situation and determine liability, issuing a decision within 10 days.

The latest and most current data on accidents involving animals are presented in the Road Safety Bulletin issued in 2025 for the year 2024 by the Ministry of Internal Affairs, the General Inspectorate of the Romanian Police, the Road Directorate, and the Institute for Research and Prevention of Crime ^[14]. Page 45 of the document lists 12 accidents ^[14, p. 45] vehicle with animal accidents throughout 2024 (no data is provided on the category of animal, but it is impossible for wild animals to be involved in the vast majority of these accidents). Of these, page 47 of the same document provides data on the type of road surface and weather conditions in which accidents involving animals occurred, as follows: 9 road accidents occurred on dry road surfaces, 2 road accidents occurred on wet road surfaces, and one accident occurred on a road surface covered with snow, sleet, ice, and mud ^[14, p. 47].

The mortality index in 2024 according to the type of motor vehicle with animal impact is presented in Table 1.

Table 1: Mortality index in 2024 according to the type of vehicle with animal impact ^[14, p. 50]

Impact type	Number of deaths	Number of serious accidents	Mortality index (number of deaths x 100 / number of serious accidents)
Vehicle-animal collision	0	5	0.0

Analyzing the data in Table 1, we find that out of five serious accidents caused by collisions between motor vehicles and animals that entered the roadway, there were no human fatalities, but there were human injuries and/or injuries to animals involved in the accident, animal deaths, and material damage (damage to motor vehicles). These were insignificant, but they did happen.

Regarding the number of road accidents involving animals and vulnerable people (motorcyclists, moped riders, cyclists, scooter riders), the data is as follows:

Table 2: Impact with animals on the road in 2024 involving vulnerable road users, resulting in serious injury or death ^[14, p. 80]

Type of impact	Cyclists	Moped driver	Electric scooter drivers
Vehicle-animal collision	1	0	0

The data researched and found in the specialized literature and online were insignificant, but these traffic incidents did occur. Aspects confirming the incidents were reported in the media at the time.

An article published by news of PRO-TV, part of the television trust of the same name, states that over the last five years, the National Road Infrastructure Administration Company has paid out over 4 million lei after it was found that there were no signs on the road warning of the presence of wildlife. Transport officials say they can only put up markings and ask drivers to take them seriously. Drivers only receive money if the court proves that there were no road signs warning of the danger on the road where the accident took place. These incidents occur mainly on national roads, where regulations do not require the installation of fences, according to CNAIR representatives. However, these are mandatory on motorways. Such a fence should protect drivers from animals that may cross their path. But in some areas, such as here, the fence is broken and animals can easily reach the highway ^[15].

A Romanian publication presents the following data: over 150 road accidents caused by collisions with wild animals, especially bears and deer, were recorded in 2024 by the Harghita County Police Inspectorate (IPJ). These accidents resulted in damage to the vehicles involved, causing significant losses. In this context, it is essential that drivers take preventive measures to reduce the risk of such events ^[16].

On July 17, 2021, on DN2 (National Road 2), between Bălcăuți and Siret, a driver behind the wheel of a Skoda Kodiaq SUV hit a deer. Although the car was repaired through CASCO, the insurer subsequently took legal action against the Regional Directorate of Roads and Bridges

(DRDP) in Iași. The court ruled that the DRDP was responsible for the accident due to the lack of warning signs installed at the legal distance. After four years, in 2025, the judges ruled that although there was a "Beware of wild animals" road sign in the area, it was located 3.2 km from the accident site, violating the provisions of the traffic regulations, which require a maximum distance of 250 meters from the risk area. The hunting law and traffic regulations were the legal basis for the final decision. Thus, responsibility lies with the road administrator when clear and correctly placed warnings are missing ^[17].

Another Romanian publication states that, starting in 1990, the Road Vertebrate Mortality Monitoring Project (PMMV) was launched in Romania.

Field data were collected between 1990 and 1992, and the results and conclusions were published in various forms, including in journals and in a final report. During the study, the PMMV team identified 43,505 vertebrates killed on Romanian roads as a result of traffic accidents. Of these, 4.9% were birds of prey, 90.9% of which were nocturnal birds of prey and 9.1% diurnal birds of prey. According to the results obtained, road accidents affected 54.5% of common species, 46.4% of Accipitriformes species, 87.5% of Strigiformes species, and 50.0% of Falconidae species. Most victims were recorded in the case of 8 species, 5 of which were nocturnal birds of prey and 3 diurnal birds of prey. Nocturnal birds of prey were the most affected by road accidents. The little owl (*Athene noctua*) and the barn owl (*Tyto alba*) accounted for 43.3% and 34.5% of the total number of birds of prey involved in accidents, respectively. As for diurnal birds of prey, the common buzzard (*Buteo buteo*) and the kestrel (*Falco tinnunculus*) were the most affected species, accounting for 2.8% and 2.6% of the total number of accidents recorded, respectively. Road accidents involving certain species were not relevant (*Pernis apivorus*, *Aegypius monachus*, *Circus aeruginosus*, or *Falco peregrinus*) ^[18].

According to the PMMV study, road accidents pose a threat to the conservation of 39.1% of the affected species. In the case of the seven species of Strigiformes, with the exception of the little owl (*Athene noctua*), mortality due to road accidents is considered a global threat. As for Accipitriformes, road accidents are considered a global threat to three species: the Egyptian vulture (*Neophron percnopterus*), the short-toed snake eagle (*Circaetus gallicus*), and the red kite (*Milvus milvus*). As for species in the Falconidae family, road accidents are not considered a threat to conservation. In addition to identifying a large number of injured birds of prey, the PMMV team also identified "black spots" on the Romanian road network. Only four such black spots were identified for birds of prey, and the species most frequently affected was the kestrel. These data are probably different now, and these spots may have changed to others. Serious monitoring of roads would allow us to obtain conclusive data to help us take clear measures to avoid accidents ^[18].

Reducing the effects of collisions between wild animals and motor vehicles is a key concern for all responsible authorities in European countries, as well as for environmental specialists.

As biodiversity increasingly suffers from the global road network and given the high risk of accidents affecting both wildlife and humans, there is a constant effort to mitigate the effects. The most common technical methods aim to keep

animals off the roads and restore connectivity between different populations fragmented by the existence of roads, but also impose obligations on drivers in areas with a high risk of vehicle-wildlife accidents ^[11].

A particular challenge for vehicle traffic on public roads is collisions between vehicles and animals at night. It is very important for drivers to watch for the reflections in animals eyes when driving at night. It is one of the simplest tricks they can use. When it's dark, dangers don't just come from the road, they can also come from the roadside. Often, these dangers go unnoticed if we don't know what to look for while driving. Most animals have a layer behind the retina of their eyes called the *tapetum lucidum*, a Latin term used in biology to describe a reflective layer located behind the retina of many vertebrates, which enhances their night vision. The word comes from Latin and can be interpreted as follows: *tapetum* (layer) + *lucidum* (shiny/bright). In other words, this layer acts like a microscopic mirror that reflects light back. For this reason, when the light from headlights hits the retinas of animals' eyes, their eyes glow. The good news is that the reflection can be seen by drivers from a distance, sometimes even before they spot the animal itself. Essentially, two small points of light are visible at the side of the road. This can give us a few extra seconds before impact with an animal. At night, a few seconds can make a huge difference when driving. It's important to focus on the following key point: if you see reflections on the roadside or on the road (on the pavement), don't look directly at them and don't panic. You should gently lift your foot off the accelerator, quickly press the brake pedal, and carefully scan the area, because often it's not just one animal, but a herd of animals. You can never tell what kind of animals they might be until they're already very close. It could be a small animal (e.g., sheep, goats, rabbits, hares, dogs, wolves, or foxes), or it could be a large animal (e.g., deer, horses, cows, buffalo, or bears). There is a huge difference between the two. It is one thing to hit a small animal, which may cause minor damage to the vehicle, and another to hit a large animal, where the impact becomes extremely dangerous and can cause significant damage to the vehicle, while also endangering the lives of the driver, passengers, or other road users. Animals do not react like humans. They may stay put, jump in front of the vehicle, and simply freeze in the headlights, remaining immobile on the road, or they may change direction quickly. We shouldn't assume that they will run out of the way of a vehicle at night. Animals' eyes reflect light differently: sometimes white, sometimes yellow, or perhaps even green, depending on the species and the angle at which the headlights' rays reflect off them. The basic idea remains the same: if we see bright spots on the side of the road, we must slow down to a speed that allows us to avoid any danger. What does it mean to slow down to a speed that allows us to avoid any danger? This means slowing down so that if an animal appears on the road, you can stop safely without running over or injuring it. You can't see everything at night, but if you know where to look, you'll spot it more quickly.

The most effective methods, techniques, and protective installations that ensure the reduction or even prevention of unwanted incidents between motor vehicles and wild animals are:

A) Road signs warning of animals, (Fig 11). It is placed 100-200 m from the dangerous road section, where there is a risk of animals crossing or walking on the public road.

When encountering this sign, drivers are required to reduce their speed and drive with increased caution. When passing animals that are being led on the roadway or shoulder, drivers are required to reduce their speed to a maximum of 30 km/h in built-up areas and a maximum of 50 km/h outside built-up areas.



Fig 11: Road signs warning of animals

B) Speed limit road signs, (Fig 12). They are located in areas where there is a risk of collision between motor vehicles and wild animals (Fig 12). They are installed in areas with a high risk of collision with wild animals. Thus, in forest areas with high biodiversity, the maximum speed limit is 70 km/h, and in critical areas, the speed must be reduced to 50 km/h. There are also places where physical speed limiters can be installed on the road. They signal to drivers that the maximum speed allowed on that section of road is 50 km/h.



Fig 12: Traffic sign, speed limit 50 and 70 km/h

C) Sensors for detecting animals approaching the edges of roads, (Fig 13). These are advanced systems, often based on PIR (Passive Infrared) or radar/laser technologies, which identify the presence of wildlife through body heat or movement, triggering visual/audible warnings for drivers (dynamic traffic lights, lights) or even mobile barriers to prevent collisions, thus protecting both animals and humans and maintaining habitat connectivity.

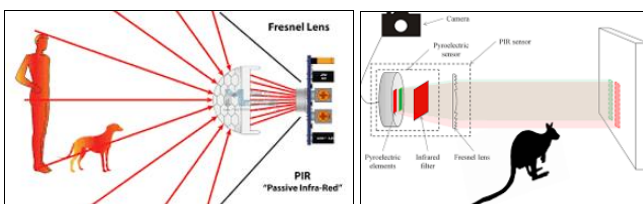


Fig 13: PIR (Passive Infrared) sensors

Types and technologies:

- **PIR (Passive Infrared) sensors:** Detects heat emitted by

bodies, often with filters to ignore small animals (pet immunity);

- **Radar/laser sensors:** Measure distance and speed, being very accurate in various weather conditions;
- **Camera with artificial intelligence (AI):** Analyzes video footage to identify species and distinguish animals from other objects, generating personalized alerts.

How it works:

- **Detection:** sensors (PIR, radar, video) detect movement or the presence of an animal near the road;
- **Processing:** A small computer (processing unit) analyzes the data, confirms that it is an animal (not a car or a shadow);
- **Alerting:** The system activates one of the following:
 - **Warning drivers:** Illuminated road signs, acoustic signals, or flashes;
 - **Physical barriers:** Automatic retractable barriers or closing gates;
 - **Data transmission:** Information sent to monitoring centers.

Benefits:

- **Safety:** Drastically reduces the number of human-animal accidents, protecting lives;
- **Conservation:** Helps maintain habitat integrity, allowing animals to migrate safely;
- **Economy:** Prevents vehicle damage and associated costs.

Examples of solutions:

- Warning systems with LEDs built into panels;
- Motion detectors integrated with smart lighting systems;
- Dynamic barriers at wildlife crossings.

D) Audible and visual warning systems for wild animals (virtual systems), (Fig 14), installed along the road, systems that emit sounds and flashing lights on the side of roads or highways are also ways to keep animals away from roadways.

These systems are based on technologies that disrupt animals' vision while also emitting loud sounds or sounds of a certain frequency that are perceived by certain categories of animals. They use specific colored LED lights (yellow/orange or blue) with a concentrated angle and automatic activation (twilight sensors) to reduce light pollution and the impact on biodiversity. They prevent animals from crossing the road, protecting both wildlife and road users without the use of chemicals, making them an environmentally friendly solution for reducing collisions. However, research has shown that animals can get used to the reflected light and become accustomed to the sounds emitted by these systems, reducing their effectiveness over time.



Fig 14: Light and sound reflection systems for repelling and directing wild animals (virtual systems)

How it works and what technologies it involves:

- **Specific light:** Use yellow-orange or blue LED lamps, colors that are foreign to the night vision of many mammals, creating a visual "scarecrow" effect;

- *Shrill sounds or sounds below a certain frequency:* The sound can be loud, driving animals away from the area where they are located, or it can be emitted at frequency thresholds perceived by different categories of animals;
- *Sensors:* Integrated with twilight sensors (crepuscular), the devices activate automatically at dusk, when animals are most active, saving energy;
- *Concentration and direction:* Light and sound are concentrated in a narrow angle (e.g., 151°), avoiding excessive "spill" into the sky or onto sensitive water surfaces, to minimize the impact on other nocturnal species;
- *Intermittent flashes:* Produce rapid flashes that discourage animals (deer, wild boar, foxes, rabbits) from approaching the road.

Benefits:

- *Road safety:* Significantly reduces accidents caused by collisions with wild animals;
- *Environmental protection:* Environmentally friendly, non-chemical solution, safe for humans, pets, and the environment;
- *Respect for biodiversity:* Does not drastically interfere with wildlife migration or habitat, unlike traditional street lighting.

Examples of applications:

- *Land protection:* Communication routes (roads, highways), gardens, orchards, sports fields, cemeteries, to repel wild boars, deer, martens;
- *Transport corridors:* Solutions for removing wildlife from roads and intelligently directing it underground or discouraging it from dangerous crossings.

Such devices are installed in a dangerous area on National Road 1 (DN1), between Perşani commune and Braşov city. The devices are installed over a distance of 2 km, as this area has seen the most road accidents involving wild animals, with over 30 bears killed in 6 years. However, these systems have failed because, during this period, there was still an accident involving a bear cub, which was attracted by the smell of food scraps left by tourists in a parking lot.

E) Animal warning sound systems, (Fig 15). Audible warning systems for animals on roads/railways are used to keep them away from vehicles/trains, being particularly suitable for areas with low traffic, and their long-term effects are more about the impact of habitat fragmentation by infrastructure, not just the sound, requiring integrated solutions for biodiversity. As with headlight reflection systems (sometimes installed together with these systems), they are less effective over time, as animals can become accustomed to the sounds they produce.

How it works:

- *Sound emission:* These systems produce specific sounds or vibrations when a train/vehicle approaches, scaring animals away.

Limitations and effectiveness:

- *Habituation:* The biggest problem is that animals can become accustomed to the sounds, becoming insensitive to the warnings;
- *Low traffic:* These systems are more effective in areas with low traffic, where trains/vehicles do not appear constantly.

Overall impact on wildlife:

- *Habitat fragmentation:* A bigger problem is that railways themselves become barriers, isolating animal populations and affecting migration, reproduction, and genetic diversity;
- *Complex solutions:* In addition to sound, solutions such as wildlife crossings (underground or above ground) and guide fences are being sought.

F) Protective fences for animals, They are usually used in areas with heavy traffic or where the risk of collision is very high. To be effective for large mammals such as deer, fences should be over two meters high. The bottom of the fence should also have small holes to prevent small animals from passing through. In protected biodiversity areas, they constitute physical or virtual barriers, made of wire, tape, or using technologies such as pheromones, to prevent wild animals (wild boars, deer, wolves, bears) from entering protected areas (roads, highways, farms, agricultural crops, gardens, etc.) or to keep domestic animals within the perimeter, thus protecting property and investments from damage. These fences can be electric (generating non-lethal but discouraging shocks), made of solid mesh, or even olfactory (based on smells to repel them).

Types of protective fences for wild animals:

F1) Electric fences, (Fig 16). It relies on high-voltage but low-amperage electrical pulses to deter animals without seriously injuring them, creating an effective barrier. The role of electric fences is to effectively delimit spaces, keeping wild animals within the desired perimeter and deterring the intrusion of wild animals or thieves, providing a secure, controlled, and cost-effective solution by applying non-lethal electrical impulses that create a lasting impression and protect communication routes (roads and highways), crops and people's property.



Fig 16: Electric fences

Operation:

- A generator converts electrical energy (from the grid, battery, solar panel) into short high-voltage pulses (5000-15000 volts);
- These pulses are sent through insulated conductors (wires) mounted on poles;
- When an animal touches the wire, the circuit closes through the animal's body and the ground, generating an unpleasant but safe shock that discourages it from approaching again;

Main roles:

- *Security and deterrence:* Keeps wild animals in their habitat, preventing them from entering the roadway;
- *Efficiency and low costs:* An economical and flexible alternative to physical fences, easy to install on various types of terrain.

Key benefits:

- *Safety:* Electric shock deters without causing serious injury, and systems can include alarms;

- *Flexibility:* Can be portable (for mobile pastures) or permanent;
- *Protection:* A modern solution for animal control and the safety of animals and road users.

F2) Steel mesh fences for protecting roads or highways against wild animals, (Fig 17). They are made of robust wire and form a solid physical barrier, ideal for keeping larger animals at bay.



Fig 17: Steel mesh fences for protecting roads or highways against wild animal intrusion

Wire mesh fences for wild animals play a crucial role in road safety by preventing animals from entering the roadway, thereby reducing the risk of serious accidents (collisions), protecting both drivers and animals, guiding wildlife to specially designed passages (wildlife crossings) and contributing to habitat conservation by clearly delimiting transit areas and limiting land fragmentation.

Key roles in road traffic:

- *Collision prevention:* The main role is to prevent animals from entering the road, eliminating one of the major causes of accidents (human-animal collisions), which can be fatal;
- *Guiding wildlife:* Directs animals to specially constructed underpasses and overpasses (tunnels, green bridges), allowing them to cross roads safely;
- *Animal protection:* Provides a safe environment for animals, reducing stress and the risk of injury or death;
- *Driver safety:* Increases road safety by eliminating unpleasant surprises on the road and helping to maintain traffic flow;
- *Area demarcation:* Clearly marks the boundary between road infrastructure and natural areas, protecting the habitat.

Types and considerations:

- Welded wire mesh is used, adapted to the size and behavior of the species (deer, wild boar, wolves);
- Can be integrated into electric fence systems, harmless but effective, for better deterrence.

F3) Virtual fences based on pheromone emissions: They use chemical substances (pheromones) to manipulate the behavior of wildlife, creating olfactory barriers or guiding them along other routes, without imposing a physical barrier. Pheromones are natural chemicals secreted by organisms, acting as messengers to influence the behavior of other individuals of the same species, from territorial marking and warning to sexual attraction, functioning as "external hormones" through olfactory communication. Although they are well known in animals (ants, insects, mammals), their role in humans is still being studied, although there are perfumes with synthetic pheromones that mimic their effects, aiming to increase attractiveness, social confidence, or emotional connection, although the exact mechanism in humans remains debated.

How it works:

- *Communication through smell:* Pheromones are volatile compounds that evaporate, sending signals detectable by the olfactory system of other individuals;
- *Subconscious reception:* In animals, they can trigger involuntary physiological and behavioral responses through the vomeronasal organ (Jacobson's organ), which in humans is vestigial, but the signals can reach the brain;
- *Various signals:* They can signal danger (ants), readiness to reproduce (mammals), or increase affection (oxytocin-inspired pheromones).

Pheromones are emitted by devices that use pheromones—natural chemicals emitted by animals to communicate with each other—to control the behavior of wildlife (the aerosol tubes shown in Fig 18). The aerosol pheromone tubes are placed in electronic devices such as those in Fig 14, and when wild animals enter the area, the device activates the tube from which the pheromones are released into the atmosphere in aerosol form, attracting the animals. For this reason, the devices will not be installed on the side of the road, but will be installed in areas close to them in order to attract the animals. Pheromones released into the atmosphere drive animals away from the road or highway.



Fig 18: Types of pheromones tubes for pheromone-based virtual fences

These "virtual fences" (virtual systems) work by: *attracting or repelling animals:* pheromones are used to create an invisible barrier that influences animal behavior (if repellent pheromones are used, the devices will be installed on the side of roads); *directing wild animals:* instead of crossing the protected area, they are guided to other routes (areas).

This innovative system is non-invasive, does not harm animals, and does not affect the environment, making it an attractive option for farmers and landowners.

They have a major advantage: *they complement electric fences.*

Pheromone devices can be strategically placed in critical areas; *low cost:* compared to installing an electric fence, the pheromone solution is considerably more affordable; *flexibility:* these barriers can be used in hard-to-reach areas or in spaces where a physical fence would be impossible to install; *increased safety:* there are no risks to humans, children, or other domestic animals, as it does not involve electricity.

Practical applications and effectiveness of pheromone fences are:

- *Protecting crops:* Wild boars can destroy an entire harvest in a matter of hours. The pheromone barrier keeps them away without harming them;
- *Protecting household spaces:* Martens and otters are notorious for the damage they can cause in attics, where

they gnaw on cables and insulation. Virtual fences can be discreetly placed to prevent their access;

- *Wildlife management in areas with road traffic:* Deer and other wild animals can unintentionally enter the roadway, but pheromones can be used to redirect them to their natural habitats;
- *Sustainability and environmental impact of pheromone fences:* Another important benefit of this technology is its low environmental impact. Unlike chemical or mechanical methods, virtual fences leave no toxic residues, do not endanger biodiversity, and do not affect the natural food chain.

The role of protective fences for animals:

- *Protection of cultures:* Prevents the destruction of crops (corn, potatoes, vines) and the intrusion of wild animals onto the roadway;
- *Animal safety:* Keeps wild animals safe within their habitat, protecting them from the dangers of collisions with motor vehicles;
- *Conflict prevention:* Reduces confrontations between humans and wildlife, protecting vehicles, drivers, passengers, transported goods, and wild animals.

Main advantages:

- *Efficiency:* Discourages animals from crossing or escaping into the road perimeter;
- *Environmentally friendly:* the electrical method does not kill animals, but forces them to stay away from the road area;
- *Cost-effective:* Reduces the need for constant human surveillance, providing permanent protection;
- *Versatile:* can be installed on any type of property (farms, orchards, gardens, roadsides, etc).

For species that tend to dig, it is necessary for the bottom of the fence to be fitted with a plastic mesh buried at a depth of 40-50 cm. Fences should be placed on both sides of the road so that they do not become a trap for animals. If they are only placed in certain sections of the road, for example along forest areas, areas in the immediate vicinity of the fenced section will become areas of increased attention and high risk of collision with wild animals that tend to form certain passageways over the barrier in their path. For this reason, protective fences should be continued with passages that allow the interconnection of animal populations living in the vicinity of the road ^[11].

The devices for emitting pheromones are shown in Fig 19.

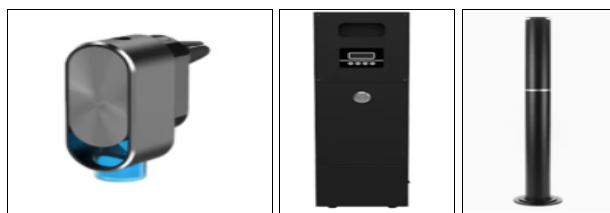


Fig 19: Pheromone diffuser device

G) Construction of ecoducts (natural passages for wild animals), (Fig 20), in order to reunite biodiversity areas separated by road networks, highways, railways, waterways, etc., represents the main method of restoring connectivity between neighbouring habitats separated by the road network. These passages are built with two main purposes: *to restore lost connectivity* between different animal populations living near the road and to provide passageways for animals that migrate or travel long distances.



Fig 20: Ecoducts (natural passages) for wild animals

For these passages to be effective and reduce the negative impact caused by roads and railways, they must be accessible to species with different ecological requirements. Another requirement would be to ensure a sufficient number of passages, which can be determined following wildlife impact studies carried out by specialists ^[11].

Data on these natural passages were presented in the context of this scientific paper.

12. Conclusions

Transport infrastructure is the spine of the European economy and an essential pillar for achieving the European Union's political agenda, from cohesion to sustainability.

In Romania, major projects such as the Cornet ecoduct on the Sibiu-Pitești Highway are planned for completion in 2025-2026 to ensure connectivity in the Carpathian Mountains.

Passages for big animals are essential for them to continue their migrations and lives, while humans continue to use road infrastructure, providing a modern solution for human coexistence with nature.

Romania is building the largest "animal passages" in the country, integrated into road infrastructure projects, such as those on highways, to connect forested areas.

Ecoducts for big animals, also known as green bridges or ecological viaducts, are specially designed structures (often bridges covered with vegetation) that allow large animals (deer, wild boars, wolves, bears) to safely cross roads and highways, connecting fragmented habitats, preventing collisions with vehicles, and protecting wildlife and road safety. These vital passages are essential for biodiversity conservation, allowing migration and genetic flow, and are increasingly being implemented in areas with heavy traffic and rich fauna, such as in Romania, with major projects on the A1 Sibiu-Pitești. Major ecoducts are under construction or planning in Romania, such as the one on the A1, which will cross National Road 7 (DN7), the railway, and the Olt River (Cornet area), being one of the largest in the country. They represent a modern and effective solution for habitat conservation, aligned with the objectives of sustainable development and environmental protection.

Animal ecoducts should be at least 100 m wide (an appropriate size, identified by a series of studies carried out, for example, in Canada and Croatia), should have sound-absorbing panels at the edges, vegetation planted above and around them, allowing animals to access and use them in complete safety. The areas immediately adjacent to the structures will be kept free of any construction (permanent or even temporary) that could threaten the functionality of the ecoducts. Due to their technical characteristics, the ecoducts will also be suitable for other species (smaller animals). In addition, this section will be fenced along its entire length with a reinforced fence, resistant to large and powerful animals (e.g., bears, mouflons, or bison), (3 m high, with the lower part buried in the ground and the upper part sloping outwards) to prevent animals from attempting to cross at locations other than the ecoducts. At the same time, the fencing will also guide animals towards the

dedicated crossing structures. Beyond the obvious benefits for wildlife species, these measures will also increase the safety of road users by preventing collisions with wildlife.

In Romania, large eco-bridges are being built for large animals (wolves, bears), but similar principles, on a smaller scale, are being used globally. Vegetation is integrated into these structures to create a familiar environment, discouraging animals from venturing onto the road. For the safety of road traffic and animals in the biodiversity area, directional fences are installed to guide animals to these safe passages.

It is very important that animals passing through climate tunnels for small animals benefit from a climate-adapted passage. Elements such as non-porous material, ventilation openings, climate plates that ensure humidity conducive to transit, as well as rapid adaptation of temperature to the outside environment, lead to a high level of acceptance by amphibians.

Essentially, a bat passage is a conservation solution that integrates human infrastructure with the habitat needs of bats, ensuring the continuity of their lives.

In Romania, at the request of environmental agencies and experts, migration passages were built on the Gilort River (as part of the "*Fish for LIFE*" project) ^[19] and there are requests for fish ladders, such as the one at the thermal power plant dam in Iernut (Mureș County).

The risk factors and monitoring of collisions between motor vehicles and wild animals are:

- *Critical season:* The highest risk of collision with large mammals is recorded in winter and during periods following daylight saving time changes, when animal activity overlaps with peak traffic hours;
- *Hotspots:* Studies from 2025 highlight that accidents often occur near water sources and in areas where habitat is fragmented by new infrastructure;
- *Database:* There is a database (WVC Romania) containing over 3,000 valid collision records, which is used to identify areas of maximum risk.

The construction of barriers that prevent animals from moving freely between different favorable habitats causes a multitude of undesirable side effects on populations: difficulties in finding mates, reproduction between related individuals, which will have serious consequences for the health of the population, low immunity to various diseases and pathogens, low ability to adapt to changes in environmental conditions, etc. All of these contribute to a decline in the viability of a population or, worse, to its extinction.

Although useful, animal warning systems are only a partial solution; the environmental problems caused by railways (habitat fragmentation) are more complex and require long-term conservation strategies.

If an animal is spotted on the road, it is recommended to reduce speed gradually and avoid sudden maneuvers that could lead to loss of control of the vehicle.

Road accidents have a significant impact on birds of prey in Romania, especially on nocturnal species such as owls and screech owls, thus posing a threat to the conservation of these species and requiring protection and prevention measures to reduce mortality caused by road traffic. Studies such as PMMV provide a deeper understanding of the impact and can be used to develop strategies for the conservation and protection of birds of prey in Romania.

Mesh fences are an essential green infrastructure solution that contributes to the peaceful coexistence of traffic and wildlife, reducing conflicts and increasing safety.

Although no exact number of road accidents involving wild animals can be presented, the numbers show a major and growing problem over the last 10-20 years, affecting Romania and Europe, with thousands of animals killed and increased risks for drivers, even if the exact data is incomplete.

In Romania, official centralized statistics on road accidents involving wild animals are limited, as many incidents are not reported unless there are human casualties or major damage. However, the data available for the last decade indicates a steady increase in this phenomenon:

- *Calls to 112:* Between 2015 and 2020, nearly 12,000 calls were made to the 112 emergency number regarding accidents involving wild animals (bears, roe deer, wild boars, foxes, etc);
- *European trends:* Across Europe, the number of accidents involving wild animals has increased by approximately 20-25% over the last 5 years, affecting around 250 million large animals annually;
- *Independent databases:* In recent years, initiatives such as the "Zăgan" app and databases maintained by environmental associations have begun to monitor these incidents, reporting over 600 events in just a year and a half (2020-2021);
- *Impact on protected species:* The brown bear is one of the most affected species in Romania; for example, on certain new infrastructure segments (such as highways in mountainous regions), numerous fatal collisions have been reported shortly after opening;
- *Collateral mortality:* Local studies on modernized road sections show that road infrastructure can cause thousands of casualties among small fauna (amphibians, birds of prey, reptiles) in a single year on a single road segment.

To address this problem, Romanian authorities began implementing more rigorous monitoring and protection programs in 2025, including orders to place injured animals in shelters and legislative measures to compensate drivers.

Romania's infrastructure has gradually adapted to European environmental requirements by incorporating the concept of *green infrastructure*, which involves the construction of ecoducts (green bridges) and dedicated wildlife crossings to ensure habitat connectivity. Although they were ignored in the past, wildlife crossings are now viewed as "vital links" (Green News) and are being built to save wildlife; Romania is actually constructing "bear highways" alongside its roadways. Wildlife crossings are no longer considered optional; they have become mandatory requirements in the process of obtaining environmental approval for new highways. Adaptation isn't limited to green bridges; the infrastructure now also includes tunnels, adapted underpasses, and high viaducts that allow wildlife to pass under the road.

Although progress has been made, experts point out that some ecological corridors are still too narrow or treated merely as administrative formalities, and there is a risk that habitat fragmentation will continue if implementation does not strictly adhere to the biological data of the monitored species.

The ecoducts presented in Chapter 8 of this scientific paper

can also be built to cross other communication routes such as over railways, waterways, rivers, et all.

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