Documents for the Mitigation of Habitat Fragmentation Caused by Transport Infrastructure

7

EDGE AND VERGE EFFECTS OF TRANSPORT INFRASTRUCTURE. MITIGATING THEIR IMPACT ON BIODIVERSITY

GOBIERNO DE ESPAÑA
MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA Y EL RETO DEMOGRÁFICO

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1 Presentation

1.1 Background

Transport infrastructure, urban sprawl and agriculture are amongst the human activities with the greatest impact on the planet. This trend will continue for decades to come. Transport infrastructure has particularly serious effects, which are manifested immediately in the loss and fragmentation of local habitats and ecosystems. The infrastructure construction phase is a direct, high-impact aggression because most of the destruction of pre-existing vegetation and the degradation of the surrounding habitats due to the continued action of several processes is irreversible. Once in service, transport infrastructure has several types of effects. Some of them are quite obvious to society, such as fauna casualties and the barrier effect, which hinders or prevents mobility from one side of the infrastructure to the other.

There are also other less well-known effects such as disturbances to aquatic systems, silt erosion and transportation, light, noise, air, water and soil pollution. The wide range of these effects hinders their integrated mitigation and prevention. Furthermore, once the infrastructure enters operation, impacts are not only caused by the existence of the infrastructure as such, but also by the traffic that it carries, which is dynamic over time. Considered together, the cumulative effects on numerous scales caused by the presence and use of transport grids causes heavy habitat fragmentation, which diminishes the environmental value of the surrounding areas and reduces the ecosystem services that they provide. For all of the above reasons, Goal 2 of the Natural Heritage and Biodiversity Strategic Plan (Spanish Royal Decree 1274/2011 of 16 September) is “To protect, conserve and restore the natural environment in Spain and reduce its major threats”. To this end, Goal 2. 2 specifically pursues the environmental connectivity of the land. For this purpose, Action 2.2.4 calls for, “An ongoing definition of technical prescriptions for the reduction of habitat fragmentation caused by transport infrastructure and their implementation and dissemination”. To date, six documents containing technical guidelines have been published, the first one of which has been updated. These six documents are part of a series aimed at the reduction of habitat fragmentation caused by transport infrastructure. The information that they present is eminently practical, and is aimed at minimising the damage to biodiversity caused by linear transport infrastructure during the planning, construction and operation phases. This objective is part of the National Strategy for Green Infrastructure and Ecological Connectivity and Restoration, drafted by the Ministry for Ecological Transition. The present document, the seventh in the series, focuses on edge effects and other impacts along the infrastructure verges. These effects were outlined in *Indicators of Habitat Fragmentation caused by Transport Infrastructure* (MARM 2010b) and the second revised and expanded edition of *Technical Prescriptions for Wildlife Crossing and Fence Design* (MAGRAMA 2015).

Some edge effects were identified in the previous manuals: light pollution, noise and vibration, the spread of other types of pollution, fires and anthropic presence. Hazardous processes identified along the verges of infrastructure included: water build-up and channelling, silt flow, and the creation of new habitats which may attract and channel the movement of different species.

The present document addresses these effects in depth. It specifically addresses the propagation of invasive alien species out from the infrastructure, their establishment along the verges, and the potential effects of potentially hazardous species. Finally, it addresses the effect of transport infrastructure as a frequent source of wildfires.

1.2 Context

Spain has more kilometres of motorways and high-speed railway lines than any other country in the European Union (European Commission, 2016).

Over the last 30 years, the construction of transport infrastructure of all kinds has been greatly intensified in Spain. The length of motorways has increased from 4,976 km in 1990 to 14,981 km in 2013 (a 300% increase in 23 years). High-speed railway lines have increased from 471 km in 1995 to 2,871 km in 2015 (600 % increase in 20 years, European Commission, 2016). The same report lists Spain's road length as 666,415 km, i.e. slightly more than 1.2 km of roadway per km^2 of surface area, while its rail network is 15,901 km long. This dense transport infrastructure grid has been the direct cause of habitat loss due to the infrastructure construction process, the fragmentation of the remaining habitat, and several additional effects resulting from its use and exploitation. These direct effects of habitat loss and fragmentation, fauna collisions and the barrier effect caused by limitations on wildlife and seed movements have attracted most efforts in terms of monitoring, mitigation and research into the environmental effects of infrastructure. Riparian habitats are most heavily affected because the infrastructure often follows rivers and other moist zones in areas with a gentle relief, which are easier to build on. Amphibians and reptiles are the most heavily affected groups of vertebrates due to their preference for these habitats and their particular features and natural cycles, with mass mortalities at certain points on roads and railway lines. The barrier effect can also have a particularly heavy impact on endangered species, which suffer from high collision mortalities and the lack of connectivity between their populations, as in the case of the Iberian lynx and the brown bear. In recent years, numerous structures have been built to make roads more permeable and enable fauna to cross them, although few studies have analysed the effectiveness of different types of these structures for populations.

The present volume of technical guidelines reviews the progress that has been made and the current state of edge and others effects that occur along infrastructure verges. Recent studies have shown the need for a paradigm shift in the consideration of infrastructure verges in the management and monitoring of geomorphological and hydrological dynamics, and also the consideration of plantation work along these verges as an ecological restoration rather than a landscaping process (Valladares et al. 2011). The need to reduce light and noise pollution has also been stressed, especially in protected natural areas (Iglesias 2014). The knowledge and experience built up in recent years about these and other infrastructure effects (see Colino 2011) has facilitated the search for technical solutions that can minimize edge effects and others along verges, with the consequential benefits for biodiversity conservation.

1.3 Objectives

The overall aim of the present document is to avoid, reduce or minimise edge effects and other environmental effects along verges caused by transport infrastructure. This general aim is divided into the following specific objectives:

- To review current scientific information about edge and other related effects of transport infrastructure, in particular:
  - Light pollution
  - Noise pollution
  - Pollutant dispersal
  - Water run-off and its management
  - Fire ignition on verges
  - Human presence
  - Establishment and spread of invasive alien species
  - Attraction for species which may damage the infrastructure
  - Attraction for species susceptible to collisions
- Draft guidelines which can facilitate the prevention of these effects in the planning sphere and, in situations where they cannot be prevented, design and implement measures aimed at reducing the effects in areas affected by this type of infrastructure.

1.4 Scope

The scope of these technical guidelines covers the full life cycle of the infrastructure, including the planning, design, construction, operation and maintenance phases. The guidelines cover a wide range of measures in addition to prevention and correction. They also serve to identify effects that can give rise to compensatory measures for impacts that cannot be mitigated. They can be particularly useful in environmental impact assessments, environmental surveillance and monitoring in the operation and maintenance phases of the infrastructure in order to evaluate the effectiveness of the measures that have been implemented.

1.5 Target audience

This document is designed for company managers and technicians, public administrations and other bodies involved in the design, construction, maintenance and operation of linear transport infrastructure, along with those involved in environmental assessment and the conservation and restoration of the natural environment. It is also relevant for citizens who are particularly interested in environmental issues, the environmental impact of transport infrastructure and its prevention and mitigation.

2 Concepts

2.1 General effects of infrastructure

Linear transport infrastructure construction is directly involved in the destruction of pre-existing habitats due to its land occupation. Although this is perhaps the most greatest effect, it receives relatively little attention because it is so obvious. Levelling for the main traffic platform alone is responsible for the destruction of a roughly 40 metre wide strip in the case of high-capacity roads, which means that 4 hectares of habitat are lost for every kilometre of new roadway. A quick calculation based on Spanish road network data (European Commission, 2016) graphically indicates that the area now occupied by roads in Spain is equivalent to the land mass of the Balearic Islands. If embankments, slipways and service roads are factored in, this area of land is doubled or even tripled if the alignment involves the duplication of pre-existing roads or convergence with other linear infrastructure. Habitat loss is a direct, immediate and irreversible impact which makes the choice of the alignment a critical issue.

The second basic effect of transport infrastructure on the local environment is the fragmentation of pre-existing habitat patches or mosaic tessellates, with potentially large-scale environmental consequences (MARM 2010b). The route planning phase must therefore always avoid the fragmentation of important natural habitat tessellates and valuable natural areas. The conservation value of non-fragmented areas, free of roads and other infrastructure, is now the focus of scientific literature (Laurance et al. 2014, Ibisch et al. 2016).

Induced urban development, together with the loss and fragmentation of habitat, is totally or partially irreversible. Preventive measures are therefore more efficient than corrective or mitigating measures. The mere presence of linear transport infrastructure and the resulting changes to natural habitats generates a barrier that halts or reduces likelihood of movements by many species from one side of the infrastructure to the other, to the detriment of connections between populations living on both sides, which can become fragmented, thus increasing their vulnerability since the smaller the population, the greater the risk of local extinction. This problem is exacerbated by the risk of collisions with individuals trying to cross. Large numbers of victims are recorded, particularly small species such as insects, amphibians, reptiles and small birds. Collisions with large mammals are also a road safety hazard. The casualty risk is so high for some species (e.g., owls and hedgehogs) that they can be threatened with extinction in habitats near the road (Grilo et al., 2012; Borda da Agua et al., 2014; Wembridge et al., 2016). The sheer scale of the collision problem has led it to be classified as a different impact from the barrier effect, despite their direct relationship, since casualties reduce connectivity between populations split by infrastructure.

In this series of documents, other effects which emanate from linear infrastructure are considered in two main categories: edge effects and effects along the road verge. They share the same physical space, they occur on the sides of the road, but differ essentially in their functional aspects. The effects emanating from the infrastructure have two main spatial components: one longitudinal, parallel to the road, and another perpendicular, penetrating the surrounding landscape and diminishing with distance. Although these effects are never exclusive, we consider edge effects to be those in which the perpendicular component is more relevant than the longitudinal one; whereas effects along the verge are those in which the longitudinal component predominates (Figure 2.1).

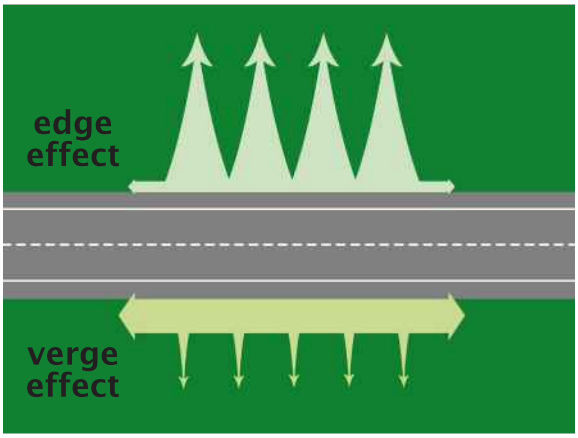


Figure 2.1. Conceptual definition of effects which emanate from the road into the surrounding habitats and effects which mainly occur along road verges. The arrow width represents the intensity of the effects.

Roads are responsible for the perpendicular spread of artificial lighting, noise, dust, heavy metals, road salts, etc. away from the infrastructure into the environment. They also trigger derived effects such as certain species being attracted to or avoiding roads, even when there are no changes to the vegetation composition or structure. If they avoid them, their density in the vicinity of the infrastructure declines, as in the case of wild ungulates and some bird species, while if they are attracted, their density increases. This happens when carnivores such as foxes use roads to facilitate their movements.

These changes in species density have an important knock-on effect on other processes such as herbivory rates and vegetation recruitment, for example, which in turn intensify the edge effect by modifying the vegetation structure to a variable degree, depending on the distance from the road. Their intensity can even trigger the emergence of new types of vegetation, with positive or negative effects, depending on the area and the species. In general, the edge effect largely depends on the percentage of the habitat affected by the infrastructure and also characteristics of certain species such as their mobility and their affinity with that habitat. The effect can be significant, especially where there is a dense road network. In the Doñana Natural Area, for example, the edge effect of the dense grid of roads and tracks has been estimated to reduce the likely presence of wild boar by 55% and deer by 40% (D'Amico et al. 2016).

The very existence of the road and the resulting changes to the habitats around its verges can channel water, silt, pollutants and fire longitudinally, and also facilitate the movement of organisms. Again, the effects can be positive or negative. The former can include strips of natural vegetation on farmland which act as a limiting factor (Figure 2.2.). The presence of this vegetation means that these strips can act as corridors to facilitate animal movements between remaining patches of natural vegetation in the area, a major environmental benefit in situations where they flank roads and tracks with little traffic in heavily humanised landscapes. This is the case in farming landscapes with lower environmental values (Ascensao et al. 2015, Arenas et al. 2017). Examples of negative impacts include eutrophication on verges due to nitrification, which in turn changes the vegetation composition and facilitates the invasion of ruderal plant species (plants that adapt to poor soils on verges and ditches), the encroachment of herbaceous plants and shrubs in forest areas, the invasion and spread of alien species which behave like weeds, favoured by environmental disturbances along verges, and propagule transportation by vehicles (Joly et al. 2011).

Figure 2.2. Natural vegetation growing on a road embankment. A-49 motorway, Rociana del Condado, Huelva. Herbaceous and low shrub vegetation facilitates the presence of insects, birds and micro-mammals. This kind of vegetation patch can have positive conservation effects in heavily humanized landscapes where there is little native vegetation. Photo: Jacinto Román.

The present document focuses on edge effects and other impacts on the verges of transport infrastructure. The former include all effects whose intensity moves outwards from the edge of the infrastructure and decreases as the distance from it increases: the dissemination of pollutants, noise and light pollution, human presence and fire ignition, which in turn cause other derivative edge effects. The latter group covers those which are typical of the new habitat, consisting of the verges, median strips and embankments of the infrastructure, as well as the channelling of silt and water along it. All these effects are manifested through different change mechanisms or processes (Figure 2.3), which can be grouped as:

- Bio-geochemical processes: changes to light intensity, noise, pollutants, silting and run-off, fires and also microclimatic variables such as temperature and wind.
- Processes at the individual level: avoidance of or attraction to the road, direct mortality (insects preyed upon after being attracted to lights) and physiological effects such as increased stress.
- Processes at the population level: local extinction, changes in density, emergence of new species (including invasive alien species) and changes in population dynamics (immigration/ emigration between populations, for example).
- Processes at the species community level: emergence and disappearance of species, changes in their composition resulting from the emergence/ disappearance of populations and subsequent changes in interactions between the constituent elements of the community.
- Processes at the ecosystem level: fragmentation, alteration and changes to dynamics (e.g. modifications to the water regime of a waterbody) and their consequences for ecosystem services (infrastructure-induced forest reduction leads to less CO^{2} capture).

Interactions and synergies

The effects of infrastructure on the environment are complex due to numerous interactions and synergies. In addition to the effects of the actual presence of the infrastructure itself, others derive from its traffic and the increased presence of people in the area, not only during its operation and maintenance but also during its construction (Figure 2.4).

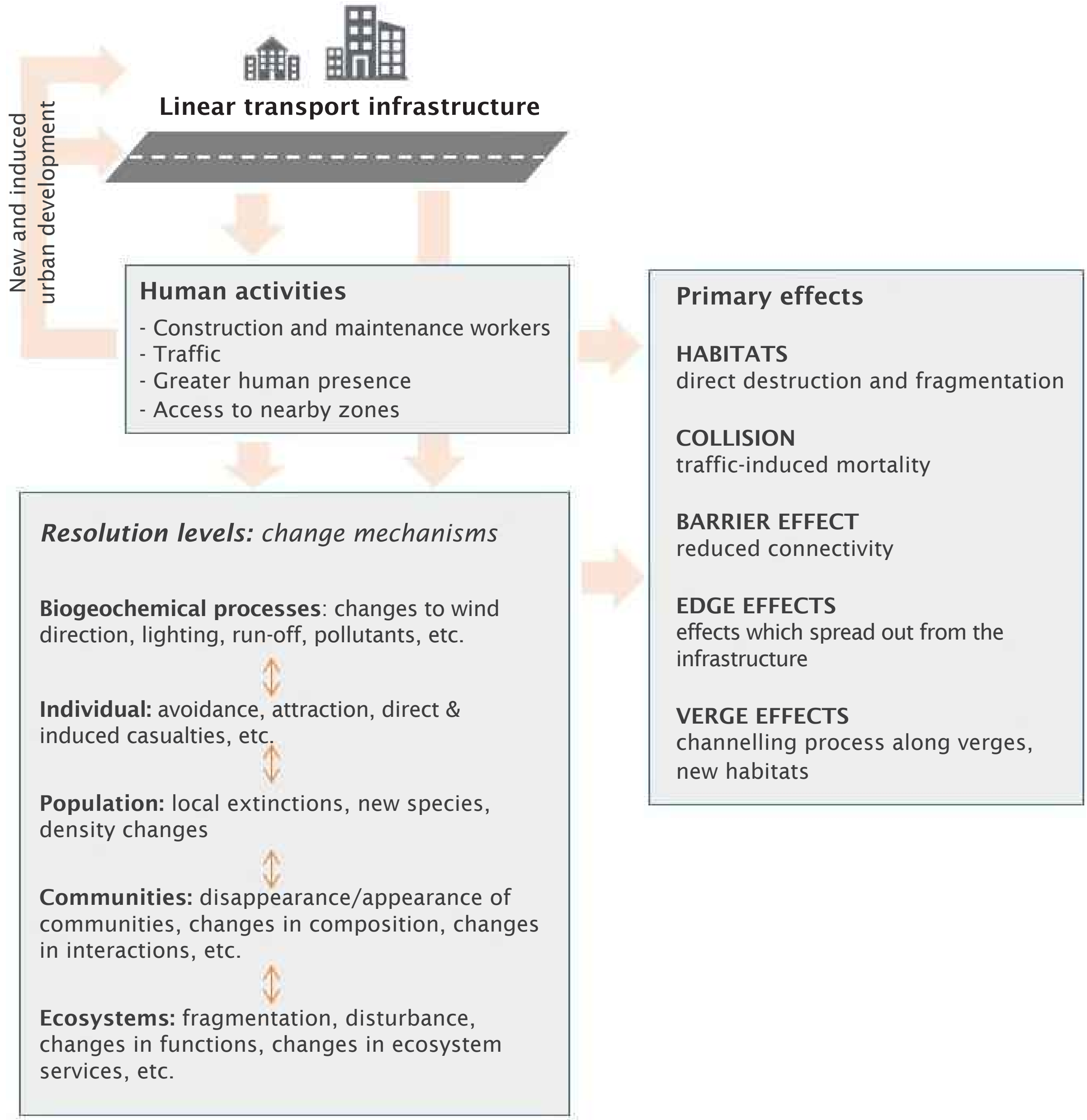


Figure 2.3. Outline of main effects of anthropisation caused by linear transport infrastructure construction, showing the main change mechanisms at different physical and biological resolutions.

Each of these components has direct effects on the fauna, the vegetation and the physical processes in the vicinity of the infrastructure. The generation, input and mobilisation of various types of pollutants must also be considered (Figure 2.4). The very existence of the infrastructure causes impacts associated with the void or gap it creates in the ecosystems that it traverses. It also affects environmental processes such as wind speed and direction, and the temperature and moisture of both the air and the ground nearby.

Many of these effects are common to the different phases in the infrastructure's lifetime (construction, operation and maintenance), and vary greatly in duration and intensity. The human activities associated with the construction phase have the greatest effects and intensity, although they general have a limited duration. Maintenance work is ad hoc, and includes major and minor improvement works which have similar effects to the initial construction process. Other effects of lesser importance can cause major environmental problems, e.g., herbicides sprayed along verges and de-icing agents in winter. The duration of the effects associated with the presence of traffic and humans on and around the infrastructure continues throughout the entire lifetime of the infrastructure. In addition to the direct effects, interactions between them compromise their isolation and the design of corrective or remedial measures. There are many examples of such interactions and synergies. Dead animals can attract scavenger species, creating an additional collision risk. Physical-chemical changes on road verges disturb the vegetation, which in turn has a direct effect on animal species that use these zones (Figure 2.4).

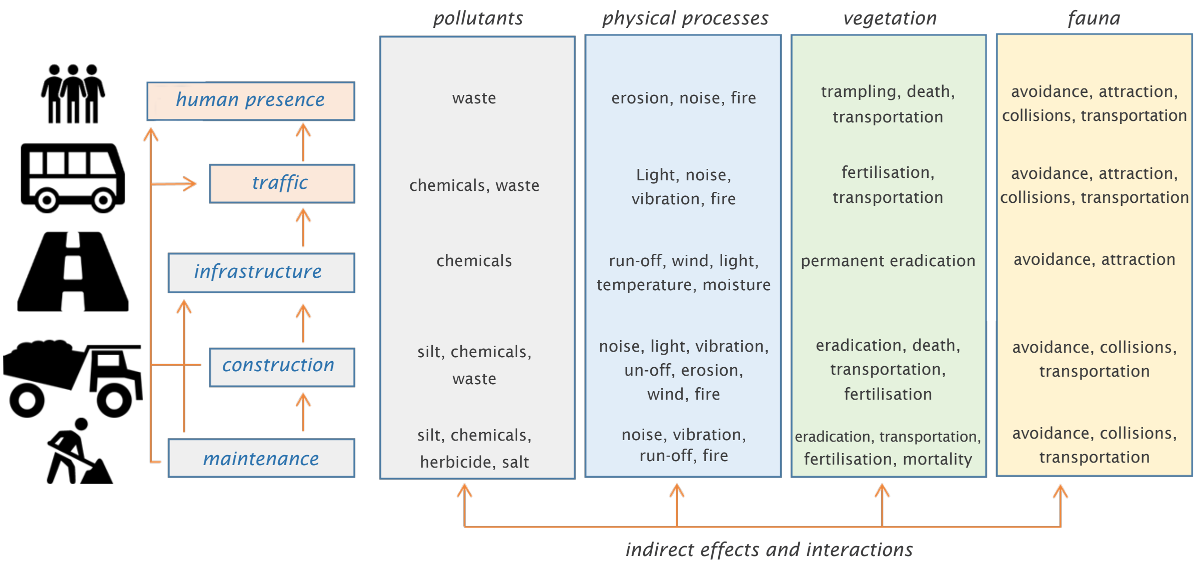


Figure 2.4. Diagram showing connections between different factors associated with transport infrastructure (presence of the road/railway line, humans and traffic, and construction and maintenance work) and their effects in terms of pollutants, physical processes, vegetation and fauna. Arrows indicate relationships, including indirect effects, and interactions between effects (e.g., silt and chemical pollutants produce death of vegetation). Note that although herbicides and road salts are chemical pollutants, they are listed in the maintenance section due to their scale.

A broad perspective is therefore necessary when designing actions in order to ensure that multiple effects are tackled at the same time. It is also important to factor in potential knock-on issues caused by the chosen preventive or corrective measures.

2.2 Effects considered in this document

The different types of effects are obviously interrelated, and it is sometimes difficult to isolate one particular problem. It is useful to identify specific problems (effects) and describe them from the perspective of the causal human actions and the mechanisms at different scales that give rise to the phenomenon. It is therefore easier to identify actions that can be useful for the reduction and correction of impacts in the design, application and management stages. The effects considered in this document which are associated with linear transport infrastructure and related to edge effects and the typical effects along road verges are:

- Light pollution. Caused by artificial road and vehicle lighting. It has both direct (glare, attraction) and indirect (physiological) effects on a large group of organisms. These effects can be long-range (kilometric), depending on the surrounding relief and vegetation.

- Noise pollution. Noise generated by traffic on the road. More important than the auditory and behavioural consequences for fauna are the non-auditory consequences (physiological stress). These effects can be medium-range (hundreds of metres), depending on the surrounding relief and vegetation.

- Other pollutants. Vehicles are the main source of chemical pollution on roads, along with the materials used in road construction and maintenance and accidental spillage. Depending on the substance involved, the range can be a few metres or even kilometric if we include air pollution and liquids spread via the road's own drainage network.

- Wildfires. More than 20% of wildfires begin on roads as a result of accidents, negligence, or fires lit deliberately for different purposes.

- Human presence. In addition to the direct impact of humans on the environment (trampling, exploitation, disturbance, etc.), the presence of people on the roads and and in their environs increases the edge effect in all aspects mentioned in this document.

- Run-off and water management. Roads often intercept various types of water bodies and streams. This changes parameters such as their hydroperiod, flow speed, silt deposition, etc. These effects can also occur at the landscape scale, depending on the size of the waterbody and the infrastructure involved.

- Invasion and spread of alien species. Roads are often mentioned as a major factor involved in invasions by alien flora and fauna. Verges and transport-related infrastructure offer a disturbed habitat in which non-native species arrive in the form of individuals, seeds and other propagules. Spread by vehicles on the road, they then become successfully established. Roads act as trunk routes for these species, enabling them to constantly expand their range.

Figure 2.5. *Pluchea ovalis* takes root on a roadside. Photo Tenerife Island government.

- Zones invaded by potentially aggressive species. In addition to alien species, others have natural features that facilitate their successful exploitation of new habitats along road verges, sometimes posing a hazard to the infrastructure itself, as is the case of sections where rabbits dig.
- Zones where species are attracted, with numerous casualties. Roads, their verges and the associated infrastructure (lighting) can attract certain fauna species and increase the likelihood of collisions with them.

For all these effects, roads are considered to be the sum of all their components: the road itself, service roads, slipways, rest areas, etc., because, although they have different traffic volumes and effect intensities, the latter are essentially the same and are generated by the road infrastructure as a whole. The present document provides up-to-date relevant information about the magnitude of these effects of infrastructure, along with solutions aimed at reducing them at the planning, design, construction and operation stages.

Figure 2.6. Partridge (*Alectoris rufa*) nest in a road culvert, a common nesting habitat in some areas. Photo: Javier Viñuela (IREC, CSIC-UCLM).

3 Description of effects

3.1 Light pollution

Nearly all living organisms have some kind of periodic physiological variation related to the light cycles in the environment. They are known as circadian rhythms. Apart from their daily patterns, organisms that live a long way from the Equator also adjust their less frequent biological rhythms to the photoperiod, and activate or halt different physiological processes in accordance with the number of hours of light that they receive. Any disturbance to the amount of light that an organism receives obviously has consequences, all the more so if these disturbances cause an abrupt change, as in the case of artificial lighting in an otherwise dark place. Artificial light is reflected and diffused by the night sky, generating what is called light pollution, which can be produced in three main ways: glare, intrusion and dazzling.

Glare is a direct result of the light projected into the night sky. It forms the well-known haloes around cities and roads (Figure 3.1). Intrusion generally consists of horizontal light rays, which are easily projected and end up penetrating areas a long way from the light source. Finally, dazzle is the sudden incidence of light in the eyes of animals.

Many kinds of impact due to light pollution have been well documented in birds, bats, insects (especially nocturnal butterflies), amphibians and many other species. The following are particularly notable: the edge effect on animals with nocturnal habits, modified behaviour patterns in feeding, breeding, navigation, filial care, migration, communication, competition and predation. Something similar occurs in plants. Impacts on the growth of some crops, the specific composition of some communities and their phenology (seasonal rhythms) have been described.

The most visible and perhaps the most important effect is on insects, which become overexcited by light pollution, causing hyperstimated behaviour known as "flying into light" (Figure 3.2). Insects are attracted to the light sources, with three main effects: direct mortality (the insect dies from exhaustion, burning or predation), the barrier effect (the insect in the process of dispersal or migration does not complete the cycle when attracted to a light) and translocation (the insect leaves its natural habitat, attracted by the light source).

Figure 3.1. Light pollution in the north of Tenerife Island. Photo: José Ángel Estévez Armas (https://www.flickr.com/photos/cestomano/).

Most of these effects have been described in town centres, where transit roads between districts, residential areas and slipways to radial motorways are lit up as if they were appendices to the town centre. Outside these areas, the biggest and still-growing source of light pollution is the light emitted by vehicles. Illuminated panels and signs also produce glare which reduces the ability to discern obstacles, especially in LED-based systems (Domke et al. 2011). With a view to mitigating impact, studies have been done on the effectiveness of semi-natural barriers, panels with better light directionality and the design of shaded zones for use as shelter by nocturnal fauna (see Bertolotti and Salmon 2005). Studies generally suggest that the implementation of a series of good practices in the use of artificial lighting significantly reduces the impact. These include: removal of lighting in places where there is a risk to endangered fauna or flora, reduction to the strictly necessary number of light sources, adjustment of light intensity (Hale et al. 2015), adaptation of lighting times to the road usage patterns, concentration of lighting into places that really need to be lit, and preventing light from being projected into the surrounding area to the greatest possible extent. Technological progress in lighting technology is extremely useful for some of these tasks, permitting relatively easy adjustments to the light intensity and spectrum (colour) along with improved directionality. This makes it easier to choose the combination with the least impact on the fauna and flora in the area. Despite the technological feasibility of adjustments to light intensity and spectrum, the complexity of responses by different organisms to light pollution makes it difficult to make generalised recommendations.

Figure 3.2. Ephemeral insects attracted by lights on a bridge over the Ebro River in Tudela (Navarre). Photo: Government of Navarre.

Lights with broad-spectrum wavelengths such as some LEDs (but also mercury vapour lamps and metal halide lamps) allow many organisms to prolong their nocturnal colour-dependent behaviour such as feeding, mating, camouflage and predation. This also affects interactions between species. On the other hand, the short wave peak (blue spectrum) emitted by white LEDs coincides with the wavelengths at which many biological responses occur, producing a particularly intense impact on invertebrates and organisms (including humans, see Longcore et al. 2017) whose physiological responses are mediated by melatonin.

Experience suggests that reddish light (long wavelengths) such as low-pressure sodium vapour lamps are least disruptive to birds (shearwaters), some mammals (including bats) and some anuran species (Spoelstra et al. 2015, 2017; van Grunsven et al. 2017). However, the phytochromatic system of plants, which controls flowering amongst other actions, is sensitive to precisely these longer wavelengths. For this and other reasons, many studies consider that there is no optimal solution that magnifies or mitigates the impact of artificial lighting on all biota, and that the best option is not to illuminate roads at all or to minimise the lighting time, the period and the illuminated area (Stone et al. 2009, Azam et al. 2015). Therefore, in the infrastructure planning and design phases, rather than identifying areas that should not be lit, exceptions should be considered where such lighting is completely necessary, given that existing measures aimed at reducing or mitigating the impact on the environment have limited effectiveness. If the infrastructure nevertheless requires lighting, it must be adapted to the essential intensity of illumination and the spectrum of the emission from the light source must be minimised. Although there is no optimal solution, several studies suggest higher sensitivity by night fauna in the short-wave ranges of the spectrum (below 500 nm). This is contemplated in various regulations and documents published by official bodies aimed at minimising the environmental repercussions in natural areas (Spanish Lighting Committee 2018).

Outdoor lighting is regulated by Royal Decree 1890/2008 of 14 November, which ratifies the guidelines for energy efficiency in outdoor lighting installations. Although it focuses on the prevention of light pollution for astronomical or night sky observation purposes, the recommendations are also applicable to the reduction of light pollution for the benefit of biodiversity. This Royal Decree was passed before LED lighting became widespread. For this reason, more recent guidelines drafted by local councils, provinces and regional governments should also be considered (e.g. Decree 190/2015 issued by the Government of Catalonia) along with more recent technical documents such as CIE 150 (2017). Royal Decree 1890/2008 defines Nocturnal Glare as, "The light emitted by outdoor lighting installations, amongst other sources, either by direct emission into the night sky or reflected off illuminated surfaces" The aim of this Royal Decree, in addition to improved efficiency, energy saving and the reduction of greenhouse gas emissions, is, "To limit nocturnal luminous glow or light pollution and reduce intrusive and annoying light". The above-mentioned regional and municipal guidelines notwithstanding, this Royal Decree is the clearest reference on the subject in Spain.

Royal Decree 1890/2008 defines four classification levels of "Zones protected against light pollution":

E1: *Areas with dark environs or landscapes:* International astronomical observatories, national parks, areas of natural importance and special protection areas, where all roads are unlit. In these areas, the complementary technical instructions set out in the aforementioned Royal Decree recommend the use of lamps with wavelengths >440 nm.

E2: *Areas with low brightness or luminosity*: Peri-urban and outlying areas around cities, non-buildable land, rural areas, and sectors generally located outside urban residential or industrial areas, where roads are lit.

E3: *Areas of medium brightness or luminosity*: Urban residential zones, where roads and pavements are illuminated.

E4: *Areas of strong brightness or luminosity*: City centres, residential areas, business and leisure sectors with intense night-time activity.

More recent documents such as the second edition of the International Commission on Illumination's Guide on the Limitation of the Effects of Obtrusive Light from Outdoor Lighting include a zone defined as E0, where artificial lighting should be completely non-existent (CIE 150: 2017).

3.2 Noise pollution

All roads, motorways, railway lines and other transport infrastructure increase the level of ambient noise. In fact, traffic is generally considered to be the main source of noise pollution, and is regarded as a major environmental health hazard. The Noise Act (Law 37/2003, of 17 November) transposes into Spanish law the EU Directive 2002/49/EC of 25 June, on the assessment and management of environmental noise. Previous regulations focused on noise sources, emission reduction (quieter engines, bodywork and tyres, emission-reducing asphalt, noise barriers, etc., see Figure 3.3), but reality has shown that despite constant technological improvements, such measures have been made less effective by the overall increase in the volume of traffic and average speeds.

The Noise Act contemplates Strategic Noise Maps as an instrument for ascertaining exposure to ambient noise. They are defined as, "Maps designed as an overall assessment of exposure to noise generated by different sources in a given area, and to make overall predictions for this area". The maps are produced for each major road and rail route in Spain, grouped into seven geographical areas and traffic corridors. They have been used to draft several action plans which identify the sections where noise exposure exceeds the advisable threshold levels for the population. In some regions and provinces (Andalusia, Catalonia, Guipuzcoa, Murcia and Navarre), the effects on the natural environment are also considered. At each stage of the action plans, the affected areas are specified in further detail, along with the measures planned and implemented to reduce the noise. Despite their limitations, noise maps and action plans are the best macro-diagnoses of noise pollution generated by transport infrastructure.

Figure 3.3. Noise abatement panels on the A-601 motorway in Gomezserracín (Segovia). Photo: Government of Castilla y León.

The Noise Act contemplates natural sound reserves, and permits the implementation of plans to preserve the natural acoustic conditions in these areas along with measures aimed at facilitating the perception of these sounds. Given the quite broad acoustic spectrum in nature —choruses of amphibians and insects, waterfalls, etc.— these areas do not have to be silent. This makes it difficult to apply sound limits (in dB) in natural spaces. The effects of noise pollution are defined in natural resource development plans and the Master Plans for their organisation (NRDP) and their use and management (NRUMP) —in Spanish, PORN and PRUG respectively— where the effects of noise pollution should be established, creating zoning and general guidelines for public use. However, a 2014 review of the NROP and NRUMP for some Spanish national parks revealed shortfalls in the treatment of variables related to soundscapes, environmental noise and noise pollution. This was most obvious in the conservation of unique sounds of a natural origin, soundscape management, control of noisy activities in parks and other potential noise sources outside them (Iglesias 2014). This study also found noise sensitivity thresholds in roe deer (30 dB) and black vultures (40 dB) at equivalent levels of sound pressure. These levels are similar to those considered for homes at night in several autonomous regions of Spain, and may therefore be employed as an indicative reference for parks.

Although noise is a relatively easy-to-measure variable, it is hard to separate its particular effects on fauna from those produced by the infrastructure as a whole. Moreover, the chronic noise endured by populations living near a road must be separated from sudden noise that can be produced in a specific way. In addition, the local casuistry can vary with the relief and the vegetation, given the existence of attenuation effects which can limit or reflect the sound as an echo. Some of the effects of noise (e.g., stress) are hard to measure, making their study even more difficult. The best known effects are those on birds, which use sound to communicate. Described impacts of noise pollution on birdsong include a local-scale homogenization scale of song diversity and a lower response capacity in individuals subjected to chronic noise due to increased basal stress levels (Injaian et al. 2018). Song diversity in a population is a good predictor of its fragmentation, since more isolated birds have poorer repertoires (Laiolo and Tella 2005). Negative impacts have also been described in mammals and insects. The most heavily affected species are usually ones which communicate on the same or similar frequencies to traffic noise. Special mention should be made of wetlands and floodable areas due to the presence of anuran amphibians, whose main communication system in the breeding season is vocalization. Given these groups' limited locomotion and their enormous vulnerability to collision, they are considered to be one of the most sensitive groups to noise pollution. It is important to note that noise can extend the edge effect of transport infrastructure, since it can be heard at greater distances, in areas where the physical habitat is intact. In some cases, noise can reduce the effectiveness of wildlife crossings, built to alleviate this effect, since the effect of the noise acts as a hindrance to animals when they approach the crossing built for them (remember that rumble strips are often used to reduce vehicle speed in the vicinity of wildlife crossings).

3.3 Other pollutants

In addition to light and noise pollution, transport infrastructure acts as a focal point for the spread of other types of pollution: solid waste, combustion gas, herbicides, road salt, etc. This pollution occurs throughout the entire lifetime of the road, and is part of the edge effect, running into the surrounding ecosystems. The most frequent pollutants in transport infrastructure are hydrocarbons, asbestos, lead, cadmium and copper. Heavy metals and the organic component of emissions are often adsorbed by particles such as clay, sand and silt, present on the road and its verges, or absorbed by the vegetation, while the dissemination of other pollutants is usually more widespread. The primary source of volatile compounds is the vehicles themselves, which emit CO^2, NO^2, volatile organic compounds and sulphur dioxide. They have an obvious effect within a range of approximately 100 m from the emission source (Bignal et al. 2007). Changes in floristic composition, higher rates of defoliation, discolouring, insect attacks and secondary effects on pollinating fauna have been observed in this range, depending on the pollutant and the sensitivity of the different species. In unfavourable atmospheric circumstances (dominant wind travelling outwards from the road), a heavy concentration of nitrous oxides can spread 1,500 m (Jerret et al. 2007). The heaviest polluting potential of particles in suspension is reached when they combine with heavy metal vapours dispersed in the air. The particles can also act as condensation nuclei in water and other vapours, leading to the formation of micro-droplets in which hygroscopic gases such as SO^2 and NO^2 react chemically and can then be carried as acids, thus increasing their aggressive effects (defoliation, stress due to leaching of essential nutrients from the soil, etc.). In the most severe cases, they give rise to acid rain (Menz & Seip 2004). Particles are capable of adsorbing polycyclic aromatic hydrocarbons such as benzene, thus increasing their penetration into the body through the respiratory tract or prolonging their permanence there, and magnifying their toxicity (Hernández et al. 2001).

Some of the pollutants from combustion engines react to form secondary pollutants, notably tropospheric ozone, produced by photochemical reactions (activated by sunlight). Indeed, road traffic is considered to be the largest source of air pollution, responsible for up to 64% of nitrous gases and particles. (EEA 2012, see Figure 3.4).

Figure 3.4. View of Madrid from the M-40 ring road with its characteristic smog dome, associated with anticyclonic winter weather. Photo: Carlos Rodríguez.

Another relevant case of pollution on roads is the use of road salt (sodium chloride, less frequently magnesium) for de-icing, which can affect the nearby soil chemistry, raising its salinity and decreasing its pH. Road salt has heavy effects on vegetation and causes high mortality levels. It also has harmful effects on amphibians, fish and other aquatic fauna by altering the osmotic balance with the environment. Salt build-up by leaching and run-off amplifies its harmful effects on aquatic ecosystems, including aquifers and reservoirs for potable water, irrigation and industry. Another side effect is that salinization of aquatic environments facilitates the spread of halophyte invasive species such as the Asian clam (Coldsnow et al. 2018). It also damages vehicles and the road structure (concrete, metal elements, etc.). Road salt is mostly used in mountain areas where frost and snow are common. Although many of them are officially protected for their natural values, salt is still normally used on roads that cross them, with no consideration of its harmful environmental effects.

During road construction, heavy machinery with high emission levels is used in the works zone, and materials with additives that can pollute the air, soil and water are employed. If the construction site is supplied with material from local stockpiles, the excavation, selection, truck loading and transportation processes all release solids which enter the air in the form of suspended dust, with a highly variable radius of action, depending on the weather conditions. The most sensitive areas are where the vegetation cover is poor or scattered such as arid and semi-arid areas, where soil is easily blown away by the wind. Rainwater and construction waste water also mobilize all these particles. This water is usually dumped onto the ground and becomes part of the surface water run-off, polluting soil and water bodies outside the area of direct influence of the works. Run-off and leached substances such as hydrocarbons, oil, additives for concrete and asphalt, paint and even organic waste left by workers can seriously contaminate surface water and aquifers. This makes it necessary to conduct prior studies (geological, climatological, biological) of the material supply zones and propose preventive measures to reduce erosion, minimize disturbance to the terrestrial environment through transportation of particles by the wind, aquatic systems and impacts on animal and plant communities.

Pollutant emissions are also widespread during the exploitation phase, and range from ions to suspended solids (see review in Smithers et al. 2016), making the assessment of their overall impact a challenging process. The main sources of chemical pollution along roads are the vehicles themselves, as well as the road infrastructure (emissions by materials such as asphalt and bituminous binders, and paint on road signs) and the necessary maintenance work. Accidental chemical spillage is also a major source of chemical pollution. Some chemicals only affect the area near the road, while others are carried greater distances by air and water. This is true with drains, which facilitate the entry of pollutants to rivers, with a notable input of nitrogen in various forms, metals, hydrocarbons, insecticides, herbicides and road salt used for de-icing.

Despite efforts to reduce the emission of contaminants, primarily lead, air pollution is still considered to be the main direct effect of transport infrastructure on the environment. It is also still be the main impact being monitored and subject to the clearest guidelines. The Air Quality and Atmospheric Protection Act 34/2007, of November 15, 2007, updated on December 23, 2017, regulates air quality protection, defines the air quality objectives, and sets out the minimum prescriptions for system assessments. This Act, amongst other things, details the pollutants and activities that must be considered, along with their thresholds and the frequency of measurements, using the SNAP (Selected Nomenclature for Air Pollution) system as an internationally valid reference. Subsequently, several EU Directives have been transposed into Spanish law to improve air quality and prevent or mitigate the harmful effects of various substances on human health and the environment. Reference methods, data validation and locations for measuring points for air quality monitoring have also been defined (Royal Decree 102/2011, January 28; Royal Decree 678/2014, August 1; Royal Decree 39/2017, January 27). The latter Decree calls for the ratification of a National Air Quality Index that will allow Spanish citizens to be informed in a clear, standardised way. In addition, Royal Decree 818/2018, of July 6, transposes Directive (EU) 2016/2284 of the European Parliament and defines new national commitments for the reduction of emissions of sulphur dioxide, nitrogen oxides, non-metallic volatile organic compounds and ammonia and also restricts emissions of fine particulate matter $PM_{2.5}$ (particles in suspension less than 2.5 micra in diameter).

3.4 Roads as fire ignition points

Roads are widely regarded as a firefighting asset. They can be used as support infrastructure for firefighting and also act as firebreaks to hinder the spread of fires due to their lack of vegetation. However, evidence proves that the opposite is true. Most fires are caused by human beings and their activities, and they start much closer to roads and vehicle tracks than could be expected on the basis of random probability (Figure 3.5). In fact, the National Forest Fire Statistics (EGIF) for the decade between 2006 and 2015 show that 19% of fires originated on roads, with the highest likelihood of ignition along their edges (Modugno, Serra and Badia 2008). A further 17% began on forest tracks. This inserts wildfires on the list of edge effects, given that their likelihood decreases with distance from a road. Fire prediction models designed for the Spanish mainland and the Balearic Islands include transport infrastructure density (roads and railway lines, Martínez et al. 2009) as one of the main predictor variables. This is reflected in several fire prevention plans and strategies drafted by regional governments.

Figure 3.5. Small fire lit between the A-1 highway and the AP-1 motorway in Quintanapalla (Burgos). Photo: Junta de Castilla y León.

Random sources such as cigarette butts thrown from vehicles —according to the EGIF, just 2% of fire sources— have been the focus of many awareness-raising campaigns and fines. Vehicle transit can also be a cause of fires due to carbon ejected by exhaust pipes, sparks from malfunctions on trains and heavy machinery, and traffic accidents where the source of the fire is the vehicle itself. Secondary sources are another frequent cause of fires on roadsides, in the form of sparks from active fires which fall into dry vegetation on verges, facilitating ignition and potentially spreading the fire. Not enough attention has been paid to the species used for revegetation in this regard. Many of these species, either planted or implanted by hydroseeding, give rise to easily propagated combustion, since they include annuals —which dry out in summer and become dead fuel— with prostrate shrubs composed of fine dry wood, all highly susceptible to ignition and combustion. This aspect must therefore be considered in forest areas with a high fire risk.

The fire hazard along road edges can reduce safety for vehicles and people driving along them, especially in the urban-forest matrix, where narrow roadways may require the adaptation of the adjacent vegetation (auxiliary strips). In addition to the fire hazard on roads and their edges, we must also consider the potential propagation of fire to the environs around the infrastructure, especially if large forest areas are affected. Here, the fire hazard is defined on the basis of several factors, some of which are static (relief, slope angle, combustibility of the species that form the forest patch) and others which are dynamic (dryness of the forest patch and weather-related elements such as wind, temperature and relative air humidity).

A third factor, related to the recurrence of fires in the area, adds an idiosyncratic component that is usually more closely related to local forest and vegetation management models and the spatial distribution of the population. All of the above in conjunction makes fires much more likely in some regions of Spain than others (Martínez et al. 2009; Figure 3.6). The infrastructure planning phase is crucial in this regard, since the fire risk can differ greatly between alignment options. The design and construction phases are also important because they determine whether specific firefighting infrastructure is provided, the availability of run-off water for use by fire-fighting equipment, the selection and spatial distribution of species in revegetation and the selection and correct implementation of wildlife passages. Finally, the type of verge maintenance during the operation phase also influences the likelihood of fire caused by an accident or negligence.

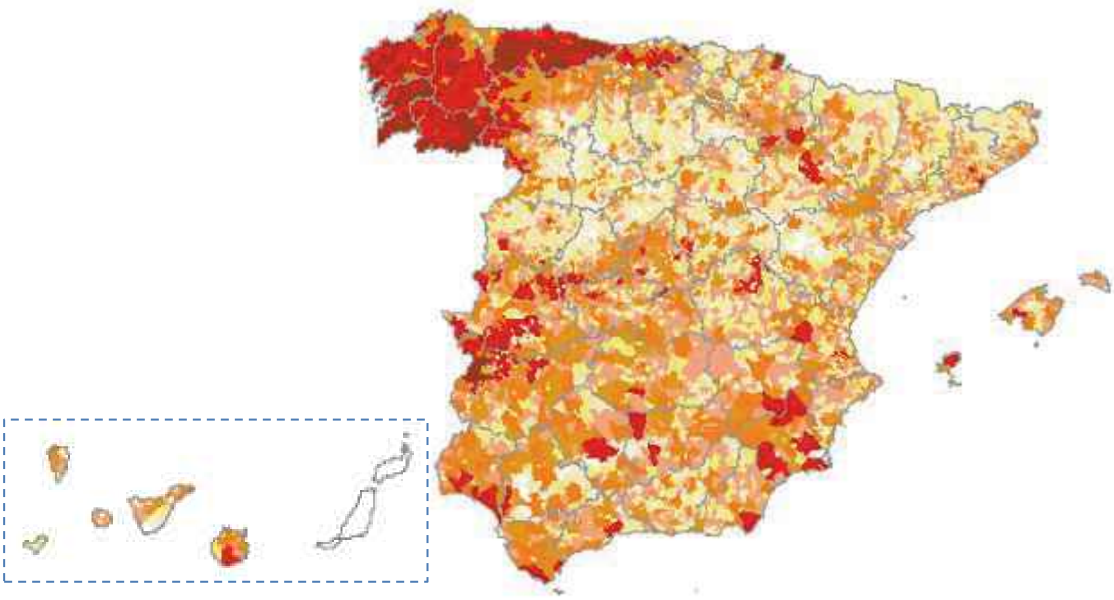


Figure 3.6. Fire frequency between 2001 and 2014. Darker colours indicate higher fire recurrence. Source: Ministry of Ecological Transition, 2016.

3.5 Human presence

Human presence along road verges and in the surrounding areas is primarily concentrated in service areas, rest areas, viewpoints, maintenance depots and, to a lesser extent, gauging stations and road salt storage facilities (Figure 3.7).

Greater presence of humans on and around roads increases some of the above-mentioned impacts, especially the fire hazard and pollutant influx, along with the invasion and subsequent spread of alien fauna and flora (see Section 3.7), thus extending the edge effect of the infrastructure.

The presence of humans has a direct impact on the environment (trampling, picking, destruction), and also acts as a disturbance that can alter the behaviour of some species or even compromise breeding in individuals nearest the areas with an intense human presence (Rodríguez-Prieto and Fernández-Juricic 2005). It is important to note that while this effect can occur along the entire length of any road, the impact is most intense precisely in areas of great scenic beauty (viewpoints, cliffs, etc.) and those that supply appreciated resources such as shade, springs and other water sources, which often host sensitive flora and fauna. In order to mitigate this impact, these effects must be taken into consideration throughout the infrastructure lifetime, from the initial planning stage to the road's exploitation stage.

Figure 3.7. Increased human presence on the verge of local road LE-321 due to the existence of a parking area. Valdeteja Gorge (León). Photo: Eloy Revilla.

The planning and design phases are crucial to the choice of alignments with the least impact. Once chosen, the zones with the most intense human presence must be situated far away from the most environmentally sensitive points. This recommendation also applies to the construction phase, for which the zones with the greatest human presence can be identified: zones designated for stockpiling, storage, equipment and rest.

3.6 Water run-off and management

Regardless of where the infrastructure is located, it affects the local drainage network and alters the local hydrology in the form of changes to surface and groundwater flow, as well as the water quality. These effects are different during the construction and operation stages.

During construction, local quarrying can change the micro-relief, create depressions at borrow points and elevations at stockpiling points. These changes affect the surface drainage network: the steeper the slope, the greater. This new run-off forms a new surface drainage system, whose effects extend upstream and downstream throughout the drainage network.

Loose material generated during excavation can be easily washed away by rainwater run-off and build up in streams and other water bodies. The presence of solids in these ecosystems hinders the penetration of light and photosynthesis in some aquatic organisms. This silt also interacts with the stream beds. It can change their structure, build up in the channels and create shallower pools which, in combination with increased turbidity, raises the water temperature. The negative effect on fish and amphibian spawning zones in mountain areas is also important. Suspended solids also alter the chemical equilibrium cycles, causing a higher demand for oxygen, and consequently the eutrophication of the waterbody, among other effects.

All these alterations bring drastic changes to the ecological conditions of the river network, on which both the fauna and the aquatic flora depend, and their survival in the project's impact area is compromised. Furthermore, the sudden destruction of the pre-existing vegetation cover can change the microclimate due to the absence of the vegetation that previously generated shade on the ground and increased evapotranspiration and its replacement by a heat-absorbing pavement. In large projects where the infrastructure construction area was covered by a well-established forest community, the changes may become mesoclimate, causing variations in the aquifer recharge process by altering the hydrological cycles, which in turn poses difficulties for ecological succession, necessary for the restoration of the affected areas.

Roads and tracks can act as barriers to natural water flow, and can cause the collapse of embankments that have captured run-off. They can also act as flow accelerators, increasing the erosion of material on steep embankments that have not been properly stabilized.

Once in service, the impact of roads on water systems depends largely on their position in relation to the drainage network and the slope, as well as the structures installed in the infrastructure to mitigate problems associated with run-off. Standard 5.2 2 IC (Order FOM/298/2016, February 15) regulates surface drainage works on national roads. Amongst its numerous considerations, it stipulates that the contents of the drainage network should not be discharged directly into the environment in environmentally sensitive areas. Many regional governments also have their own guidelines in this regard, forcing construction projects to contemplate alternative measures for run-off accumulation and pre-treatment: culverts and drainage channels, flow restraint structures, settlement ponds, and redirection to non-sensitive areas. These protection systems are not usually considered in the case of unpaved roads and tracks, where run-off and erosion issues are more significant. On the landscape scale, road networks interact with river networks by altering the natural water flow, and can act as an extension of the drainage network of both lotic (rivers and streams) and lentic (wetlands with stagnant water) water bodies. When an infrastructure intersects a river or stream, the water speed is usually accelerated when its flow is narrowed by a bridge, for example, thus increasing the energy of the system, eroding the channels and increasing the likelihood of flooding downstream. The different erosion rates of the intersecting channel and the culvert construction material often produce small waterfalls, which form new barriers for aquatic wildlife (Figure 3.8), as do construction tracks which interrupt water channels.

Figure 3.8. Bridge over the Burgantó River (Girona). The differential erosion on the concrete bed and the natural watercourse downstream from the bridge forms a barrier to the movement of aquatic animals along the river. Photo: Miguel Clavero.

3.7 Establishment and spread of invasive alien species

Many plant and animal species are able to exploit road and railway verges. Once established, they can spread along embankments, verges and median strips, in some cases aided by the very vehicles that help to spread seeds, individuals and other propagules along this infrastructure (Figure 3.9).

The most favoured elements are invasive alien species (IAS), non-native species introduced or established in an ecosystem or a natural/semi-natural habitat which act as agents of change and pose a threat to the native biological diversity either by their invasive behaviour or their threat of genetic contamination. They are usually generalist species which can survive in a wide range of ecological conditions and benefit from the abundant light and lack of competition along the disturbed verges of the infrastructure, facilitating their fast establishment. These species also tend to have efficient dispersal mechanisms. They are repeatedly introduced by vehicles which transport them in numerous ways, e.g., as seeds encrusted in tyre treads and released at high speed or, in the case of insects such as tiger mosquitoes, transported inside vehicles. This, in conjunction with the nearly ubiquitous and uninterrupted expansion of transport infrastructure in Spain in recent years, has made roads and railway lines particularly sensitive to invasion and the main vector for the successful spread of alien fauna and flora. In Spain, the most frequent IAS are tropical or subtropical, primarily found in places with a heavy human impact, low altitude and a warm, dry climate (Gasso et al. 2009). However, there are also documented cases of IAS in virtually all ecosystems throughout the country. Apart from the frequent entry of seeds and propagules and their settlement on the verges, there are two additional mechanisms that favour IAS in infrastructure: the use of inappropriate species in revegetation and earthworks during construction.

Figure 3.9. Edge of A-8076 road in Coca de la Piñera (Seville), with *Ailanthus* on the right and *Robinia* on the left. The colonizing potential of *Ailanthus* can be appreciated in its fresh shoots (foreground). Photo: Carlos Rodriguez

Although IAS are currently considered to be the second major threat to the planet's biodiversity after habitat loss (Clavero and Garcia- Berthou 2005), this condition is yet to be efficiently reflected in revegetation policies for transport infrastructure verges, median strips and emblements, whose value as zones of ecological interaction with the surrounding environment has only recently been considered (Valladares et al. 2011). In fact, for many years, IAS have been deliberately planted to revegetate infrastructure verges. In Spain, many kilometres of verges can be found with plantations of IAS (*Acacia dealbata*, *Agave americana*, *Ailanthus altissima*, *Cortaderia selloana*, *Pennisetum setaceum* and *Robinia pseudoacacia*, amongst others), with invasion fronts spreading out into natural areas and surrounding croplands. As a result, Spain's transport infrastructure is both a reservoir and a source of introduced IAS, setting the country behind the national and EU biodiversity conservation objectives.

Earth movements associated with the construction of linear infrastructure is one of the world's most active and effective geomorphological processes. In Spain, it is estimated to have a similar magnitude to the silt transported along the country's rivers into the ocean (Barbero 2013). Most of the invasive alien plants detected in Spain are favoured by these activities, producing a high risk of expansion in association with infrastructure construction. Nevertheless, latent seed banks in the soil used during infrastructure construction are also a valuable resource when replanting the embankments, since they contain seeds and propagules of native species already present in the area. In fact, these seed banks, along with those from the surrounding native vegetation, are the best material available to re-vegetate verges, median strips and embankments. They also simplify the task of species selection, reduce the number of individuals and substantially lower the cost of revegetation. The detection of IAS during the phases prior to earthworks is therefore extremely important, since it determines whether eradication treatment is necessary and when to implement it during the design, construction and operation phases.

Pathogens and quarantine organisms are a case in point. The entry of *Phytophthora cinnamomi*, *Xylella fastidiosa* and *Erwinia amylovora*, to mention some of the best-known examples in Spain, is associated with the movement of primarily ornamental and agricultural plants. Many of these plants can be used to revegetate verges, and they may also be a source of inoculum, infecting crops and wild vegetation in the vicinity of the infrastructure.

Article 54.2 of the Natural Heritage and Biodiversity Act 42/2007 of 13 December, modified by Act 7/2018 of 20 June, prohibits the introduction of non-native species and sub-species anywhere in Spain if they are likely to compete with wild native species, alter their genetic purity or disturb their ecological balance.

NOMBRE COMÚN: Mimosa, acacia francesa.

TAXONOMÍA: Phylum: *Magnoliophyta*. Clase: *Magnoliopsida*. Orden: *Fabales*. Familia: *Mimosaceae*.

DISTRIBUCIÓN GENERAL NATIVA: Sureste de Australia y Tasmania.

DESCRIPCIÓN DE LA ESPECIE

Árbol perennifolio erecto, de 2-15 m de altura, aunque puede alcanzar los 30 m. El **tronco** es liso o algo agrietado, de color marrón grisáceo a gris oscuro; los tallos jóvenes tienen el color más suave. Las **hojas** son compuestas, de color verde plateado, bipinnadas, de hasta 10 cm de largo, con 7-26 pares de pinnas de 15-30 mm de largo, cada una de las cuales presenta entre 20 y 50 pares de pínulas lineares de 2-5 mm de longitud. Tiene una glándula prominente en la inserción de cada par de pinnas y en el peciolo.

Las **inflorescencias** son muy características, en glomérulos globosos amarillo dorado o amarillo limón de unos 5 mm de diámetro, olorosos y agrupados en racimos o panículas. Las flores presentan el cáliz y la corola en forma de campana; tienen largos estambres que sobresalen de la corola. El **fruto** es una legumbre comprimida, dehiscente, con constricciones entre las semillas, de color verde, azulado glauco o pardo rojizo, de 4 a 10 cm de longitud. Las semillas son oscuras, de 4-5 mm, en forma de elipse comprimida y se disponen longitudinalmente en la vaina.

PRINCIPALES CARACTERÍSTICAS DISTINTIVAS DE LA ESPECIE FRENTE A OTRAS DE POSIBLE CONFUSIÓN

A. dealbata tiene una morfología similar a otras especies del mismo género, y suele ser confundida con *A. mearnsii:*

Figure 3.10. *Acacia dealbata information file* in the online edition of the Spanish Catalogue of Invasive Alien Species. It includes (in Spanish) the common name, the native distribution, a description, and how to distinguish it from similar species.

Species which fulfil the legal definition of invasive aliens are listed in the Spanish Catalogue of Invasive Alien Species, which is updated as knowledge about their impact on native biodiversity improves. This Catalogue is the country's best reference tool. It facilitates the identification of hazardous species and thus helps to prevent their propagation during infrastructure revegetation work. The Catalogue includes every invasive alien species and subspecies which is or could potentially pose a serious threat to native species, habitats, ecosystems, agronomy or the economic resources associated with the use of the natural heritage, as determined by the respective guidelines. The contents of the Catalogue can be accessed at the Ministry for Ecological Transition's website. This resource is most useful since it contains an information file for each species (Figure 3.10). In addition to an illustrated description, the file indicates any possible confusion with other species and the ecological traits that facilitate its introduction or hinder its eradication. The website also provides detailed mapping layers for each species. In addition to this national list, some regional governments have produced their own catalogues, which contain a subset of species that already or may potentially affect their region. This is particularly relevant in the Balearic and Canary Islands. These catalogues include useful details for their management, along with activities and additional material to improve our knowledge about the species and initiatives implemented to date (Figure 3.11).

European Parliament and Council Regulation (EU) 1143/2014 of 22 October 2014 covers the Prevention and Management of IAS introduction and dissemination spread. Like the Spanish Regulations, it defines an official List of Species of Concern for the European Union which must be controlled and eradicated if necessary, whose possession, trafficking and use is initially prohibited.

Other information sources include several supranational networks on the global (GISIN) and European (EASIN) levels. They can be used as a reference point for decision-making about species that may be present along the edges of linear infrastructure.

Asparagus asparagoides (L.) Druce. RD 630/2013

Actuaciones de gestión

Estrategia/objetivo

Control de poblaciones invasoras en hábitats de interés comunitario (arenales costeros con *Juniperus* spp. y *Pinus* spp.).

Localidades

Parque Periurbano de La Barrosa (Chiclana, Cádiz).

Metodología

Debido a la existencia de flora amenazada, se procedió mediante eliminación manual selectiva, tanto de la parte aérea como de la masa de bulbos subterráneos.

A. asparagoides asfixiando a un enebro costero (*Juniperus macrocarpa*).

Figure 3.11. Andalusia Catalogue of Invasive Alien Species information file for *Asparagus asparagoides*. It includes (in Spanish) the strategy, the places where it was found, and the removal methods.

The EASIN (http://easin.jrc.ec.europa.eu) has several online tools and web functions to facilitate the search for additional information about each species, including cartographic information for each country. This information is extremely useful for assessing species which are not in the Spanish IAS Catalogue but are considered invasive in other countries and should be dealt with as soon as their presence is detected.

Although the regulations are clear and compulsory, they may be difficult to implement due to the existence of synonyms, the availability of erroneously-labelled IAS in nurseries and the possibility of cross-contamination (seedlings which are not in the Catalogue but do carry IAS seeds or propagules in their branches or their root bundle). In addition, many IAS were previously classified simply as alien and have subsequently been labelled as invasive. The precautionary principle thus suggests that from the outset, all alien plants should be regarded as potentially invasive. Material to be used for revegetation should therefore be bought from native plant nurseries to prevent non-native species from being introduced either directly or indirectly.

In spite of all these preventive measures, the basic pillars of the struggle against IAS, they are still able to enter natural areas, making their active management essential as well. This management work includes early warning and rapid response, followed by treatment and eradication (Capdevila et al. 2006). The former initiative is addressed in Article 14 of Royal Decree 630/2013 of August 2, which regulates the Catalogue and establishes a Warning Network for monitoring invasive alien species, aimed at facilitating coordination and communication between the different administrative authorities, which must report on the appearance and detection of IAS in their respective territories. These administrations provide several tools (telephone, web forms) for citizens to report on IAS (Figure 3.12). Similarly, European Regulation 1143/2014 establishes a system of early detection and rapid eradication of IAS of concern to the Union.

The limited resources available and the varying degrees of aggressiveness and threat of different IAS make it necessary to define hierarchies for the identification and management of each species on the basis of their ecological, economic and health impact, their invasive potential and their difficulty to control. This facilitates the identification of species for which early detection and management are most important. In Spain, there is currently only one plan for IAS control and elimination for dune ecosystems, and a management, control and possible eradication strategy for Pampa grass (*Cortaderia selloana*) and other *Cortaderia* species. Regional governments are also designing specific programs for the eradication of various species. For transport infrastructure, IAS detection and management models must cover the full process, from the planning to the operative stages. The aim is to prevent the expansion of IAS associated with the infrastructure construction, while also implementing treatments to eradicate these species during the construction and operation phases and thus prevent their spread across the country via transport infrastructure corridors. This elimination process must follow the protocols for each species, since the same method is not always equally effective for different species and can sometimes even be counterproductive. For example, South African ragwort (*Senecio inaequidens*) invades grasslands and displaces the native flora to form a single-species blanket cover of all the available space. It thrives in sunny areas, making road and motorway verges its preferential propagation channels. To eradicate this plant and others like *Conyza bonaerensis*, mechanical control is required as it can be eliminated by regular soil tilling. The invasive action of other species such as Fountain grass (*Pennisetum setaceum*) and Pampa grass is largely dependent on their great seed production, and standard verge mowing exacerbates its capacity by dispersing its seeds even further and aggravating the invasion.


Si descubres una especie invasora...

¡¡ Red de ALERTA !!

ESPECIES INVASORAS

FAUNA AUTÓCTONA EN PELIGRO

¡Las especies invasoras son un problema de todos y su colaboración es fundamental!

¡Colabore con nosotros y avísenos si detecta cualquier especie invasora en el medio natural!

Para ayudarle a localizar el sitio de avistamiento puede utilizar MapsLive, GoogleMaps, IDE o el SIGPAC:

Nombre:

Apellidos:

Email:

Teléfono:

Datos de avistamiento:

Localidad:

Paraje:

Coordenadas UTM: Coord X:

Coord Y:

Especie observada: Agrio, vinagrera (Oxalis pes-caprae)

Huso (29 ó 30):

Datum: WGS84

(Puede usar el SIGPAC para ayudarse en la localización de las coordenadas UTM)

Observaciones:

Adjuntar fotos: Examinar... Examinar... Examinar...

Borrar Enviar

Siquieres tambien puedes contactar por email en : invasep@juntaex.es

Figure 3.12. Standard citizen science form for observations of alien species, available under the Extremadura regional government's early warning network for biological invasions. The form (in Spanish) asks for a few personal details about the observer and location of the invasive plant. It also allows pictures to be uploaded.

3.8 Potentially hazardous species around verges

Roads and their verges are a habitat for some micro-mammals and arthropods, they are used as nesting and foraging sites by some birds, and road-kill victims are a food source for scavengers.

The use of roads by animals largely depends on their location, the design and maintenance of the verges and the traffic intensity. Differences in verge mowing frequency and the chosen type of vegetation cover in relation to the surrounding environment influence the nature of the impact of roads on bird, insect and mammal populations. Similarly, the traffic volume on a road can shape its use by different species. Raptors, for example, exhibit seasonal activity patterns associated with this factor (Bautista et al 2004). Other species like foxes and wolves also use roads, especially less frequented ones, to move more easily around their territory. Bats often hunt on roads which run through forests because they are vegetation-free spaces that facilitate their activity. Although some animals use road and their verges in different ways, it is important to remember that most species perceive them as inhospitable habitats which act as barriers to their movement.

Red fox using a road to move more easily. Photo: Jacinto Román.

Sometimes, when the surrounding habitat has been profoundly disturbed, e.g., the vast croplands in central and southern Iberia, road verges contain remnants of native vegetation, an important source of biodiversity in the landscape, especially in areas with little traffic. In such cases, roads play a major role as corridors. The Cabrera vole (*Microtus cabrerae*), an endangered species in Spain, is one such case. It lives in tall, moist pastureland. In areas with a heavy herbivore stocking density, its population is often constrained to roadsides whose perimeter fencing keeps the tall grass livestock-free.

It is important to note that the use of road verges by different species is not necessarily due to an intense attraction to such areas, but rather to differences in the availability, quality or permanence of various resources in relation to the surrounding landscape and the effect of predator exclusion. The proliferation of the European rabbit (*Oryctolagus cuniculus*) along transport infrastructure corridors is mainly found in farming environments because when the fields are ploughed, the verges act as refuges, the only areas with predictable food, water and stable, moist soil (Figure 3.13). They are also frequent in urban and outer-suburban environments, again because they are the only places with available resources. Differences in abundance along different verges mainly depend on variations in these resources along the edge of the infrastructure. When roads run through heavily humanized landscapes such as Spain's northern plateau, the abundance of rabbits seems to depend much more on road-specific features such as the width of the verge than the surrounding land (Planillo and Malo 2018), a pattern observed in other countries as well.

Most of the species attracted to roads are not problematic apart from the collision risk (see Section 3.9). Nevertheless, some species are favoured by the verges and begin to inhabit them, compromising the stability of the infrastructure in the case of rabbits, voles (genus *Microtus*, primarily *M.*

arvalis) and the invasive muskrat (*Ondatra zibethicus*), which can cause serious damage to roads and embankments. These species share several ecological features which help to understand the problems they cause and their possible solutions: 1) they are prey species, 2) they inhabit subterranean tunnels which they dig themselves and 3) they can form high-density populations.

Embankments built in Spain's Mediterranean environments on unconsolidated material are quite vulnerable to water erosion due to the local climate and their physical properties, which makes their restoration quite difficult and aggravates the impact of burrowing fauna. This is especially important along railway lines with steep embankments which are more vulnerable to excavation and are very attractive for rabbits.

Figure 3.13. Rabbit burrows on a railway embankment. Photo: Jacinto Román.

3.9 Attracted species with high casualty rates

Road collisions are one of the major direct causes of animal mortality linked to human activity. Rates are particularly heavy in the case of insects, amphibians and reptiles, but equally high for scavenging birds and medium to large-sized mammals. Most studies classify this impact as part of the barrier effect of the infrastructure, given that the infrastructure hinders or blocks movements by individuals and fragments their breeding populations, reduces or prevents genetic exchanges between them, thereby increasing the risk of local extinction for each of the sub-populations resulting from the fragmentation effect of the infrastructure. Even when the impact on their mortality rate is not high, many species change their behaviour near roads, and cases have been reported in which, over time, individuals learn to avoid both collisions and human activity in general, modifying their spatial and temporal patterns. For some species, these changes are a major source of stress which alters their essential survival parameters.

Animals access roads which run through their habitats and their dispersal and migration routes, leading them to easily stray onto them when moving around in search of food or towards their overwintering or breeding areas. To avoid this situation, it is necessary to identify the factors which increase the risk of fauna collisions such as the presence (even ephemeral) of water bodies in the environs of the road and the dispersal and foraging patterns of the potentially involved species, since many studies have found that these spatial and temporal patterns influence the casualty rates. The correct planning and location of fauna crossings is also important, bearing in mind the collision patterns found and their expected risk (MAGRAMA 2015).

Animals can also be attracted by resources associated with the presence of roads, such as asphalt used as a heat regulation device by reptiles (Figure 3.14) or habitats resulting from verge revegetation, often the only habitat available for some species. In addition to the above-mentioned example of the Cabrera vole, forest and shrub-dwelling species can be attracted by trees and shrubs planted along verges which do not exist elsewhere in the vicinity. Dead animals on roads (from insects to large vertebrates) can attract other animals which feed on these resources. Similarly, in winter, road salt can attract medium and large-sized herbivores, especially during the antler growth phase. Finally, road lighting can be a powerful source of attraction for nocturnal night butterflies, ephemerals and other insects, as well as their predators (see Section 3.1).

Figure 3.14. Ocellated lizard (*Timon lepidus*) run over in Aznalcázar (Seville). Photo: Jacinto Román.

4 Technical guidelines

4.1 Scope and extent of guidelines

Transport infrastructure has a greater effect on biodiversity in places where the biological component is also greater. The presence of infrastructure in the vicinity of priority habitats or catalogued species makes them more sensitive to its effects. In this chapter, the importance of applying the guidelines and suggestions listed in the fact sheets (Section 4.3) is therefore emphatically recommended in zones designated as environmentally sensitive areas. These areas are part of the Green Infrastructure network which includes at least:

- Protected natural areas.
- Natura 2000 Network.
- Other areas of major natural value.
- Ecological corridors, both riverbanks and others identified as such.
- Areas which affect listed sensitive species.

Many of the following recommendations are also useful in populated areas, since humans also suffer from the effects of transport infrastructure in a similar way to many other mammals.

4.2 General considerations

The technical guideline sheets (Files) contained in this document are drafted for the planning, design, maintenance and operation phases of linear transport infrastructure. Their use does not, however, obviate the need to consult information from more recent sources and legal requirements defined by legislation in force concerning such infrastructure and the environment. We therefore strongly recommend consultation of current conservation strategies and their most recent updates at both the national and regional levels. These include catalogued species, invasive species, green infrastructure strategies and climate change strategies, amongst others. The complexity of the issues that need be addressed, as well as the shared responsibility between different administrations and between departments under any one administration makes it important to ensure coordination between administrations with different responsibilities concerning any particular issue and other related issues.

4.3 Guideline Files

File 1: LIGHT POLLUTION

File 2: NOISE POLLUTION

File 3: POLLUTANT DISPERSAL

File 4: FIRE IGNITION AND SPREAD

File 5: HUMAN PRESENCE

File 6: WATER RUN-OFF AND MANAGEMENT

File 7: ESTABLISHMENT AND SPREAD OF INVASIVE ALIEN SPECIES

File 8: POTENTIALLY HAZARDOUS SPECIES AROUND VERGES

File 9: AVOIDANCE OF ATTRACTION TOWARDS ROADS

Preventive measures (non-installation of artificial lighting, removal from unjustified points, intensity reduction and shortened or interrupted operating times at or after certain times) generally have a greater positive effect than any other potential mitigating action.

Planning

- Study and take into account any potential light pollution issues during the route planning phase, particularly with respect to the distribution of environmentally sensitive areas (see Section 4.1). Defragmentation priority areas must also be taken into account (see Technical Prescriptions, File 6, MAGRAMA 2013, and other references).
- Take the necessary steps to install lights outside environmentally sensitive areas (Royal Decree 1890/2008 of 14 November and Circular 36/2015 on Criteria for Lighting Open-air Roads and Tunnels, Volume 1), given the importance of interchanges and junctions in decisions made on artificial lighting for roads.

Design and construction

- Circular 36/2015 stipulates that the criteria for the lighting source on a section of road must be:
  - *Highways and motorways:*
    Lighting is justified if the road runs through urban land (both verges), concurrently with one of the following circumstances:
    - Average daily traffic intensity (ADI) equal to or above 80,000 vehicles/r a (ADI ≥80,000 vehicles/day).
    - ADI ≥60,000 vehicles/day and over 120 rain days per year.
  - *Conventional roads:*
    Normally unlit, although lighting may be justified in an accident-prone section (APS) where over 50% of accidents in the last two years have been at night.
  - *Special points:*
    Lighting is justified at special points in the following cases:
    - Roundabouts on conventional roads with heavy traffic density or danger where correct signposting and marking is insufficient.
    - Link roads in interurban zones with ADI ≥80,000 vehicles/day.
    - Links located in interurban areas with ADI ≥60,000 vehicles/day and over 120 rain days per year.
    - Roundabouts and intersections with ADI ≥10,000 vehicles/day, or APS where over 50% of accidents in the last two years have been at night.

- In such cases, the type of road lighting must match as closely as possible the zoning scenarios set out in Royal Decree 1890/2008, summarized below in Table 4.1, and the Complementary Technical Instruction of the Ministry of Industry, Energy and Tourism on lighting levels and any regional-level recommendations (e.g., the Catalonia Environmental Lighting Decalogue).
- The broad recommendation is to dispense with artificial lighting unless one of the above-mentioned assumptions, normally set on the basis of road safety criteria, is applicable. Whatever the case, it is preferable to increase the provision of passive lighting elements (reflective signage, beacons, headlight capture, markers, cat's eyes) or their intensity as an alternative to lighting. Where it is not possible to dispense with lighting, appropriate measures shall be taken to minimize its impact on the environment:
  - Lighting should only be projected onto the surface that has to be lit, following the *utility criteria* or the *sustained use factor* (IAC 2018), in order to reduce night-time glare and light leakage away from the road. The light source must never be the globe type.
  - The luminance-illuminance ratio (L/E) must be considered in the assessment of different lighting solutions with a view to minimising the luminous flux that is projected skywards.
  - Wherever possible, use devices to regulate the light intensity and programmed interruptions (daily or seasonal, as required).
  - Take care with the position, focus and direction of lighting devices. Prevent direct vision of the light source wherever possible. Direct lights downwards, not upwards, with suitable optical systems, deflectors and shields where appropriate to prevent dispersal of the light beam and thus mitigate intrusive light.
  - Floodlights should be asymmetrical as they increase the lighting level and uniformity in comparison with symmetrical floodlights. Alternatively, install shields on symmetrical floodlights to prevent glare and light emission outwards towards the horizon, and minimize the light flux which is wasted when not focused on the area that has to be illuminated.
  - Use a lower late-night emission cycle if possible (normally between 11pm and 5am, see Order 36/2015).
  - Use light sources which minimize the harmful spectrum for living beings. If this spectrum is unknown, emissions below 500 nm should generally be avoided. In environmentally sensitive areas, emissions below this threshold must not exceed 1%.

- Examples of these guidelines are available at the Sky Quality Protection Office of the Canary Islands Astrophysics Institute website (Figure 4.1.2), with technical guidelines for outdoor lighting and a list of technical specifications for lights, lamps and floodlights certified by the Institute (http://www.iac.es/servicios.php?op1=28&op2=69).

Operation and maintenance

- Design monitoring protocols for the detection and correction of potential issues.
  - Environmental monitoring for potential effects is necessary, especially in Zones E0 and E1 (dark zones and countryside, see Figure 4.1.1). Pay special attention to potential episodes of mortality, mass attraction, disturbance of interactions amongst species or ecosystems and any other episode directly caused by lighting. Pioneering studies in this field use invertebrate fauna biomass as a bioindicator. Include other fauna or flora groups in the bioindicator system if they are found to be particularly affected by issues related to outdoor lighting. Identify the affected species (or groups of species if the individuals cannot be identified) in order to apply corrective measures, paying special attention to endangered-list species.

    Environmental monitoring must include the identification and location of light sources that are incorrectly designed, badly placed or have inappropriate lighting (intensity, spectrum, etc.), and others which must be removed due to their low utility or high impact.
  - Design seasonal measures to prevent potential effects of artificial lighting during critical periods of the relevant fauna and flora and their phenology (seasonal patterns), e.g., emancipation period and migration of juvenile Cory's shearwaters (see Rodríguez and Rodríguez 2009). Although these measures target particular species, in critical biological periods, the impact on road safety should be assessed as well. If road safety is not affected, the lighting should be removed permanently.

Figure 4.1.1. Information sign advising priority usage of short car beams near the Montsec Astronomical Observatory. Photo: DGQACC. Generalitat de Catalunya.

Table 4.1. Classification of zones protected against light pollution and criteria for installation of artificial lighting infrastructure (Complementary Technical Instructions, Royal Decree 1890/2008 of 14th November). Zone E0 data is based on information in CIE 150:2017. These zones must always be surrounded by Zones E1.

	Upward hemispheric flow	Vertical illuminance	Light intensity
Zone E0. Intrinsically dark areas and landscapes. UNESCO *Starlight* Reserves, *IDA Dark Sky Parks* and world-class astronomical observatories.	0	0	0
Zone E1. Dark areas and landscapes. National parks, areas of natural importance and special protection areas.	≤1%. λ > 440nm	2 lux	2500cd
Zone E2. Areas with little brightness or luminosity. Periurban and suburban areas of cities, undeveloped land, rural areas and sectors generally located outside urban residential and industrial areas.	≤5%	5 lux	7500cd
Zone E3. Areas with medium brightness or luminosity. Urban residential areas.	≤15%	10 lux	10,000cd
Zone E4. Areas with high brightness or luminosity. Town centres, residential, shopping and leisure zones.	≤25%	25 lux	25,000cd

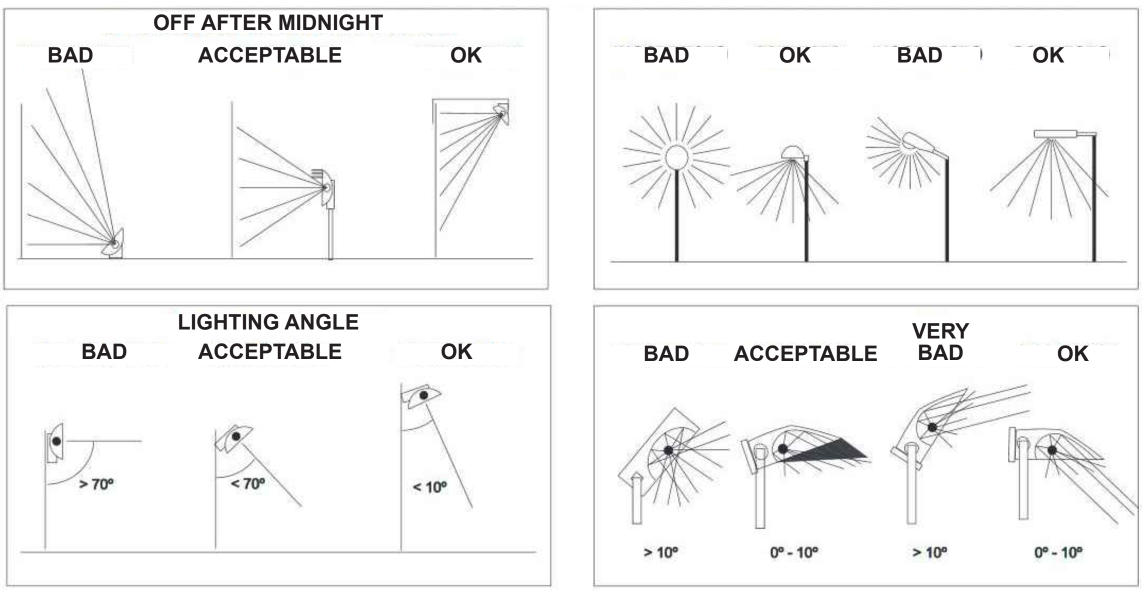


Figure 4.1.2. Basic guidelines issued by the Sky Quality Protection Office of the Canary Islands Astrophysics Institute for the use and correction of street lighting equipment. They are applicable to the design, installation and service phases.

Figure 4.1.3. General and detailed view of shielding options on a Barcelona motorway. It avoids the intrusion of light in areas near the infrastructure. Photo: DGQACC. Generalitat de Catalunya.

Figure 4.1.5. Example of peri-urban road lighting with globe street light fixtures, which shed light in every direction, thus decreasing illumination of the actual road. Photo: Government of Castilla y León.

Figure 4.1.4. View of yellow LED street light and near-zero skyward flux emission. Photo: DGQACC. Government of Catalonia.

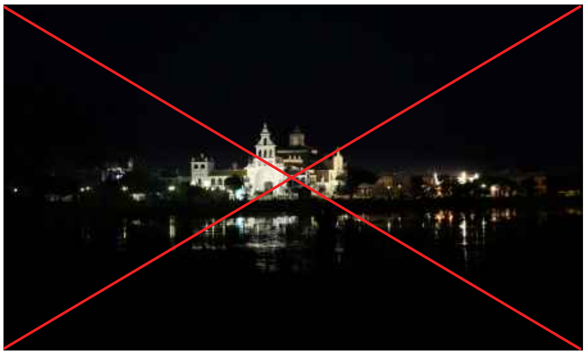


Figure 4.1.6. Light pollution across the northern boundary of Doñana National Park from nearby El Rocío township. Photo: Eloy Revilla.

It is hard to isolate the effects of transport infrastructure noise pollution from other effects. Nevertheless, we can assume that any locations, including environmentally sensitive zones (see Section 4.1), where the biotic component is most important are also highly sensitive to noise pollution.

Planning

- Identify environmentally sensitive areas during the alignment decision-making process. Strive to reduce the impact of noise pollution from the infrastructure in these areas, and measure the potential accumulated effect on both sides.
- Wherever possible, ensure that intersections, slipways and steep or long grades, points of frequent acceleration, are not near environmentally sensitive areas. Take into account the prevailing wind directions to avoid or reduce the spread of noise towards such areas.
- Alignments which converge with other infrastructure (impact concentration) are preferable to other options which generate a new source of noise (impact dissemination).
- Follow the provisions for noise pollution mitigation in natural resource management plans and other guidelines and plans for protected natural areas, along with indications for zoning and general regulations on public use.

Design and construction

Identify all areas requiring protection from noise pollution.

- Construction projects must also abide by the instructions contained in the relevant planning tools and environmental regulations.
- Given the lack of specific limits in the Noise Law for natural areas requiring special protection against noise pollution, the general rule of 50 dB as the most restrictive level should be applied. Nevertheless, experience with roe deer and black vultures suggests that even lower levels (between 30 and 40 dB) should be applied in such spaces (see Iglesias 2014).
- The following noise abatement methods must be employed (MAGRAMA 2013; Bendsten et al. 2017):
  - Sound barriers (10-20dB reduction).
  - Sound absorption panels rendered with porous concrete.
  - Vegetated panels, with soil to support the vegetation which in turn absorbs the noise projected directly onto it and also noise reflected by the sloping concrete backing on the upper layers.
  - Sound-absorbent concrete cladding with porous acoustic insulation, attached directly to structural elements of the infrastructure.

- Earthen ridges. Their effectiveness depends on their size. The advantage of these structures over other systems is that they permit the reuse of material from earthworks stockpiled during the construction phase.
- Noise-abatement pavements (2 dB).
- Lower speed limits. A reduction of 5-10 km/h reduces noise by 1 dB, while a 10-20 km/h reduction reduces noise by 2 dB.

Operation and maintenance

- Include the detection and correction of conflict points in monitoring protocols.
- Environmental monitoring must include checks on preventive and correction measures, the detection of unforeseen impacts and their correction, and noise abatement measurements for two years after the infrastructure comes into service.
- If the road is already in operation, use noise maps and action plans drafted by regional or provincial governments to identify locations with high noise levels in environmentally sensitive zones where the above-mentioned mitigation measures have not been implemented.
- Follow the recommendations in the latest planning tools or environmental regulations during the implementation of the above-mentioned measures.

Figure 4.2.1. Highway equipped with infrastructure noise abatement barriers. Subsequent landscaping has improved the aesthetics but has not improved noise reduction. Photo: Basque Government.

Figure 4.2.2. Conventional bridge replaced by a viaduct to increase the permeability of the infrastructure near Doñana National Park. Unfortunately, the option of sound absorption panels was not contemplated. Photo: Jacinto Román.

Planning

- Identify environmentally sensitive areas (see Section 4.1), with a special focus on wetlands to reduce future effects from pollutants dispersed from the infrastructure. In such areas, avoid the location of intersections and slipways, steep or long embankments wherever possible. Take the impact of the prevailing wind into account to avoid the dispersal of gases towards these sensitive areas.

- Reduce the influence of winter snow and ice (e.g., use sunlit mountainsides) in the design of roads in mountain areas in order to minimise the need for road salt. Also consider the fire hazard and pertinent preventive measures (see File 4).

Design and construction

- Some general measures which can reduce the impact of construction activity on air quality include:
  - Compacting all service road surfaces and maintaining them in good condition.
  - 20 km/h speed limit in works areas.
  - Vehicle cleaning systems, especially for wheels, to prevent the transportation of adhered matter.

There are different types of pollutants:

- *Aerosols*:
  - Air quality near a road depends on two physical mechanisms: pollutant dispersal and deposition. The latter is associated with the presence of vegetation. Wherever possible, consider a reduction in the speed limit in the road design as a way to reduce pollutant emissions, particularly in environmentally sensitive areas. Where the distance between the roadway and the perimeter fence permits revegetation in the outermost part of the verge, aim to build up a broad barrier of vegetation with a high leaf density. This model significantly reduces the dispersal of contaminants into the environment and increases their deposition (Tong et al. 2016, see Gheorghe et al. 2011). Nevertheless, it is important to comply with road safety regulations as well as recommendations aimed at preventing accidents and fire proliferation (see Chapters 3.4 and 3.9).
  - Program regular checks on internal combustion engines and exhaust pipes of machinery and transport vehicles.

- *Dust:*
  - Material must be covered with canvas during transportation to prevent it from being scattered by the wind.

- Tracks used by vehicles during construction must be watered to limit the volume of dust particles. The water should be free of contaminants, pathogens and invasive alien species.
- Elements on the construction site which may release dust (conveyor belts, elevators, screeds, classifiers, etc.) must be covered.

- *Liquids:*
  - Culvert outlets should flow into zones with no impact on fauna, flora or aquifers, and under no circumstances into running or dammed water. Alternatively, the liquid must flow into retention structures for subsequent treatment (see File 6).
  - In areas where road salt is often used, especially in environmentally sensitive areas (see 4.1), these liquid retention structures should also limit the release of the salt into the environment (channels and holding tanks, sand traps, physical filters, plant filters, etc.; Fay and Shi 2012). Proper maintenance of these structures includes the corresponding treatment (coagulation, flocculation, filtration, etc.), and also the removal and transfer of sludge to authorized landfills in accordance with the regulations in force.
  - Geothermal energy should be studied (Balbay and Esen 2010) as an option to prevent ice formation in zones with frequent ice cover.
  - In environmentally sensitive areas at least, pavements that absorb some pollutants such as nitrous oxides (mineral polymers, photocatalytic nanocomposites and specific bituminous mixtures) may also be considered (e.g. Ballari and Brouwers 2013).

Operation and maintenance

- *Aerosols*
  - Speed restrictions generally decrease pollutant emissions. This may be useful in environmental hot spots or sensitive areas. Correct maintenance of the road, especially the surface, also helps to prevent increased pollutant emissions (Condurat et al. 2017)
- *Liquids*
  - Preventive measures (agents that prevent or reduce road ice) are more effective than reactive measures (e.g., road salt) for limiting the concentration of run-off substances (Fay and Shi 2012). Pollutant input to the environment via run-off is significantly reduced by such measures in combination with structural measures installed on the infrastructure (channels and retention ponds, sand traps, filters and plant filters; see Design and Construction, below).

These structures must be checked regularly to prevent clogging and remove pollutants in accordance with the procedures defined by the regulations in force. In areas with a high probability of snow, signposts recommending winter tyres should be installed.

- Optimize the amount of road salt discharged into the environment. Salt-dispensing vehicles must be equipped with sensors to detect the amount of salt already on the road. Alternatives to pure salt include calcium-magnesium acetate, magnesium chloride), brine, combinations of the above with solid particles (sand, ash), additives from industrial food waste and a number of experimental products. However, some of these additives have been found to have harmful environmental effects (Schuler et al. 2017), and thus require careful analysis prior to their use as an alternative to common salt.

- Directive 2009/128/EC of the European Parliament and the Council and Spanish Royal Decree 1311/2012, of September 14 on the Sustainable Use of Phytosanitary Products prohibits the use of biocides of any type (herbicides, insecticides, rodenticides) on the verges of road and railway infrastructure. Other techniques must be used to manage vegetation along verges, such as mechanical clearing, grazing (see examples in the Netherlands and the USA; Hart 2001; Valladares et al. 2011), vinegar (Commission Implementing Regulation (EU) 2019/149) or water vapour, all of which are are more suitable for vegetation management along verges. Nevertheless, the presence of invasive species and plagues must be monitored as the protocols for their control may contemplate additional limitations or exemptions from the above-mentioned prohibitions.

Figure 4.3.1. Mechanically mown verge, clear of debris. Photo: Eloy Revilla.

Figure 4.3.2. Herbicide-cleared verge with discarded rubbish. Photo: Eloy Revilla.

This file should be consulted in combination with Section 4.1 to ensure compatibility with the Technical Prescriptions, File 1 (MAGRAMA 2015) on verges and revegetation.

Planning

Wherever possible, avoid routes through areas with a high fire risk, steep embankments or uninterrupted stands of forest.

- If such routes are unavoidable, identify and implement all necessary action to reduce the fire hazard and the vulnerability of the infrastructure's users, considering criteria which avoid or reduce the fragmentation of the traversed habitats.

Design and construction

- Firefighting water supply points must be in viable locations (verge and culvert outlets to permit damming), where access by fire trucks and aerial resources is facilitated (no power lines, posts or other infrastructure).
- Consider the vegetation combustion risk and flammability, and the continuity and surface area of surrounding forests in order to adapt the intensity and features of the prevention and correction measures to be applied based on the fire hazard associated with the road, also using the available information on meteorological risks and recurrence (Figure 3.6).
- Measures to be adopted in high-risk areas and forest sections (adapted from Mestres and Miranda 1997) include:
  - Build direct access routes for fire-fighting equipment, closed off to the general public, to expedite access to fires. These routes must not affect fauna crossings.
  - When building access roads to certain areas with high natural values and intense human pressure, consider their public closure during periods of high fire danger.
  - Design areas where fire hoses can be rolled out on verges and embankments, and facilitate access for fire prevention equipment.
  - In extreme fire hazard zones, verges must be made of cement or other types to prevent the growth of fire-friendly vegetation.
- The identification of the most suitable fauna crossings must also take the local fire risk into consideration. When planning the construction or installation of such crossings and their vegetation, consider the fire risk when choosing materials and the vegetation composition and structure. The use of fireproof materials such as rock, drywalls, concrete panels, gravel beds, etc. is particularly important in the case of ecoducts and also overpass structures.

Open zones in the centre of ecoducts (see MAGRAM 2015) can also act as firebreaks. This requires careful design and maintenance. The correct choice of options with the lowest fire risk (inert panels, rocks at the entrance of the ecoduct to stop vehicle entry, etc.) is also an important decision.

- Longitudinal culvert outlets can be used to fill troughs near fauna crossings (MAGRAMA 2015) and to water low-flammable plant species.
- Locate rest areas and other specific points along roads where users congregate (see File 5) in places with a low fire risk, with perimeter fences made of environmentally integrated materials, with maintenance treatments for their outer perimeters to act as firebreaks. If timber is used to build elements or buildings alongside the road, it must be fireproofed.
- Sections of roads running through high fire risk zones must be signposted as such.
- Revegetation design:
  - Use low-flammability native plants in ecological restoration work and revegetation (Elvira and Hernando 1989). Avoid plants with a high content in highly flammable volatile organic compounds and those which shed fine litter with a slow decomposition rate (e.g., conifers). Give a higher priority to species that hinder fire ignition and propagation. Suitable options include species with green leaves and a high water content in their tissue in summer, which produce a low aerial load of dead wood, plants with a compact structure, a low percentage of air with respect to combustible material (lower surface/volume ratio), and those which produce little fine litter and whose leaves and remains decompose quickly. Species with dense wood and a high caloric capacity, which need to absorb a more heat before igniting, can also be selected. Avoid annual plants which are easily ignited when dry wherever possible.
  - Adapt the vegetation structure (proportions of species in each layer: herbaceous, shrub or tree) along verges to the local fire risk. Prioritise combinations that generate a lower fire risk or facilitate the action of the infrastructure as a firebreak. If the verges are expected to act as active infrastructure (safe zones for firefighting equipment), they should tend to have open structures or be composed of low-flammability shrubs. This vegetation structure generally requires more intensive maintenance.
  - Minimise annual grasses in the herbaceous layer and encourage native plants with a lower flammability structure and ecological characteristics, e.g., crassulaceae, urticaceae, plantaginae, chenopods

and some papilionaceous plants. Crassulas are particularly drought-resistant and have a low nutrient demand. Herbaceous plants should be avoided because they dry out in periods of peak fire danger.

- Encourage continuity with the surrounding habitats. Only use native species from the local region, typical of the surrounding habitats, which fulfil the above-mentioned low-flammability requirements. Avoid flammable species which can contribute to fire propagation (e.g. conifers). Plan for additional measures such as clearing, grazing and reduction of both the horizontal and the vertical biomass In zones where these species are a genuine, characteristic part of the ecosystem.

- Firefighting infrastructure:
  - Install or supply firefighting infrastructure such as automatic detection and alarm systems, signs showing the current level of fire danger.
- Inter-administration coordination
  - Transport infrastructure plays a dual role in the fire prevention and extinction system as a firebreak and access route. Coordination between different levels of public administrations and their departments is therefore important to facilitate the establishment of firefighting water supply points using road culverts and surveillance points if road is located in a prominent place that is suitable for this purpose.

Operation and maintenance

- Specific coordination protocols between civil protection agency, public works, agricultural and forestry authorities are required for roadway management in the event of high-intensity fires, in order to reduce the risk of trapped vehicles with fatal consequences. Given the current projections of increased fire intensity due to climate change, these protocols should also cover large-scale infrastructure (primarily highways and motorways) which could become high risk areas in the event of traffic jams.
- Treatment of adjacent zones (public domain):
  - Implement measures on the basis of fire risk maps, seasons and habitats adjacent to the infrastructure.
  - Build a safe strip to allow the road to act as a firebreak. This buffer zone generally includes the public domain and the easements. Keep it free of flammable material, especially in the herbaceous and shrub layer, during fire danger periods.
  - When necessary, adapt the vegetation density along verges to the local fire risk in order to shape structural models that hinder wildfire ignition and thus create a firebreak as well. Forest fuel removal treatment must

be selective. Remove dry plants, those with a high proportion of dead biomass, plants which supply less nutrients and those which contribute less to avoid soil erosion, as well as the most flammable species. Respect plants with a greater water content during the dry season and individuals from catalogued species or considered unique. In leafy ecosystems, a good tree cover provides shade for the understory and hinders the growth of dry scrub and herbaceous vegetation which facilitates the ignition and spread of wildfires. These measures must never compromise road safety.

- In areas with high summer rainfall, where herbaceous plants along the verges maintain their moisture, we do not recommend mowing because this increases their flammability by removing the greenest part and helps to dry up the rest. Moreover, some clearing methods pose a fire risk.

- The optimum width of the firebreak depends on the nature of the pre-existing vegetation. Prune dry tree branches. Remove, bury or shred all pruned material.

- Plan for the maintenance of these firebreaks. Controlled grazing with temporary fencing along the verges for road safety purposes is generally a non-intrusive technique that stimulates natural values and has considerable social repercussions for the local area, does not generate plant remains which are a fire hazard, does not produce sparks and is highly effective in controlling the plant biomass of the understory. Nevertheless, the necessary steps must be taken to prevent livestock from acting as a vector for the spread of invasive alien species (see File 7).

- In cases where there is an extreme risk and other methods cannot be employed, the relevant authority may authorize prescribed control burns of herbaceous and dead wood by specialized staff.

- Keep automatic detection and alarm systems and wildfire warning signs and panels in perfect working order, especially in regular stopping points, service areas, etc. These signs must be permanent.

- Monitor the vegetation for changes which may lead to an increased fire risk in the area, especially on roads through large forests which may require additional fire prevention measures.

- During prescribed burns for infrastructure maintenance near roads, signposts must warn that these burns are not fires, in order to avoid saturating the emergency service call centres.

- Draft dissemination protocols for experiences with infrastructure maintenance near roads and their effectiveness, in order to help to plan maintenance treatment and define sensitive zones where more intensive maintenance is a priority.

Figure 4.4.1. Verge treatment involving mowing and ploughing to avoid wildfire ignition on a roadside. Photo: Jacinto Román.

Figure 4.4.2. Verge with uncut grass, a potential fire hazard. Photo: Jacito Román.

Planning

- Decisions on a new alignment must take into account any foreseeable human disturbance of environmentally sensitive areas (see Section 4.1), their zoning and describe guidelines in the corresponding plans.

Design and construction

- Wherever possible, locate points where roads are most frequented by humans (service roads, rest areas, winter road equipment depots, maintenance and operation centres, etc.) outside environmentally sensitive areas.
- Designate areas with a greater human use during construction (machinery depots, material storage and stockpiling areas, rest areas, borrow zones and any other auxiliary infrastructure, whether temporary or permanent) in areas of low natural value and far from wildlife crossings.
- When designing solid waste containers in service areas and rest areas, plan for the potential presence of scavenging fauna (foxes, wild boar, bears, etc.) to prevent these species from raiding them (raised containers, metal barriers, etc.).
- In service and rest areas, install warning signs about forbidden action such as rubbish dumping, lighting fires, harm to the surrounding fauna and flora, etc.

Operation and maintenance

- Once in operation, rubbish collection and handling should be carefully planned in areas frequented by road users to avoid litter build-up, especially where it might be scavenged by wildlife.
- Identify lookouts, car parks, rest areas and other roadside areas under major anthropic pressure, particularly those in service but also planned zones. If they are in or affect environmentally sensitive areas, relocate and restore them to minimise this impact. Consider their temporary closure if they are affected in certain period (e.g. during the breeding season).
- Design monitoring protocols to detect these hotspots, ranking them according to their impact and then relocating them to less sensitive locations. Their access from the road must then be blocked and restored with a low impact on the surrounding areas, e.g., limits on the use of heavy machinery, avoid work during the breeding season of sensitive fauna, revegetation with local species, removal of waste material generated during restoration, etc.

Figure 4.5.1. Parking zone in Ponga Natural Park (Asturias), used to manage human traffic at one of the park entrances. Environment-friendly building material was used and seeds from local species were collected for replanting. Photo: Principality of Asturias Government.

Figure 4.5.2. Unregulated parking in the Pyrenees (Huesca) resulting in dispersed human presence and potential effects on the local fauna and flora. Photo: Eloy Revilla.

Planning

- New alignments must generally minimise the interception, build-up and diversion of run-off generated during the infrastructure construction phase. Run-off must be evacuated spatially and temporally to increase infiltration and prevent erosion.

Design and construction

- Run-off from roads must be redirected and not flow directly into environmentally sensitive water bodies. In terrestrial environments, discharges must flow into zones with a good plant cover to prevent soil erosion. Revegetation of run-off channels helps to reduce velocity and thus minimize the potential erosion. Alternatively, install special treatment devices (temporary settling or retention ponds, stormwater tanks, earthen or gabion dykes, filters and infiltration systems) as a buffer for flood peaks to prevent breaches, sudden clogging and the degradation of the surrounding habitat.

- Integrate these measures to the greatest possible extent with others proposed in this document such as drainage channel diversion to irrigate vegetation screens, storage for use by fire fighting vehicles or new fauna watering holes in the vicinity of wildlife crossings. Drainage channels should not run towards embankments without protection against water erosion (Martin-Duque et al. 2011).

- All structures associated with run-off must be compatible with the measures set out in Technical Prescriptions, File 1 (MAGRAMA 2015). For example, they must not act as traps or barriers to fauna movements, and must include escape ramps to assist any fauna that may fall into them.

Operation and maintenance

- Make regular checks on the structural and functional state of the elements which comprise the road, both longitudinally and transversally. Check them to ensure that they are used exclusively for the road, that there are no gaps in them, and that they have the appropriate dimensions for the size of the road and the prevailing weather conditions. The environmental considerations described in "Design and Construction" to prevent effects on the surrounding environment are applicable here as well.

- Once in operation, design up-to-date protocols for the infrastructure in the event of spillage from the infrastructure as a result of accidents or breakdowns. These protocols must plan for every type of spillage that may occur (fuel, oil, detergent, etc.).

- When direct spillage into environmentally sensitive areas is detected on roads in operation, consider channelling the flow into less sensitive areas or implement special devices which hold back the run-off water or accidental spillage to permit its correct treatment.
- Check structures associated with run-off and water management to ensure that they do not act as traps or barriers to the free movement of fauna. If they do, implement corrective measures, as set out in Document 1 of the Technical Specifications (MAGRAMA 2015).

Figure 4.6.1. Run-off channelled by a gutter into a drainage system. Photo: Ministry of Public Works

Figure 4.6.2. Culvert between two roads. A trap with no escape for small animals. Photo: Carlos Rodríguez.

Design

- Due to the major implications for the subsequent construction and operation phases (see below), it is important to check for invasive alien species (IAS) and report their location during the detailed alignment design phase.

- Revegetation design and species composition:

  - Use native species in the design of embankment revegetation. Consult publications which comply with current regulations (since Law 42/2007, of 13 December), given that classic catalogues and manuals for revegetation species selection, written prior to the consideration and definition of IAS, are still in circulation.

  - If IAS are detected during the design phase, take note of their location and define the necessary treatment to eradicate individuals and their propagules, along with subsequent treatments once the plants have sprouted or emerged. Include their eradication from the infrastructure and its verges in the works budgets. The eradication of IAS specimens as defined by law is compulsory for all public and private landowners. The different administration bodies and individuals involved should therefore coordinate their efforts to eradicate IAS specimens found in and around the infrastructure. Otherwise, specific eradication work done on an individual basis by each party may well be extremely inefficient if specimens are left in nearby locations and act as sources of new propagation. This work, done beyond the specific area of the infrastructure can be contemplated as an additional coordinated action for the various parties involved. IAS should be removed by specialists in compliance with protocols in force, with authorisation by the relevant environmental administration.

  - Verge and embankment designs which are compatible with equipment access facilitate eradication work on IAS. This is particularly important in large areas that may contain large populations of invasive species.

  - Purchase seedlings and seed mixtures for replanting from native plant nurseries, found in every region, under either public or private ownership. The following criteria are recommended for the selection of species (Valladares et al. 2011):

    - Native species.

    - From nearby locations.

    - Species which enhance continuity with the surrounding landscape, especially in cases where there is an adjacent reference of wild vegetation cover.

- Wildfire prevention is another criterion to consider in revegetation, given the importance of species composition in fire behaviour (File 4).

- Only sow and plant in the most favourable period in order to minimise failures. If the number of plants needed for the infrastructure is expected to be high, inform the supplier in advance to ensure that enough plants are available.

- Respect any limits on the spread of pathogens under local, regional and national legislation in force, primarily concerning *Phytophthora cinnamomi*, *Xylella fastidiosa* and *Erwinia amylovora*, along with new pathogens considered likely to emerge.

Construction

- Treatment of soil and verges to prevent the establishment of invasive alien species:

  - The dormant seed bank in the subsoil is an extremely valuable resource for verge revegetation. However, due to the potential presence of invasive alien species, this soil and borrow stockpiles require treatment to prevent the establishment of such species in the new infrastructure. This will depend on the identified species (see following sections), as simple soil tilling often prevents their consolidation. The viability of many treatments and their effectiveness are both greater during the construction phase because they are implemented early in the process and there is still no public use of the infrastructure. The construction period is therefore the recommended time for IAS treatments.

Operation and maintenance

- If grazing is used as part of the biomass clearing and control work along verges (see File 4), ensure that the animals are from IAS-free areas. In case of doubt, stable herds for at least three days (Frost et al. 2013) to ensure that they do not disperse viable IAS seeds.

- In addition to the preventive measures taken during the design and construction phases, plan for the potential input of IAS or their prior existence on infrastructure already in use, and assess their danger and the need for early response. On the basis of these parameters, decide on the treatment(s) recommended for their removal. The national management strategies, the National IAS Inventory and regional and provincial authorities can all supply examples of treatments and practical recommendations for almost every IAS.

  The following general recommendations cover the treatment or eradication of IAS:

  - Fast action is of vital importance in the case of Pampa grass (*Cortaderia selloana*), subject to a management, control and eradication plan, since the eradication of adult specimens is costly due to the vigorous growth of both the aerial and the subterranean parts, its great capacity for regrowth and the dispersal of its seeds during handling. In this and many other cases, rapid action facilitates the manual removal of young specimens and obviates the need for mechanised work (not always feasible) and other difficulties associated with the size of the specimen. In general, early detection and action are our best allies in the fight against these species, as many of them are hard to eradicate once they form stable populations in a given area. Always refer to the most recent editions of the documents accompanying the Catalogue of Invasive Alien Species, since the list of species and the management recommendations are updated regularly.

- Some of the most common species and their known treatments are listed in the Appendix to this document. Experiences in the eradication of South African ragwort in the Port Bou range (Girona), for example, have been documented, including details of the best combination of mechanical and chemical methods in a relatively large area (Rojo et al. 2009).

- Nevertheless, the highly specific nature of the treatments and the ongoing results of new experiences in IAS eradication (including biological control) prevent this document from providing more detailed information for the treatment of IAS. It is important to consider that the use of standardised methods may aggravate rather than mitigate the problem. This is the case with Purple fountain grass (*Pennisetum setaceum*) and Pampa grass, for example. Their aggressive dispersal capacity is aggravated by brush cutting during their seed propagation period.

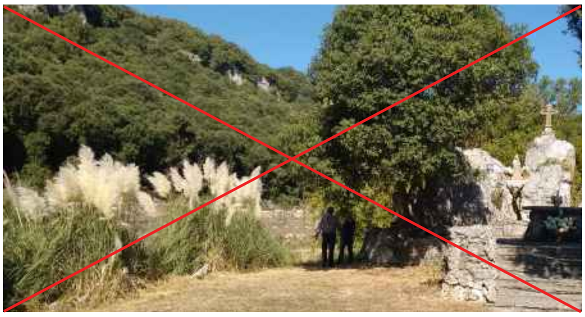
- Eradication treatments are rarely fully effective the first time round, and need to be repeated several times until the invasion is considered to be beaten. Regular monitoring of the treatment locations is therefore necessary. A combination of eradication methods (e.g., mechanical and chemical) often improves their effectiveness. Regulations governing the use of chemical treatment agents (Royal Decree 1311/2012 of 14 September) and potential effects on the surrounding land which might prohibit their use (e.g., near waterbodies) must therefore be heeded.

- Avoid plant reproduction periods, when handled plants can scatter seeds and propagules. Take particular care with thorns and stinging appendages on some of these species, which oblige operators to use the corresponding personal protection equipment (PPE).

- Although aquatic IAS are not normally in area affected directly by transport infrastructure, they deserve a mention in this chapter (see also the Appendix) as they usually have a much greater dispersal capacity than terrestrial species. Efforts to limit their expansion are therefore crucial to prevent an invasion from becoming unmanageable. For this reason, appropriate steps should be taken to eradicate IAS from any waterbody related to the infrastructure (drains, pondage of any kind, etc.) to prevent the IAS in question from entering natural waterbodies in the area.

- Hiring staff with botanical training to join the work teams is of great help, particularly in detecting and identifying the presence of IAS, a fundamental part of the design, construction and operation phases of the infrastructure.

Figure 4.7.1. Rest area on the A-5 motorway, where pre-existing stands of native species have been preserved. Photo: Carlos Rodríguez.



4.7.2. Recreation area on NA-7135, where invasive alien species including Pampa grass have been planted. Photo: Government of Navarre.

Table 7.1. Summary table of recommendations for invasive alien species during the infrastructure design, construction and operation phases.

PHASE	ACTION
Planning and Design	1. If the presence of an IAS along the route is detected or known, inform the relevant authority and take its location into account in order to assess alternative options to stockpiling earth in the area, as well as treatments for the zone in the following phases if necessary. 2. Ensure that no IAS is accidentally introduced when replanting verges (Spanish Catalogue of Invasive Alien Species). 3. Use native and local plants and seeds. 4. Use the natural environment as a reference when choosing species for reforestation. The local seed bank in the stockpiled subsoil may be used if no IAS are present.
Construction	1. If the presence of an IAS is known (detected during the alignment planning phase or during construction), remove and destroy the whole plant, using auxiliary machinery which may be on hand. 2. Report to the competent authority about the presence of the IAS. Include treatment in the following stages, if necessary.
Operation: new infrastructure	1. If the presence of an IAS is known (detected or previous treatment during the construction phase or once in use), remove and destroy the whole plant. Include this and other treatments employed in previous phases in the vegetation maintenance protocols for verges. 2. Pay particular attention to the presence of aquatic IAS in drains or ponds of any kind. Inform the competent authority about their presence and take action to contain them within the structure and treat them specifically as quickly as possible. If the presence of an IAS is detected, report it to the competent authority.
Operation: pre-existing infrastructure	1. If the presence of an IAS is detected, report it to the competent authority. 2. Remove and destroy the entire plant manually, including both its aerial and buried parts, if permitted by the spread and growth of the individuals. 3. If the spread and growth of an IAS individual does not permit manual removal, design a plan for the eradication of any IAS along the route and in the surrounding land. Coordinated action with the competent authorities on the whole territory involved is the only efficient way to combat the invasion. 4. If an aquatic IAS is present in culverts or ponds of any kind, inform the competent authority about its presence and take steps to contain it within the structure and treat it specifically as soon as possible.

This file focuses on rabbits and other burrowing mammals which use verges and embankments as a breeding habitat and damage the infrastructure. Although many micromammal species with digging habits live along infrastructure verges, they are unlikely to damage the infrastructure due to their small size. In these cases, no action of any kind is necessary. This is the case with voles in the genus *Microtus*, some of whose species are listed as endangered. The Cabrera vole (*Microtus cabrerae*), for example, often lives on road and track verges with tall herbaceous vegetation. Pay careful attention to its presence and avoid the destruction of its habitats and the populations which live along these verges.

Design and construction

- Identify potentially problematic sites on the basis of the features of the infrastructure (zones where mammal digging may pose a threat) and the environment (mainly along sections that run through farmed environments with no patches of natural vegetation and roads with average traffic intensities). Action in these areas is only necessary by means of:
  - Embankment design:
    - Prevent external run-off from flowing towards embankments. Increase their roughness. Inward run-off flow can be reduced by means of perimeter ditches, conveniently channelled by gutters designed to dissipate the energy channelled towards the drainage system. Increased slope roughness encourages water filtration and the collection of seeds and nutrients. These measures accelerate the embankment's revegetation and gives it more consistency (Martín Duque et al. 2011), thus reducing the potential impact of rabbit burrowing on the infrastructure.
    - Consider machinery access to facilitate burrow clearing and removal work in the design of verges and embankments, especially for large-scale ones.
    - Install fences and other systems that hinder access by mammals to platforms with perimeter enclosures (MAGRAMA 2015). Whenever possible, install the perimeter fences as close as possible to the roadway, never more than 10 m from the edge (Planillo and Malo 2018). This measure applies to all new roads with perimeter fences. We recommend 3 x 3 cm hexagonal triple chain-link fencing, rising at least 60 cm above ground level, installed on top of the pre-existing mesh. It is particularly important to bury part of the fence (see MAGRAM 2015). Recent experience shows that in some cases, it should be buried up to 50 cm to achieve the desired effect. Do not leave gaps

at intersection points with verges, pipes, culverts, etc.

- Soil and verge treatment:
  - In areas identified as potential burrow conflict points for the infrastructure and where the fence cannot be less than 10 m from the edge, reduce the vegetation cover as much as possible or lay substrates that prevent or hinder burrowing.

Operation and maintenance

- Embankment modification:
  - Program regular mechanical mowing of the herbaceous vegetation along verges during periods of vegetative growth (autumn and spring in south; spring and summer in the north), to reduce food availability. Remove any existing burrows mechanically by ploughing and then compacting the soil.
- Capture and translocation:
  - If potentially troublesome colonies are detected, remove the rabbits manually with traps and release them in habitat patches some distance away (less than 5 km) from the infrastructure. Respect the legislation in force in each region, which vary in the type of authorised capture methods, as well as the handling of captured individuals.
- Fencing and other systems which hinder access by mammals to transport infrastructure with perimeter enclosures (MAGRAMA 2015):
  - Install 3 x 3 cm hexagonal triple chain-link fencing to a height of at least 60 cm above ground level. It is especially important to bury part of the fence. Recent experience shows that in some cases, the base should be buried up to 50 cm to achieve the desired effect (see MAGRAM 2015).
- Regular checks:
  - Check for new rabbit colonies along the verges at least once a year, and assess their potential effects on the infrastructure.
  - Also include a regular check (annually at least) on the state of the fences to detect their potential loss of effectiveness.
- Coordinate work by different administrative authorities on the affected land in order to implement any action jointly and thus increase the effectiveness of the adopted measures.

Figure 4.8.1. Rabbit burrows on motorway embankment Photo: Government of Navarra.

Figure 4.8.3. Example of poorly designed gate in a fence which cancels out the effectiveness of the rest of the measures (buried mesh, double fencing) aimed at keeping rabbits out of a railway embankment. Photo: Carlos Rodríguez.

Figure 4.8.2. Road verge with perimeter fence more than 10 m from the roadway in a farmed area. Although rabbits will probably settle here, no impacts on the infrastructure are expected. Photo: Ministry of Development.

Figure 4.8.4. Burrows between fence and railway tracks. Although the fence is correctly installed around the culvert, gaps (see Figure 4.8.3) probably facilitated access by animals. Photo: Carlos Rodriguez.

Planning

- Infrastructure alignment planners must maximise efforts not to fragment forest patches, wetlands or any other sensitive habitats. They must carefully avoid the interception of migratory routes and dispersal of animal species present in the area.
- Consider increasing the nesting substrates of pollinating insects between crops and roads with little traffic in order to avoid negative impacts on these insect communities (TEA 2019, Sánchez et al. 2014).

Design and construction

- Installation of perimeter fences less than 10 m from a road reduces the likelihood of rabbit colonies (see File 8) in areas (generally farms) where the verge is a resource (permanent layer) that they lack outside it. Install perimeter fences as close as possible to the outer edge of the graded zone in areas where the stability of the infrastructure may be compromised and which converge with farmland.
- Follow the prescriptions set out in Guideline File 1 on road lighting to reduce harmful effects on biodiversity and avoid mass attraction of insects and the bats that feed on them.
- Vertical warning signs mitigate collisions (D'Amico et al. 2015) but they do not prevent attraction to the road, presumably used as a heat-regulation device by cold-blooded animals such as reptiles. Their installation is nevertheless recommended wherever the road runs through environmentally sensitive zones and collision hotspots.

Operation and maintenance

- Frequent verge mowing or brushcutting helps to mitigate the attraction of vegetation for fauna, one of the causes of roadkill. It also increases visibility for drivers by enabling them to react successfully to collision risks from a greater distance, and aids fire prevention (see File 4). Nevertheless, take into consideration the potential presence of invasive alien species favoured by brushcutting (see File 7).
- Assess the role of the infrastructure's attraction for fauna in collisions and check whether there are collision hotspots in certain areas. Propose solutions for the fauna groups involved on the basis of this assessment.
- Ensure that all preventive measures receive proper maintenance, including perimeter fences, signs and vegetation in and around fauna crossings.
- Animals killed on roads and verges attract other species as a food source, which in turn may also be run over. Remove roadkill as quickly as possible and implement the stipulated data collection protocols which must include at least the date, coordinates or km mark, the species and a photograph of the animal.

- Where necessary, implement measures to prevent the verges from being colonised by species which give rise to a large number of attacks, e.g., rabbits (see File 8).

- Ensure that lighting fixtures (angle, timing and duration) and their lamps are properly maintained, monitor for cases of excessive fauna attraction and propose the appropriate corrective measures (see File 1).

Figure 4.9.1. Manual verge clearance in a forest zone to reduce the presence of fauna in its immediate surroundings and increase their detection at a distance by drivers, thus reducing the likelihood of collisions. Photo: Community of Madrid.

Figure 4.9.2. Road with an obvious fragmentation effect on water bodies, which will trigger massive amphibian mortality in the breeding season. Photo: Jacinto Román.

Figure 4.9.3. Ladder snake (*Rhinechis scalaris*) using a warm road surface for heat regulation. Photo: Jacinto Román.

5

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6 Appendix

The most common invasive alien plant species and their eradication or control methods are listed below. Species in terrestrial ecosystems are separated from species in aquatic environments. Species whose treatment is potentially hazardous because they have physical or chemical defence mechanisms are marked with an asterisk. In the case of species which are too big to be removed manually, cut down the individuals and remove the stump with suitable equipment. The most appropriate type of herbicide treatment and biological control varies for different species, making it necessary to consult the Catalogue of Invasive Alien Species and similar guides produced by authorities at other levels and specialist publications before choosing the specific methods.

Herbicides are generally aimed at individual specimens of invasive species, not the widespread treatment of an area due to their heavy impact on the rest of the flora. Herbicide application to stumps and ringbarking are commonly used. Always pay heed to the reproduction strategies of the species in question (seeds, rhizomes) to prevent these structures from remaining in the soil and perpetuating the invasion. In most cases, the eradication of invasive alien flora is a laborious and long-term process that requires regular checks and operations. The premature interruption of treatment usually results in a more virulent invasion processes. In some cases, the invasion is so widespread that the only feasible action is to contain its spread into the surrounding land.

The species and their control methods listed in the catalogues of IAS may change over time, making it necessary to always consult the latest edition.

Species	Control method (in order of priority)
Terrestrial Ecosystems	
Acacia dealbata	Manual removal, herbicide
Acacia farnesiana	Manual removal, herbicide
Acacia salicina	Manual removal, herbicide
Agave americana	Manual removal
Ageratina adenophora	Mechanical control, biological treatment
Ageratina riparia	Mechanical control, biological treatment
Ailanthus altissima	Manual removal, herbicide, biological treatment
Ambrosia artemisiifolia	Manual removal, herbicide
Araujia sericifera *	Manual removal, herbicide
Arundo donax	Manual removal, herbicide
Asparagus asparagoides	Manual removal, herbicide, biological treatment
Atriplex semilunaris	Manual removal
Buddleja davidii	Manual removal, herbicide, biological treatment
Carpobrotus acinaciformis	Manual removal, herbicide
Carpobrotus edulis	Manual removal, herbicide
Centranthus ruber	Manual removal, herbicide
Cortaderia spp.	Manual removal, herbicide
Cotula coronipifolia	Manual removal, herbicide, biological treatment
Cylindropuntia spp. *	Manual removal

Species (continuation)	Control method (in order of priority)
Terrestrial Ecosystems	
Cyrtomium falcatum	Manual removal
Cytisus scoparius (Canary Islands)	Manual removal, herbicide, biological treatment
Eschscholzia californica	Manual removal
Fallopia japonica	Manual removal, herbicide, constant grazing
Furcraea foetida	Manual removal, sterilization (monocarpic)
Hedychium gardnerianum	Manual removal, herbicide
Helianthus tuberosus	Manual removal, herbicide
Heracleum mantegazzianum *	Manual removal, herbicide
Ipomoea indica	Manual removal, herbicide
Leucaena leucocephala	Biological treatment
Maireana brevifolia	Manual removal
Nassella neesiana	Manual removal
Opuntia dillenii *	Manual removal, biological treatment
Opuntia maxima *	Manual removal, herbicide, biological treatment
Opuntia stricta *	Manual removal, herbicide, biological treatment
Oxalis pes-caprae	Manual removal, herbicide, biological treatment
Pennisetum clandestinum	Manual removal
Pennisetum purpureum	Manual removal, herbicide
Pennisetum setaceum	Manual removal, herbicide
Pistia stratiotes	Manual removal
Ricinus communis *	Manual removal, herbicide
Robinia psudoacacia *	Manual removal, herbicide
Senecio inaequidens	Manual removal, herbicide, biological treatment
Spartina alterniflora	Herbicide
Spartina densiflora	Manual removal, herbicide
Spartina patens	Manual removal, herbicide
Spartium junceum (Canary Islands)	Manual removal
Tradescantia fluminensis	Manual removal, herbicide, shading
Ulex europaeus (Canary Islands *)	Manual removal, mechanical control, biological treatment
Aquatic ecosystems	
Alternanthera philoxeroides	Manual removal, herbicide, biological treatment
Azolla spp.	Manual removal, herbicide, biological treatment
Baccharis halimifolia	Immersion, manual removal, herbicide
Cabomba caroliniana	Manual removal, drying
Crassula helmsii	Drying, manual removal, shading
Egeria densa	Drying, herbicide, manual removal
Eichhornia crassipes	Manual removal, herbicide
Elodea canadensis	Manual removal
Elodea nutallii	Manual removal
Hydrocotyle ranunculoides	Manual removal, herbicide
Ludwigia spp. (except *L. palustris*)	Manual removal, herbicide, shading
Myriophyllum aquaticum	Manual removal, biological treatment
Nymphaea mexicana	Manual removal, herbicide
Salvinia spp.	Manual removal, biological treatment

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