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Call 2016 Biodiversity Final Programme Report: Measures to enhance biodiversity and address invasive species in road verges

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Measures to enhance biodiversity and address invasive species in road verges

by

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Cover photographs, clockwise from top left: Golden Marguerite (*Cota tinctoria*) and Viper's Bugloss (*Echium vulgare*) by Mats Lindqvist; Bee Orchid (*Ophrys apifera*) by Brian Gaynor; Spotted Orchid (*Dactylorhiza fuchsia*) by Brian Gaynor; Field Scabious (*Knautia arvensis*) and Ox-eye Daisy (*Leucanthemum vulgare*) by Mats Lindqvist; Burning bush (*Dictamnus albus*) by Peter Fazekas (Pexels 2345807).

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Executive Summary

This document provides a summary of recommendations from two projects commissioned under the CEDR Biodiversity Programme, 2016: *EPIC Roads* and *ControlinRoad*. It is a guideline on measures to enhance biodiversity and to control invasive species in the verges of Europe's roads.

The report starts with an introduction to the main terms and issues, targeted at non-experts. Simple explanations are provided for terms such as disturbance and plant succession, habitat fragmentation and connectivity, ecological traps and ecotones.

Three national/regional studies are recommended, that should be completed prior to the construction of any particular road: (i) For route selection, the landscape of the country/region should be mapped for biodiversity value/potential. The existing road network should also be mapped, identifying verges with high nature value or which have particular potential for biodiversity (hotspots). A biodiversity classification method for verges is described that may assist in this process. (ii) National Road Authorities (NRAs) should have a Maintenance Handbook that describes general procedures and specific maintenance policy for all verge segments in the network. (iii) NRAs should also have an Invasive Alien Plant management strategy. Recommendations are provided for what should be included in such a strategy document.

Major road construction and upgrading projects have a considerable impact on biodiversity. While much of this impact is negative, there are also opportunities for positive impacts, where biodiversity is enhanced. Several examples are provided where the verge can be designed to add value to biodiversity. In the early stages of design, for example, the verge can be designed to connect patches of high nature value habitat in the landscape. In the detailed stages of design, many details are described that can make a verge more nature-friendly. There are recommendations for the design of ecotones (habitat edges) and the planting (or not) of verges and hedgerows. Summary tables are provided with ratings of the effectiveness of many road mitigation measures, some general and some specific to particular habitats.

Verge maintenance activities are particularly important from a biodiversity perspective. For roadsides without invasive plants, general guidance is provided on maintenance. The frequency and timing of mowing are major issues and guidance is provided on both. Removal of cuttings is also an important policy for which guidance is given. There are also recommendations on the maintenance of hedgerows.

Roadsides with invasive alien plants need to be treated separately from others. Guidance is provided on monitoring and control. Summary information is given on which methods are more cost-effective. Disposal of alien plant matter is a particular challenge that is also addressed.

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1. Introduction

This manual is based on two projects (CEDR 2022), *EPIC Roads* on biodiversity and *ControlinRoad* on invasive species. It presents summary recommendations on both of these topics, targeted at non-experts. Where more detailed information is sought on any topic, the relevant deliverables for these projects should be consulted, as referenced here and as listed in Tables C1 and C2.

Roadsides are characterised by disturbance (due to construction/maintenance) and a linear structure. The latter creates a potential for the roadside to become a dispersal corridor, for better or worse. Where they have high traffic load and/or are fenced, roadsides also exclude large animals so, unlike pasture, they are not grazed by large mammals. Further, for the most part, they are not fertilised or ploughed for tillage.

A roadside may contain species of conservation concern and, in some cases act as a refuge or a resource (seedbank or source populations) for recolonisation of the landscape. A study of alpine meadows (Jacot et al. 2012) found that almost 50% of all recorded plant species were found exclusively in the transition zones between habitats, which a roadside often is. Some species now only (or nearly only) occur in road verges (see Figure 1). Verges can make a significant positive contribution to biodiversity. This opportunity can be exploited by getting input from appropriate experts early in the road planning stages and at all key stages of construction and maintenance.

Figure 1 – In Sweden, the Autumn Gentian (Gentianella amarella) occurs mainly in roadside habitats today. Funäsdalen, Sweden

The capacity of the verge to host species depends primarily on the habitats and species already present in the surrounding landscape and much of the value in a roadside habitat comes from its interaction with that landscape. Habitat that was previously in the landscape is also relevant – there can be cases where the verge retains fragments of habitat or a seed bank for vegetation that was once present but no longer exists in the surroundings. An exception to this general principle of focussing on existing/historical landscape habitats is when the road construction creates embankments that favour some important specialist species (e.g. digging bees/wasps). Roadside verges, including hedgerows, can also provide connectivity between patches of good habitat in the landscape, creating a mosaic of habitats. Good connectivity reduces the risks of local extinction of small populations and adds biodiversity value to the area.

Given the particular characteristics of roadsides, target species groups to encourage should be plants, invertebrates and small vertebrates (amphibians, reptiles and small mammals). Initiatives to promote biodiversity should combine construction with maintenance and monitoring or, if the habitat already exists, should combine maintenance with monitoring. It is important to assess the effectiveness of maintenance policy and adapt as necessary.

Some of the key ecological concepts referred to in this report are summarised in the following boxes.

Box 1 – Disturbance and succession
Roadsides are characterised by disturbance – construction is a one-off disturbance, drain maintenance may be occasional and activities such as mowing are periodic (e.g. annual) disturbances. Succession follows disturbance: initial colonising species are succeeded by others and these in turn by others. In the absence of active planting, a major disturbance exposes bare earth and promotes temporary plants, so called 'ruderal' or coloniser species, such as poppy (*Papaver rhoeas*). This is generally considered positive for biodiversity and the establishment of ecological communities. Over years, the ruderal species are replaced in the natural succession process. If left alone, this culminates in a stable situation with a small number of dominant competitive species – usually trees or grasses. Biodiversity is generally better if these dominant species are discouraged. Succession can be delayed through annual disturbance or maintenance activities – usually mowing. • In traditional low-intensity farming, grazing and grass cutting are semi-natural disturbance processes. A key task in biodiversity conservation is often to restore such disturbance regimes. Road verges are similar to semi-natural managed environments such as unfertilised meadows. • The disturbance regime acts as a filter that favours some species over others. • Disturbance counteracts succession towards taller vegetation dominated by competitive species – typically grasses/herbs initially and later shrubs and trees.

Box 2 – Connectivity/fragmentation

Roads often fragment habitats by creating a barrier to animal crossings. The strength of the barrier depends, amongst other things, on the road width, traffic volume and species considered. Verges, on the other hand, have potential to connect habitats, promoting the dispersal of plants and animals. This can be positive, providing connectivity between habitat patches, or negative, facilitating the spread of invasive species.

- There is evidence of high densities of fleshy fruit shrubs on unpaved road verges in Spain. This is due to animal and bird movements along the road verge.
- There is much evidence of seeds dispersing along roads by cars and maintenance machinery which serves to enhance the connectivity potential of the verge for plants.

Box 3 – Ecological traps

Ecological traps may happen when species are attracted to the roadside but do not fare well there. For example, lizards and snakes like to bask on hot pavements where they are often killed. This can create a sink effect and a drain on the population in adjacent areas. While it is important to acknowledge the risk, there is little evidence in the literature that ecological traps occur along roads.

- The proportion of the population that occurs in the roadside is key – a large proportion makes the population more vulnerable to any threat.
- The suitability of the roadside for reproduction is important – a reproduction rate below 1 may be a cause for concern. If the roadside population is viable, then there is not a trap problem.
- Mortality is critical. The proportion of animals killed relative to their reproductive success determines if it acts as an ecological trap or not. The results need to be judged over several years as there can be considerable fluctuations for unrelated reasons.
- High speed and high traffic volumes on small roads with narrow verges, are high risk situations.
- Narrow roadsides with steep gradients are more likely to create traps.
- Lack of connectivity between habitats promotes traps.

Box 4 – Ecotones

An ecotone is an edge between habitats and can be a rich feature that promotes biodiversity by providing unique ecological conditions not otherwise present in the landscape. Some ecotone species depend on the specific conditions at habitat interfaces, while others require a combination of habitats (e.g., for larval and adult stages). A fundamental principle in promoting biodiversity is to provide ecotones, i.e., transitions, between habitats. This applies both along the length of the road and across the width of the roadside verge.

When the verge is narrow, there may not be space for large ecotones and the whole verge may constitute the transition between the immediate roadside (usually closely cut grass) and better quality habitat in the landscape. Even in narrow verges, there may be different habitats and it is always beneficial to provide transitions, even when they cannot be of optimal width.

Box 5 – Invasive and dominant species
Roads and adjacent areas are habitats which are disturbed, mostly well drained, nutrient rich and polluted with heavy metals and de-icing salts. These characteristics provide a growth advantage to robust plants which are well adapted to harsh conditions. Roadsides are also natural corridors of similar habitat and maintenance activities can promote the spread of such species. Three classes of undesirable species are: • Noxious species such as ragwort (*Jacobaea vulgaris*) which is native to northern Eurasia but is a risk to grazing livestock in some circumstances. • Species such as gorse/furze (*Ulex europaeus*) which are also native to Europe but aggressive colonisers that can dominate habitats, resulting in poor biodiversity. • Invasive alien plants (IAPs) are a particular threat. As they have not evolved in the region, they have no natural enemies and may have other traits that give them an advantage over native competitors. IAPs damage species richness and may be a threat to the road construction itself (e.g., Japanese Knotweed (*Fallopia japonica*) can halt or delay construction). This document only addresses IAPs. However, plants in the other two categories may be dealt with in a similar way. Three types of measure are used to combat IAPs: • Prevention of introduction, • Early detection and rapid eradication to prevent establishment and, • Management: Actions to prevent further spreading and to minimize harm. IAP species considered to be the most problematic in Europe are listed in Appendix A. However, some road owners may wish to customise their priority list, based on what is locally problematic.

2. Background Studies

Some national/regional studies should be carried out and policy documents/plans developed, if not already available. Specifically, countries/regions should (i) identify and map high nature value landscape and roadside segments with biodiversity potential, (ii) develop a Maintenance Handbook and (iii) develop an Invasive Species policy.

2.1 Landscape and Road Network Biodiversity Potential Mapping

General Principles

In advance of any specific road construction plans, the national or regional landscapes should be reviewed and classified according to their nature value. This can be done with maps of protected areas and known locations with species or habitats of conservation concern. The landscape nature value map will inform route selection for the construction of new roads.

New and existing road segments should also be reviewed according to their biodiversity value or potential. A target should be set for biodiversity ‘hotspots’ (e.g. 20% of all verge area) which will be managed to exploit their biodiversity potential. The biodiversity value of a roadside is a function of the species pool in the surrounding landscape, plus some properties of the verge such as area, soil type, slope and aspect (Sjölund et al. 1999). Therefore, roadside segments should be reviewed in terms of soil type (e.g. nutrient-poor, calcareous soil), topography (e.g. steep slopes), orientation (e.g. south facing) and size of habitat. The goal is to identify roadsides with good properties that are adjacent to medium or high nature value habitats. This includes areas that were once rich in biodiversity and are now deteriorating as well as those that are still rich. The resulting network map of biodiversity potential will inform road upgrading works and the national maintenance plan.

Some general principles for identifying the value of a roadside segment are listed in Box 6 and a numerical rating system is described in the next sub-section.

Recommended Classification System

Table 1 can be used to quantify the biodiversity value of a roadside habitat. (An alternative approach would be to use the abundance of an indicator species as a measure of the biological quality of a habitat). Segments are rated in each of 13 criteria (A1, A2, etc.) and given a score between 0 and 2 in each. The scores are added, divided by the maximum possible value and multiplied by 100, to give an overall rating between zero and 100. If all 13 criteria are used, the sum ranges from zero to 2x13 = 26. Hence the adjustment consists of multiplying the sum by 100/26.

If data is not available for some criteria, these can be ignored and the same formula applied. For example, if only 10 criteria are used, the sum is multiplied by 100 and divided by 2 times 10, again giving a roadside rating between zero and 100. Roadside segments should be classified separately for each side of the road.

It should be noted that the classification system only gives an indication of the value of a roadside habitat. There may be other reasons for a particular roadside to be given a priority status, such as known migration corridors, or the verge acting as a refuge for wildlife in a low biodiversity landscape.

Box 6 – General principles for biodiversity potential mapping (continued on next page)

- A good indication of conservation value is that the verge hosts a high % of the surrounding landscape's species (assuming that these species have high conservation value). Being similar to the surrounding landscape is strongly recommended.
- The value of a roadside depends on its distance from, and its connections to, quality habitat patches in the landscape. Past landscape use will also affect the available species pool.
- Some species are threatened in the surrounding landscape by a *lack of* disturbance (e.g. neglected land, abandoned farmland) and can do better in the managed environment of the roadside.
- Soil properties (moisture, nutrient level, alkalinity) are important.
  - Moisture is about rainfall, seepage and groundwater but also about aspect and water retention (sandy soil, etc.). Nutrients require moisture for uptake.
  - Alkaline soil is generally more species-rich. In general the road pavement tends to increase alkalinity. However, it should be borne in mind that acidic soils may also support high nature value habitats.
  - Low nutrient levels promote species richness in grasslands.
- Agrochemicals are a problem in many verges – verges adjacent to organic farms tend to be much better than those adjacent to intensive agriculture.
- Trees: Roads probably have potential to favour biodiversity of light-demanding shrubs and old trees, especially in the edge between an open road corridor and an adjacent forest and in hedgerows and tree avenues.
- While nutrient-poor verges are usually better in terms of species richness, there are examples of nutrient-rich biodiversity hotspots. However, these are hard to maintain.
- Forest edges may be important. However, while open roadsides through a forest may increase biodiversity, they are unlikely to favour the desired forest landscape's species (edge effect). And they can provide threats through IAPs.
- To prioritize segments of roadside for biodiversity, patches with a high number of specialists should be distinguished from patches with a similar number of generalists. Specialist species have particular habitat requirements and are generally less common. Generalist species, on the other hand, can adapt to different habitats and are usually common. As the objective is to promote global species richness, specialists tend to have greater value.
- Ecological contrast between the roadside and the adjacent landscape is an important factor. In general, medium contrast is considered best as low contrast roadside may not provide anything complementary to the landscape and high contrast may make it difficult to contribute to the adjacent species pool. However, there are notable exceptions and the most desirable level of contrast is highly context-specific.
- Important groups of roadside habitats can be identified using the Habitat Directive's framework for habitat quality assessment and classification (Habitats Directive 2022). Further information on the classification of roadside biodiversity potential is provided in EPIC Roads Deliverable 3.1 (EPIC Roads 3.1 2021).

Box 6 (continued)
• Regional lists of species of conservation concern should be established that are, or have the potential to be, favoured by roadside habitats. Conservation concern here refers to nationally red-listed or legally protected species, Annex II and IV species in the Habitats Directive, species in the Birds Directive, species with ecological key functions etc. However, caution is advised when attracting rare species to roadsides because of the risk of ecological traps. • Locations with species/habitats of particular value (hotspots) can be identified with geo-location coordinates.

Table 1 – Scoring of roadside biodiversity potential according to quality of landscape, area and habitat (additional details of the criteria are provided in Appendix B)

Criterion		***Description***	**Score**		
			0	**1**	**2**
Landscape	A1	Habitat quality and biodiversity in the surrounding landscape (plant/animal composition in the landscape can affect the roadside)	low	medium	high
	A2	Connectivity to adjacent habitats: (a) laterally, (b) longitudinally and (c) across the road	one of three	two of three	three of three
	A3	Regional plant or animal species pool as a source of roadside biodiversity	low	medium	high
Area	B1	Longitudinal extent of verge	< 1 km	1-5 km	> 5 km
	B2	Lateral extent (width)	< 5 m	5-20 m	> 20 m
	B3	Orientation/aspect of slope: North (N), East or West (E/W) or South (S); and steepness (whether road is above or below embankment).	N or E/W & >20%; any & <5%;	N & 5-20%; S & >20%	S or E/W & 5-20%
	B4	Frequency and intensity of human influence	high	medium	low
Habitat	C1	Sunlight intensity (except where hedgerows are being preserved)	0-40%	40-80%	80-100%
	C2	Water intensity (both extreme wet and extreme dry, favour biodiversity)	mesic (medium)	-	dry or wet
	C3	Nutrient availability	high	medium	low
	C4	Soil pH	< 5.0	5.0-7.0	> 7.0
	C5	Degree of pollution, related primarily to traffic volume	high volume	medium volume	low volume
	C6	Potential for improved biodiversity management over current practice	low	medium	high

2.2 National/Regional Maintenance Handbook

There are many verge management processes. A Maintenance Handbook (or green management plan) should specify which processes should be carried out for each segment of roadside throughout the network and when. As much of the roadside has less value for nature, the focus can be on priority segments with good potential. A default maintenance policy can be applied to groups of less valuable verges – for example, policies such as removal of cuttings can result in overall biodiversity improvement. Even for these, there are management practices such as late mowing, that cost little and can benefit biodiversity. Many NRAs will implement an integrated verge management plan that takes account of criteria other than biodiversity such as safety and drainage. However, only biodiversity is addressed in this document.

Training of maintenance personnel is important so that they have an understanding of the reasons for the maintenance practices from a biodiversity perspective. This needs to be repeated regularly to cater for changes in personnel.

The Maintenance Handbook should specify the maintenance schedule for each roadside segment or group of segments. Some general principles are given in Box 7.

Box 7 – General principles for maintenance handbook

- Roadsides with low biodiversity potential may be grouped into broad classes with the same standard maintenance regime. However, while recognising the value of simplicity, a plan that is diverse overall, with many different maintenance approaches, will tend to enhance biodiversity.
- A prioritization process is recommended based on biodiversity potential, with some roadsides designated with higher maintenance priority than others.
- Sites with invasive species should be treated separately from other sites.
- Gradual transition zones (ecotones) should be provided where segments meet. While it depends on the context, a typical ecotone width is equal to the road width.
- Management differentiation longitudinally along the verge is important for diversity. Thus, it is advantageous if adjacent roadside segments have different management regimes.
- Frequency of mowing is key and timing is important (see Section 4). Routine removal of cuttings is often required to keep nutrient levels low in biodiversity priority areas.
- When the roadside is going to be disturbed by road maintenance (e.g. to improve drainage), there may be an opportunity to enhance biodiversity. For example, dead vegetation can be removed to enhance drainage and can expose nutrient poor soil to enhance biodiversity. Islands of species rich vegetation can be left untouched to add further diversity.
- If repeated trenchworks are necessary to maintain drainage over time, guidance should be included in the Handbook on procedures that favour species richness where appropriate. Trenchworks can have a decisive impact on roadside biodiversity.

Examples of Targeted Species Groups and Habitats

A diversity of habitats and maintenance approaches is clearly good for biodiversity. Nevertheless, a number of focus areas have particular potential, as listed in Table 2. It is emphasized that this is not an exhaustive list – many other opportunities may arise to contribute to biodiversity in particular circumstances. NRAs are encouraged to identify and avail of opportunities as they arise.

Table 2 – Examples of Priority Species Groups (continued on next page)

Focus	***Comment***
1. Butterflies, Bees and Other Pollinators	Sedentary and smaller species of butterfly have much less road-kill (<2% vs 7%) when compared to larger, more mobile, species. However, both percentages are considered non-threatening. Roads with lower traffic volumes will have less road-kill. It is important to provide for as much of the lifecycle as possible (e.g. plants for caterpillars, over-wintering adult butterflies and pupae). Undisturbed ground may be provided for nesting bees and compact sandy earth banks can provide habitat for solitary bees to nest. Late mowing will reduce the risk of disturbance to larval stages and increase the wildflower seed set. These habitats may also provide plant food sources for small mammals and seed-eating birds.
2. Wetland Insects	There are sometimes opportunities to design the roadside drainage scheme in a way that generates patches of wetland which can be beneficial to some insect groups, particularly those with aquatic juvenile stages. Some information on this 'over-the-edge' drainage concept is given in (TII 2015).
3. Rare Plants and Associated Habitats	Roadsides are important for some rare plant communities and species, particularly those that favour disturbance or low nutrient habitats (e.g. some orchids (*Orchidaceae*)). Endangered insects are significantly more common in rare plant communities and species richness of insects and spiders (arthropods) is correlated with plant species richness. The management of these areas should match what happens naturally in the landscape.
4. Ruderal Plants (poppies, etc.)	Ruderal plants are the first colonisers after major disturbances that expose bare earth. Given the nature of road construction and widening, roadsides can be a refuge habitat for these. Ruderal plants can be promoted by not planting and by measures to delay succession by more dominant species (e.g. late mowing).
5. Species Rich Wildflower Meadows (Low-nutrient Soils)	High species richness and biodiversity of conservation concern is often associated with sparse vegetation in nutrient-poor (or moderately nutrient-rich) sandy or peaty soils. This valuable stage tends to follow on from ruderal plants, but can take some years to achieve, depending on management.
6. Digging Insects (Undisturbed Soil)	Many insects live on or within the soil, including bumble (*Bumbus*) and solitary bees, some species of wasps, dung beetles and carabid beetles (*Scarabaeidae*). Compacted sandy soil banks and patches of bare soil are good for ground nesting wild mining bees and wasps.

Table 2 (continued)

Focus	***Comment***
7. Thermophilic Species (South-facing Embankments)	South and West-facing slopes can provide sunny surfaces that attract heat-loving (thermophilic) and drought-tolerant (xerophilic) insects and plants. As for digging insects, bare soil provides good establishment conditions (as it exposes the ground to the sun). This includes several endangered species in Europe. Woch & Hawryluk (2014) found 18 species of rare or protected plants in xerothermic roadside slopes.
8. Hedgerows	Roadside hedgerows have the potential to provide connectivity of habitat between hedgerows in the landscape, while capturing carbon from the atmosphere.

2.3 Invasive Species

It is recommended to establish a national/regional strategy for the control of invasive plants, as it relates to roads. This strategy should incorporate:

- A clear statement of responsibilities and budgeting.
- Targets and plans for control should be realistic, taking account of budgets for each region.
- A spatial database with data on the distributions of invasive species throughout the network. This should be as comprehensive and uniform as possible and should be updated on an ongoing basis. It should include:
    a) the size of each infestation,
    b) control methods that have been applied (including disposal),
    c) monitoring afterwards (e.g. for at least 5 years), rating the effectiveness of the control,
    d) current status, complete with categories (e.g. new location, expansion, treated and successfully removed, including date of observation),
    e) plans for future controls,
    f) details of any planting or landscaping that may have caused the infestation, and,
    g) any sensitive ecological receptors (e.g. water courses, conservation areas).
- A policy on competencies, training and awareness.
- An inventory of control methods, including timings, and their effectiveness (to be kept updated).
- The establishment of a prioritization strategy (e.g. level of infestation, risk to humans).

It is important to raise awareness of invasive species among road operators, decision makers (political) and the general public.

2.4 Other

In advance of the design of any road scheme, mechanisms should be explored to develop seed sources for native plant species of local origin (which are often difficult to source). This may be best accomplished through collaboration with volunteer organizations and/or local farmers.

3. Planning and Constructing New or Upgrading Existing Roads

3.1 Early Stages of Road Planning

In the early stages of route selection, potential impacts of the construction should be identified through an analysis of planned topography (sloped or flat), soil (free-draining/not, acidic/alkaline) and what species/habitats of high nature value are already in the landscape. There may be opportunities at this point to strengthen biodiversity significantly and these may influence route selection and detailed design. Locations along the planned route(s) where there is potential to strengthen biodiversity should be identified at an early stage.

Planners should attempt to minimise the building of roads through more pristine habitats. However, the impacts of roads on species richness are likely always highly context dependent. Road construction and management projects should work on a case by case basis and identify specific prioritisation targets to allow consideration of habitat and dietary requirements for focal species groups. It is recommended to take a landscape perspective that considers adjacent habitats and their biotic communities as opposed to looking at roadside habitats in isolation.

Some negative and positive effects are listed in Boxes 8 and 9. The key environmental risks will be available from the Environmental Impact Assessment report. An inventory of invasive alien plants along the planned route should be carried out at the project planning stage.

Box 8 – Negative effects of road construction and widening
• The area of habitat affected is greater than the land lost through construction alone – because of disturbance, collisions, habitat fragmentation, etc., the impact can extend quite a distance from the road (e.g. for animals that have a large home range, such as bats (*Chiroptera*)). • Species population declines in response to road construction may not become apparent for a long time, even for decades. • The accumulated effects at the scale of the road network are often different from the effects at local level. • Indirect effects can be significant (e.g. road construction may lead to industrialisation or urbanisation).

Box 9 – Positive effects of road construction and widening (continued on next page)
• The verge has the potential to provide a connection between patches of quality habitat (e.g. through an area of intensive agriculture or urbanisation). • Where species of conservation concern are in the landscape that are compatible with roadside habitat, the verge can add value to a habitat. • There may be remnants of historical land use with high biodiversity (such as semi-natural meadows) which can be supported by roadsides. There are particular circumstances where an adjacent habitat is declining due to changes in land use (such as the intensification of agriculture) and the roadside has the potential to provide a refuge (Figure 2). For example, there may be patches of open ground in the landscape with ground-digging Hymenoptera (ants, bees and wasps) that are becoming overgrown by grasses (due to a change in grazing practice).

Box 9 (continued)
• Cuttings in rock and through (low nutrient) sub-soil have potential to provide habitat for some specialist species of conservation concern. In particular, South- and West-facing surfaces are valuable for heat-loving (thermophilic) plants, reptiles and insects and can favour biodiversity in colder and more humid regions in particular. • Low-productivity (nutrient-poor or moderately rich and well-drained) soils have in general the best potential for forming biodiversity-rich meadows.

Figure 2 – When management ceases and the landscape is overgrown, much of the grassland flora may remain in the roadside habitat (Province of Öland, Sweden).

3.2 Detailed Design of Road Construction and Upgrading

For the detailed design stage, some general principles are given in Box 10 and some active measures to promote biodiversity are given in Box 11. For some roadsides, there are opportunities to greatly enhance the biodiversity and particular efforts may be made. These are listed in Box 12.

Box 10 – General principles for detailed design
• In general (and with some exceptions), it is advised to not introduce new habitats into the landscape. It is best to support or develop existing or historical habitats. • Wide verges are better, with habitat differentiation and/or structural variation. • Create cohesion and connections with locations nearby in the landscape with high biodiversity and facilitate species exchange. • Reduce barrier effects of roads by facilitating animal crossings. • Ecological traps may be a risk for some species. It is important to assess the risk of traps. If there is a risk, features should be avoided that attract target species to the roadside, especially when there are high traffic volumes. • For animals, there should be a focus on attracting those where all (or the most critical parts) of their lifecycle can be in the verge habitat. This will reduce their need to move and the risk of collisions with vehicles.

Box 11 – Active measures to promote biodiversity in all roadsides
• Uneven surfaces are recommended in the verge (indents, bumps, piles of stones, logs). This can create biodiversity-rich habitats (e.g., drought-tolerant insect communities, rock habitats, shrub habitats). General topographic variation (ditches, banks, slopes, uneven terrain) has been shown to increase the diversity of breeding habitats for butterflies. • It is sometimes beneficial to incorporate irregular edges between the verge and the surrounding land to facilitate light-dependent shrubs. • There may be potential to provide pockets of wetland habitat – roadside ditches and drainage constructions may provide wet or moist habitats of great value for biodiversity. For example, 'over-the-edge' drainage systems (TII 2015) can be used for this purpose. Clearly it is important to ensure that this does not result in contamination of the groundwater with pollutants from the road, nor attract animals that may then be at risk of collision with traffic. • There may be potential to create low-growing shrub-rich habitats. However, shrubs will bring shade and will elevate nutrient levels so this is not recommended where the priority is low-nutrient open spaces. • In areas of high biodiversity, it may be useful to re-use existing soil which may contain valuable seeds of local origin. However, it is generally not advised to apply nutrient rich topsoil if trying to create a nutrient poor community. • Roadside locations where active measures have been taken to promote biodiversity, should be logged in a database and monitored. It is important to determine if measures are effective and to adapt maintenance practices if necessary.

Box 12 – Priority active measures – particular opportunities to greatly enhance biodiversity
• Universally good qualities are nutrient-poor, dry and sun-exposed sites. Also, some specific factors attract certain target species (e.g. wet ditches). • In general, bigger areas have greater potential to strengthen biodiversity, because parts of them are less exposed to traffic and the adjacent environment (agricultural or urban activities). Hence, higher slopes and wider verges, and those that extend for longer lengths, should be prioritised for positive action. An exception is bare soil suitable for digging insects where a few square metres can be enough. • In fragmented landscapes with high-value habitats and barriers to dispersal in the landscape, high-quality roadsides should be developed to connect habitat patches and to provide structural connectivity. If invasive or dominant species are present, good design and management is needed to minimise the risk of them spreading along the road, especially near high nature value sites. • A long patchwork of connected habitats can also be valuable. A rough estimate of distances between 'stepping-stone' patches is a few hundred metres for small insects and spiders (arthropods) to a few kilometres for flying insects, reptiles and small mammals. Continuity along the road increases population size of target species and facilitates dispersal. • Connectivity can be enhanced by providing continuity of structures such as hedgerows, tree rows and individual trees. The focus may be plant species with low to moderate dispersal distances. Dispersion can be multi-generational when the verge is a complete habitat. • A high percentage of invertebrates complete their full life cycle in verges, facilitating a multi-generational corridor function. This is true for most spiders, grasshoppers (*Caelifera*), ground beetle (*Carabidae*) and weevil (*Curculionoidea*) species (Raemakers et al. 2001). • Support for declining and vulnerable habitats: There is sometimes potential to support species in habitats that are in decline in the surrounding landscape. Typically, roads can favour species belonging to grassland habitats, dry habitats, sandy habitats, ruderal habitats, and semi-open or edge habitats with light-influenced shrubs and trees, including avenues and hedges. Locally, several other roadside habitats may be formed that can support certain species groups, for example species from various shore habitats, rock habitats, karst or alvar habitats, and wetlands.

Design of Ecotones (Transitions between Habitats)

An ecotone is an edge or transition between habitats. Ecotones tend to be species-rich and biodiversity can be greatly enhanced by incorporating such transitions between habitats. Some general recommendations are given in Box 13.

Planting

Verges can be actively planted or allowed to recolonize naturally but must always be managed and monitored to achieve the objectives and to prevent the spread of invasive species. Natural colonisation is recommended except where there is a risk of soil erosion or the spreading of invasive species. When planting, seed mixtures of grasses, and local native plants are recommended (Figure 3). For example, verges dominated by native species are known to host a greater abundance and species richness of wild bees and butterflies. There can be difficulties finding sufficient sources of native seeds of local origin, in which case, it may be possible to spread hay from local species-rich vegetation.

Box 13 – Recommendations regarding ecotones

• Ecotones should be provided between habitats along the road length and, where space allows, across the width of verges.
• When the surrounding landscape has high nature value and the verge is wide enough, an ecotone can provide a transition between the landscape and the verge habitat.
• For narrower verges, the whole verge can be the ecotone between the roadside and the surrounding landscape. Even when verges are narrow, (small) transitions between habitats will benefit biodiversity.
• Ecotone Width:
  o Goldilocks Principle: Wide ecotones provide more habitat (so larger populations) but very wide ecological gradients do not develop the distinct ‘edge’ features of ecotones. Narrow ecotones enhance connectivity but also increase the risk of mortality. Medium-width ecotones support the most biodiversity.
  o The definition of best width depends on the species (bigger species/taller vegetation favour wider ecotones) but, roughly speaking, the recommended medium-width ecotone is about equal to the road width.
  o In intensively used landscapes, ecotones tend to be more nutrient rich and well supplied with soil moisture. This favours wider ecotones.
• Southern European roadside ecotones (and those in lowlands) are more species-rich, and thus require more targeted management (Jakobsson et al. 2018).

Figure 3 – Introduction of meadow flora on recently disturbed ground by sowing collected seeds and by placing hay from the meadow on the roadside. Sweden 2020.

When planting roadsides, there are several criteria to determine which species to select. These are listed in Box 14. Recommendations for the planting of hedgerows are given in Box 15. Road maintenance activity can have negative or potentially positive influences on biodiversity. These are listed in Box 16.

Box 14 – Criteria for selecting species to plant
• Some plants are themselves endangered and will enhance biodiversity. • Some plants contribute general resources (e.g. pollen and nectar plants for flower-visiting animals). Some species are food plants (e.g. for caterpillars). • When reseeding, avoid competitive and high-density grasses. • Avoid the application of nutrient-rich topsoil. It is even possible to cover nutrient rich soil with a thick layer (≥ 50 cm) of nutrient poor soil. • Avoid the use of a thick grass sward, even if it is from a species-rich grassland (but it is possible to provide 'islands' of species rich sward to provide a seed bank).

Box 15 – Recommendations for the planting of hedgerows (Heritage Council 2016):
• Drainage should be considered at the outset. A bank and ditch is traditional in some regions. • It is important to leave sufficient width (about 2 m minimum). • Young plants should be closely spaced (50 cm maximum) and should be planted in a zigzag pattern, not a straight line. • If possible, connect the new hedge to existing ones to provide a wildlife corridor. • Use native species, already in hedgerows in the area, using locally sourced seeds or cuttings. • New growth should be protected from competition until established. • When sufficiently mature, young plants should be cut back to half their height to promote regrowth. • Young hedges should be protected from browsing livestock by fences at least 1 m away.

Box 16 – Influences of road maintenance activity on biodiversity
• If scraping is done for drainage or other reasons in a species-poor roadside, there is an opportunity to promote coloniser (ruderal) plants. • If scraping is done where a diverse flora remains, steps should be taken to save the flora. Leave unscraped islands of vegetation or re-sow target species or the plant community with seeds or hay collected in advance. Alternatively, re-use smaller portions of topsoil with its seedbank (not the whole topsoil). • In nutrient-poor or dry conditions, competitive species may establish (e.g. drought tolerant grasses). This may be mitigated with a cutting regime that hampers the competitors (e.g. one early cutting). • If invasive species establish, the management plan needs to focus entirely on that.

Mitigating the Impacts of Roads

There are a number of well-known direct impacts of roads. These are listed, with a number of possible mitigation measures, in Table 3. Other mitigations are limited to specific circumstances in sensitive landscapes. These are listed in Table 4.

Table 3 – Major Impacts of Roads and Possible Mitigation Measures (continued on next page)

Impact	*Possible Mitigations*	*Effectiveness*
1. Habitat fragmentation (see COST 341 2003)	Crossings (green bridges, ecoducts)	Depends on density and quality of crossings
2. Road-kill: Largely related to species presence/abundance. Tends to be greatest for medium traffic volumes (high volume causes barrier effect). Assessment of traffic volume level depends on species but medium volume is about 1000 vehicles per day. Natural wildlife corridors (hedges/streams) perpendicular to road are road-kill hotspots.	Fencing (with crossings)	Very good
	Increasing visibility (low vegetation, especially in forests)	Good (but may impact biodiversity)
	General warning sign for drivers	Low
	Variable message sign for drivers activated by animal movement	Good
	Warning noise for animals activated by approaching traffic	Good potential for low-traffic roads (only)
	Speed restriction	Good
	Degrade mid-road (median) habitats	Medium
	Habitats should be different on opposite sides of the road	Low
3. Light pollution: An issue in coastal areas for nocturnal birds and turtles. An issue in many areas for bats and nocturnal birds. Also, many insects are sensitive to light pollution. Further information by Pothukuchi (2021).	No street lights	Very good
	Use of red- or amber-coloured LED lights (avoid blue light)	Less negative effect on many species groups
	Directed street lights	Better than undirected
	Timed or sensor-triggered street lights	Good if well designed
	Shelter belts (trees or shrubs) for street lighting and headlights	Good if done well
	Artificial barrier	Very good

Table 3 (continued)

Impact	*Possible Mitigations*	*Effectiveness*
4. Noise pollution: Can affect vocal communication of birds.	Shelter belts	Good if done well
	Artificial noise barriers – transparent	Medium. There is a risk of bird collisions and they may constitute barrier to animals
	Artificial noise barriers – opaque	Good if they do not constitute a barrier
5. Chemical pollution: Persistence of pollutants tends to be higher in cold landscapes.	Shelter belts	Good if done well
6. Changes in hydrogeology	Deep-rooted native vegetation (and geotextiles) can reduce risk of erosion.	Of some value

Table 4 – Specific Mitigation and Active Measures for Sensitive Landscapes (continued on next page)

Habitat	*Measures to Enhance Biodiversity and Mitigate Impact of Road*	*Effectiveness*
Warm	Provide rocky outcrops, sand &/or gravel patches on South-facing slopes to attract reptile basking activity away from pavement	Medium
Snowy/ frosty	Develop management strategy that reduces use of de-icing salt (which influences plant communities and may attract mammals)	Medium
	Replace de-icing salt with alternative, less toxic, compounds	Effective but expensive and risk of pollution of nearby water bodies
Arid	Roadside tends to be more moist than surroundings, enhancing diversity. Promote this with micro-climatic measures (see EPIC Roads 2.3-2.5 2021).	Need for caution with regard to ecological traps

Table 4 (continued)

Habitat	*Measures to Enhance Biodiversity and Mitigate Impact of Road*	*Effectiveness*
Mountain	Make downhill side unattractive to discourage roadkill	Medium
	Provide escape ramps on steep uphill roadsides	Good
	Mitigated streetlamps, on downhill roadside only	See Table 3
Flatland	Mitigated streetlamps, on both sides.	See Table 3
	Fences along roads in areas with high risks of amphibian-vehicle and general animal-vehicle collisions, in combination with crossing structures.	Very effective if designed well and maintained
Wetland	Beware of aquatic invasive species	
	Drift fences along roads, combined with crossing structures for migrating amphibians	Effective if designed well
	Several wetland insect species are affected by artificial light	See Table 3
Dryland	It is possible to promote roadside moisture with micro-climatic measures, especially for low-traffic roads (see EPIC Roads 2.3-2.5 2021). However, there is a need to be aware of the risk of an ecological trap.	Inconclusive
Coastal	To reduce roadkill of coastal vertebrates, manage vegetation to be unattractive on inland side	Useful in some circumstances
	Mitigated streetlamps on coastal side, with light directed inland (for nocturnal seabirds and new-born sea turtles). But this may adversely affect other species such as bats.	See Table 3

Invasive Species

Methods of control of invasive species and disposal of invasive alien plant material are given in Section 4. A few additional points are mentioned in Box 17 that relate to road construction.

Box 17 – Invasive alien plant species in the context of road construction
• In the road construction design stage, there should be a survey for invasive species and a plan should be developed for their elimination or containment. • Careful quality assurance is recommended of cut-and-fill material to prevent the spread of invasive species and to protect ecologically valuable soils/sub-soils. • Where invasive species exist, enabling works may include pre-treatment on site (e.g. mowing, application of herbicides, removal and controlled disposal). • Excavated soil that contains invasive plant material must be handled with great care (stored on site and clearly labelled). • Particular construction measures may include thicker base course layers and growth/plant barriers. • When bare earth is exposed, it may be planted with special seed mixtures that provide robust competition against invasive species. • When invasive species are initially present, post-construction monitoring for recurrence is recommended. • Even where invasive species are not known to exist, movements of excavated soil must be subject to quality control procedures, i.e., careful checks for the possible presence of invasive species.

4. Maintenance of Existing Roadsides

4.1 Roadsides without Invasive Species

General Principles

There should be longitudinal and lateral variation in management (mowing, etc.). This will generate additional habitats, and transitions between habitats (ecotones), which increases species diversity. Some general principles relating to maintenance are listed in Box 18.

Box 18 – General maintenance principles
• The management plan for the network should be diverse so there will be differences in management practice between segments of roadside, along the length of the road. Transition zones (ecotones) should be provided between segments. • There should also be management differentiation laterally across the verge. For example, within a roadside segment, there may be mosaics or gradients of management intensity, i.e., diversity in the approach (e.g. some parts may be allowed to grow higher than others). Unmown sections can become refuges for sensitive species when adjacent areas are freshly mown. Micro-habitat (e.g. with fallen trees) is particularly valuable. • Rotational management of hedges, e.g., trimming different parts in different years, can be effective. • Management practice at a site should not change too often, as this favours generalist species. • Species population trends should be monitored to determine if the management practice is effective in promoting desired biodiversity outcomes. This requires an inventory of species and an assessment of the effectiveness of the management practice. • Invasive Alien Plant (IAP) sites should be removed from the routine vegetation management schedule and handled separately.

Mowing Frequency and Timing

In general there is little need for mowing other than to prevent the establishment of woody vegetation (or for non-biodiversity purposes). The frequency and timing of mowing needs to be adapted to the local vegetation but some general recommendations are provided in Table 5 and Box 19.

Table 5 – When to mow (for biodiversity purposes)

Early Summer	***Late Summer***	***Late Autumn***
• Reflowering, grazing tolerant grassland plants • Ruderal vegetation with tall pioneers • Where a late summer flower resource would favour pollinators • Where dominant species need to be suppressed	• Later successional stages in nutrient-poor soils • Semi-natural grassland • Spring and early summer flowering species (e.g. in deciduous forests)	• Ruderal plants with low tolerance to mowing • Dry habitats • Very nutrient-poor sites • Sites where summer flower resource is important for pollinators

Box 19 – Issues relating to the frequency and timing of mowing

• Nutrient richness can result in a low diversity of dominant species. High-frequency mowing, with removal of cuttings, can reduce nutrient richness and this can be maintained by continued mowing and removal. While it is context dependent, reduced nutrient richness tends to be better for biodiversity. Other low vegetation is favoured by moderate mowing frequency.
• Succession:
  ○ Mowing can preserve mid-succession species richness (which can be higher than late succession richness – the number of species tend to go down with succession).
  ○ Hence mowing can be used to slow down succession, leading to a reasonably stable mid-succession stage, comprising grasses and perennials, long term.
• Mosaic mowing (leaving 15 to 30% per year in a rotating scheme) is recommended in a Dutch practical guideline (Provincie Zuid-Holland 2019).
• Late season mowing is often recommended but in some cases, an additional spring cut can be beneficial.
• Some variation in the time of mowing from year to year, is generally beneficial for biodiversity.
• To promote diversity and in order to extend the flower resource over the season, a mix of early and late-mown sites is often favourable in a region.
• In general, the following is recommended:
  ○ Frequent mowing (2 to 3 times per year) for nutrient-rich verges and
  ○ Single mowing, when most plants have finished reproduction, for low-nutrient verges with less grass dominance.

When to Remove Cut Material

In most situations, removing cut material favours biodiversity. One study (based on a review of 400 papers) and many guidelines, strongly recommend removal of mown vegetation (Svensson 2013). This reduces nutrient levels which favours plant species richness (and hence several groups of invertebrates). Even for verges of low biodiversity value, that value can be improved through removal of cuttings. However, removal of cut material is not always necessary and can be done on the basis of priority, as indicated in Table 6.

- Plant litter obstructs germination and the establishment of early life stages and small plants. Many rare plants are sensitive to litter.
- Mulching is not recommended (mulching causes nutrient enrichment and succession towards species-poor swards).
- How cuttings are removed is important – care should be taken not to remove animals or seeds.
- Disposal of removed cuttings is a challenge and perhaps an opportunity for carbon capture.

Table 6 – When to remove cut material

Circumstance	*Not often*	*Sometimes*	*Always*
Habitats that are species-rich but deteriorating			x
Habitats where growth of priority species is inhibited by a thick layer of plant litter			x
Habitats of digging bees or wasps or ground-dwelling thermophilic beetles			x
Roadsides of low biodiversity value		x	
Where the vegetation is low and sparse enough not to accumulate litter	x		
Dry or very nutrient-poor habitats		x	
Roadsides with medium or high nutrient levels		x	
Most types of species-rich roadsides with species from unfertilised semi-natural grasslands			x

When to Cut Hedges

Some recommendations on the cutting of hedges are provided in Box 20.

Box 20 – Recommendations for the cutting of hedges (Heritage Council 2016)

- Hedges should be cut outside the bird nesting season, i.e., between 1st September and the end of February (Birds Directive 2022).
- It is beneficial if hedgerow cutting can be delayed further, until after 1st December, to allow birds to avail of the available food sources there.
- Hedges should not be cut more frequently than once per year and once in two to three years is recommended. A rotational cutting policy will benefit biodiversity, i.e., cut adjacent hedges in different years.
- Hedges should not be cut in a vertical plane – the objective is an A-shape, wider at the bottom than the top.
- Overgrown or neglected hedges may be restored by coppicing, i.e., selective cutting at ground level to promote bushy regrowth.
- Gaps in hedgerows should be closed by planting.
- Hedge laying is labour intensive but effective. It involves part-cutting through selected stems, bending them over at an angle of 70 to 80 degrees and securing the stems.
- Crushing of hedgerows by heavy machinery should not be done.
- Only smooth wood species such as willow, hazel and cherry are suited to flail cutting.
- A circular saw should not be used for general maintenance.
- If practicable, hedge cuttings should be retained on site to provide habitat.

Potential Positive Maintenance Actions to Favour Biodiversity

There are situations where positive actions can be taken to promote biodiversity. Some of the best known examples are programmes to reconnect habitats that were fragmented in the past. However, other interventions are possible such as scraping (see Box 16) or burning, currently being trialled in Denmark (Hald & Bruun 2015). Both burning and scraping remove dominant species and expose bare earth, providing an opportunity for ruderal species to compete.

4.2 Management of Invasive Plant Species

IAPs damage species richness and may be a threat to the road construction itself (e.g., Japanese Knotweed (*Fallopia japonica*) can delay or halt construction). Member states of the European Union are legally required to take measures to achieve early detection and ultimately eradication of IAPs and to manage those species that are already widespread in their territories. The management of invasive alien plant species requires early detection, monitoring, prioritization, control and removal.

Monitoring of Invasive Species

Many IAPs are resistant to treatment and regrow afterwards. Hence, monitoring is an essential part of the management process, typically six to eight weeks after treatment.

- Early detection of IAP invasions is clearly beneficial so a national/regional system of monitoring should be implemented.
    - There is scope for the use of citizen science to contribute to this at low cost (for example see Flora Incognita 2022). It typically involves the development of a website and/or app, where members of the public can (a) identify and (b) report suspected infestations. The ControlinRoad booklet, (ControlinRoad D2.2 2018), may be useful for this.
    - Automated measurement vehicles using digital image processing may support the identification of infestations.
    - Trained personnel should be available to routinely monitor and to follow up on reported occurrence, particularly where other approaches are missing or ineffective.
- All infestations on the network should be mapped.
- Training of personnel is needed to recognize IAPs, at all stages of their lifecycle.

Methods of Control of Invasive Species

Strategies for the control of invasive alien plant species are addressed in Box 21. There are many control methods in use and in trials – see (ControlinRoad D3.1 2018) for details. A review of the literature on treatment methods is summarised in Appendix A. Herbicide treatment of IAPs is generally the most cost-effective option but is not allowed in most European countries. Some of the non-herbicide methods of treatment were tested in ControlinRoad. The results are summarised in Table 7. Recommendations on frequencies of treatment and duration of monitoring are given in Appendix A.

Box 21 – Control of invasive species
• Eradication or containment: In the context of limited resources, a strategic decision on IAP infestations in the short term may be to contain them (in areas where removal is impractical) and to remove them from new areas of infestation (ControlinRoad FR 2020). • Mowing of perennial invasive plants should be done twice a year, at the beginning of the growing stage (May/June) and before resources are transported to the storage organs of the plant (i.e. generally September/October), to weaken the plants (ControlinRoad D4.2 2019). • As the flowering period for most species is from June onwards, control measures should optimally be initiated during spring (late February to late May) to prevent plants flowering and thus producing seeds (ControlinRoad D4.2 2019). • Reseeding the roadside with desirable competitors after removal of IAPs is an important part of the treatment process. An alternative is to remove the topsoil. • Follow-up treatment for several years (around five years) will be required for Japanese knotweed (due to the extensive underground rhizomes causing re-growth) and giant hogweed (due to the soil seed bank). • For a few IAPs, mowing regimes are available: Ragweed (*Ambrosia artemisiifolia*) – Milakovic et al. 2014; Garden Lupin (*Lupinus polyphyllus*) – Brobäck 2015.

Table 7 – Some of the more effective methods of controlling invasive species evaluated in ControlinRoad (continued on next page)

	Description	*Advantages*	*Disadvantages*	*Suitable for IAP*
Mulching	Mulching is the standard method for reducing the height of plants and keeping the crop on site to avoid disposal costs. Further, the equipment used is robust and readily available.	Low cost relative to other mechanical control options, for medium to large-sized populations.	High frequency needed. To prevent seed production the timing is very important. High rate of re-sprouting, only short-term effect.	Common milkweed (*Asclepias syriaca*), Garden lupin (*Lupinus polyphyllus*), Giant hogweed (*Heracleum mantegazzianum*), Himalayan balsam (*Impatiens glandulifera*), Ragweed (*Ambrosia artemisiifolia*)
Mowing	In contrast to mulching, the biomass is not finely shredded during mowing, but is actively removed.	Low cost compared to other mechanical control options, for medium to large-sized populations.	High frequency needed. To prevent seed production the timing is very important. High rate of re-sprouting, only short-term effect.	Common milkweed *(Asclepias syriaca)*, Garden lupin *(Lupinus polyphyllus)*, Giant hogweed *(Heracleum mantegazzianum)*, Himalayan balsam *(Impatiens glandulifera)*, Ragweed *(Ambrosia artemisiifolia)*

Table 7 (continued)

	Description	*Advantages*	*Disadvantages*	*Suitable for IAP*
Hand removal	Removal of biomass by hand (uprooting)	Effective; highly targeted; surrounding native species unaffected.	High cost, labour intensive, only suitable in areas with low infestation (small stands)	Himalayan balsam (*Impatiens glandulifera*), Ragweed (*Ambrosia artemisiifolia*)
Digging	Removal of biomass by shovel, spade or bulldozer	Effective, highly targeted, surrounding native species remain largely unaffected.	High cost, labour intensive, only suitable in areas with low infestation, requires good access.	Common milkweed (*Asclepias syriaca*), Giant hogweed (*Heracleum mantegazzianum*), Giant rhubarb (*Gunnera tinctoria*), Sakhalin knotweed (*Fallopia sachalinensis*)
Herbicides	Chemical substances used to control unwanted plants	Effective, flexible, low cost	Prohibited in many countries for environmental reasons; herbicide resistance	All
Electrical	This is an electro-technical process for weed control	Effective against (young) annual grass and broadleaf plants	The deep root system of perennials seems not to be affected sufficiently. Still experimental.	Ragweed (*Ambrosia artemisiifolia*)

Cost Effectiveness of Methods of Control

Cost effectiveness depends on the type of species to be treated (annual/perennial/difficult to handle), infestation size and treatment width. ControlinRoad identified the most cost-effective and 2nd most cost-effective non-herbicide methods for three representative species. A summary is given in Table 8, with further details in Appendix A.

Table 8 – Most cost-effective non-herbicide methods of control of IAPs (ControlinRoad FR 2020)

Representative species	*Low plant density, 1 m treatment width*	*Medium plant density,3 m treatment width*	*High plant density, 10 m treatment width*
Giant hogweed (*H. mantegazzianum*)	1. Hand removal & disposal	1. Hand removal & disposal	1. Hand removal & disposal
	2. Mulching	2. Mulching	2. Mulching
Rhizome: Knotweed (*Fallopia* spp.)	1. Digging & disposal	1. Digging & disposal	1. Electricity
	2. Mowing & disposal	2. Electricity	2. Digging & disposal
Annual: Common ragweed (*A. artemisifolia)*	1. Hand removal & disposal	1. Electricity	1. Electricity
	2. Natural products (pelargonic acid)	2. Mulching	2. Mulching

Disposal of IAP Material

Part of the control of IAPs is disposal which should be done with great care and in accordance with legal obligations. Table 9 summarises the main methods of disposal. The choice of the method depends on the plant category (e.g. annual, perennial, woody species) and the developmental stage (before/after flowering). Some general recommendations are made in Box 22.

Table 9 – Methods of disposal of IAPs

Composting	*Burial*	*Burning*
For (industrial/commercial) composting, the plant material is maintained in heaps (‘windrows’) for several weeks to allow the decomposing organisms to break down the organic material (i.e. seeds and other propagules). It is an aerobic and exothermic process where the temperature rises to over 55°C for several weeks or months. The temperatures reached should destroy the seeds and seedlings of most IAPs. When temperature reaches 65ºC, just 1 week is enough (Nature Protection Institute of Slovenia 2020).	Plant material or soils containing seeds or fragments of IAPs can be buried at a minimum depth of 2 m, either at the original site or elsewhere. Plant material of Knotweed (*Fallopia* spp.) is recommended to be sealed in a geotextile membrane or buried at least 5 m deep in an authorized landfill site. (Environment Agency 2016)	Burning of plant material should be done in an industrial/ commercial incineration facility.

Box 22 – Recommendations for disposal of invasive alien plant material
• Annual and perennial herbaceous IAPs can be composted in industrial/commercial facilities, deep buried (on-site, landfill) or burned. • Some species cannot regrow from cut material (e.g., ragweed, *Heracleum mantegazzianum*, lupin) and do not need to be disposed of. Others (e.g., Himalayan balsam, *Fallopia* spp.) can easily regrow from cut stems and need to be safely disposed of. • Specific IAPs such as Knotweed (*Fallopia* spp.) should normally not be composted because they have vegetative parts (rhizomes, corms) that may survive in compost and spread to new locations when the compost is distributed. The plant material should be disposed of by deep burial or controlled burning. • Woody IAPs should be chipped and used as mulch on-site or added to compost once fully dead and dried. Incineration of material may also be a viable option at (or near) the point of disposal, or it can be used as biomass or for wooden products. Open burning is not recommended for fruits of plants that can be transmitted by the wind because the seeds could be spread in the surrounding area by warm air that rises during combustion (Nature Protection Institute of Slovenia 2020). • Dehydration of cut material on site provides an opportunity to reduce mass and volume and hence transportation costs. • Disposal of mowing/cutting materials near water bodies is a particular risk. • Biosafety: To avoid the spread of plant parts and seeds, equipment (e.g. machines, tools) and clothing/shoes must be carefully cleaned.

5. Conclusions

This report provides guidance on methods to promote biodiversity and address invasive alien plants in road verges. An introduction provides brief explanations for non-experts of the main issues, including disturbance and succession, connectivity/fragmentation, ecological traps and ecotones. Road owners are advised to develop their own guidance documents in three areas in advance of any road planning or construction: (i) a biodiversity potential map of the landscape and the road network, (ii) a maintenance masterplan and (iii) a policy strategy on the issue of invasive alien plants. A scoring system is recommended which can be used to rate the biodiversity value of verges and examples are provided of species groups that might be the focus in biodiversity priority areas.

In the early stages of planning for road construction and widening, it is recommended that the potential for biodiversity enhancement be taken into account. For example, the verge may have the potential to provide connectivity between patches of quality habitat in the landscape. At the detailed design stage, many features can be incorporated that positively influence biodiversity such as irregular edges, uneven surfaces and wet patches. Methods commonly used to mitigate the negative impacts of road construction are rated for effectiveness.

General principles are provided for biodiversity-friendly maintenance practices and specific recommendations are provided on the frequency and timing of mowing and hedge cutting. Specific recommendations are provided on the treatment of verges that contain invasive alien plants. Advantages and disadvantages of both established and new approaches are provided and the most cost-effective non-herbicide methods are identified. Disposal of invasive plant material is also addressed.

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Appendix A – Additional Information on Invasive Species and their Treatment

The most problematic Invasive Alien Species (IAPs) in Europe are listed in Table A1. It is recommended that the focus should be on the species listed as of Union Concern ('EU'). However, some road owners may wish to customise their priority list, based on what is locally problematic.

Table A1 – Most problematic IAPs along roadsides, 2022 (EU = of European Union Concern; EPPO = European and Mediterranean Plant Protection Organisation list)

Species	Category	Species	Category
Acacia saligna	EU	*Heracleum sosnowskyi*	EU
Ailanthus altissima	EU, EPPO	*Humulus scandens*	EU
Alternanthera philoxeroides	EU	*Hydrocotyle ranunculoides*	EU
Andropogon virginicus	EU	*Impatiens glandulifera*	EU, EPPO
Arthurdendyus triangulatus	EU	*Koenigia polystachya*	EU
Ambrosia artemisiifolia	EPPO	*Lagarosiphon majo*	EU
Amelanchier spicata	EPPO	*Lespedeza cuneata*	EU
Asclepias syriaca	EU	*Ludwigia grandiflora*	EU
Baccharis halimifolia	EU	*Ludwigia peploides*	EU
Buddleja davidii	EPPO	*Lygodium japonicum*	EU
Cabomba caroliniana	EU	*Lysichiton americanus*	EU
Cardiospermum grandiflorum	EU	*Microstegium vimineum*	EU
Cortaderia jubata	EU	*Myriophyllum aquaticum*	EU
Cornus sericea	EPPO	*Myriophyllum heterophyllum*	EU
Ehrharta calycina	EU	*Parthenium hysterophorus*	EU
Eichhornia crassipes	EU	*Pennisetum setaceum*	EU
Elodea nuttallii	EU	*Persicaria perfoliata*	EU
Fallopia japonica	EPPO	*Prosopis juliflora*	EU
Fallopia sachalinensis	EPPO	*Prunus serotina*	EPPO
Fallopia x bohemica	EPPO	*Pueraria montana*	EU
Gunnera tinctoria	EU	*Rugulopteryx okamurae*	EU
Gymnocoronis spilanthoides	EU	*Salvinia molesta*	EU
Hakea sericea	EU	*Senecio inaequidens*	EPPO
Helianthus tuberosus	EPPO	*Solidago canadensis*	EPPO
Heracleum mantegazzianum	EU, EPPO	*Solidago gigantea*	EPPO
Heracleum persicum	EU	*Triadica sebifera*	EU

Table A2, taken from ControlinRoad D3.1 (2018), lists advantages and disadvantages of various methods of treatment of IAPs. Some of these methods are still being tested.

Table A2 – Review of Literature on Methods of Treatment, established and in tests. In the last column (continued on following pages)

Method	*Advantage*	*Disadvantage*	*Plant species*	*IAPs (selection)*	*Main references*
Standard methods – Mechanical control					
Mowing & Mulching	Comparable low cost to other mechanical control options for medium to large-sized populations; standard measure.	High frequency needed to prevent seed production. The timing is very important. Some IAPs (*Fallopia* sp.) sprout from stem fragments. High rate of sprouting; only short-term effect.	Annuals, perennials.	*Ambrosia artemisiifolia, Lupinus polyphyllus, Asclepias syriaca, Heracleum mantegazzianum, Impatiens glandulifera.*	Pyšek et al. 2007, Brobäck 2015, Zalai et al. 2017, Lommen et al. 2017, G. Gebhard (road maintenance unit, Burgenland, Austria), pers. com.
Hand removal (uprooting)	Effective, highly targeted, surrounding native species unaffected.	High cost, labour intensive, only suitable in areas with low infestation (small stands).	Annuals	*Impatiens glandulifera, Ambrosia artemisiifolia*	Howell 2002, D. Fischer (Zürich), pers. com
Digging	Effective, highly targeted, surrounding native species remains largely unaffected.	High cost, labour intensive, only suitable in areas with low infestation, requires good access.	Annuals, perennials.	*Fallopia* sp., *Asclepias syriaca*, *Gunnera tinctoria, Heracleum mantegazzianum.*	Pyšek et al. 2007, D. Fischer (Zürich), per. com.
Brushing	Effective	Only used on hard surfaces, negative effect on the pavement.	Annuals, perennials.	Experimental, field tests available, not yet tested on relevant IAPs.	Rask & Kristoffersen 2007.

Table A2 – (continued)

Method	*Advantage*	*Disadvantage*	*Plant species*	*IAPs (selection)*	*Main references*
Standard methods – Chemical control					
Herbicides	Effective, flexible, low cost.	Environmental problems, herbicide resistance.	Annuals, perennials, shrubs, trees.	Experimental and/or field tests available, tested on relevant IAPs.	Jones et al. 2018
Alternative methods – Mechanical control					
Mowing (removal). competitive seed mixture	Sustainable method.	Restoration of native vegetation is critical	Annuals and biannuals.	*Ambrosia artemisiifolia*	Schuster et al. 2018
Stem girdling (ring-barking)	Effective to prevent re-sprouting, surrounding native species unaffected.	High cost, labour intensive, only suitable in areas with low infestation.	Shrubs and trees.	*Robinia pseudoacacia*, *Ailanthus altissima, Acer negundo*	Böcker & Dirk 2008, Merceron et al. 2016.
Suffocation/ Smothering	Effective (inhibits germination and budding). Prevents spread into neighbouring sites, used during road construction.	Less effective against rhizome perennials (e.g. *Fallopia japonica*), maintenance effort, difficulty of removal, disposal management. Alternative: biodegradable mulch film.	Annual, perennials.	Practical use in agriculture (vegetables), experimental, tested on relevant IAPs (e.g. *Fallopia japonica, Heracleum mantegazzianum, Impatiens glandulifera*)	Jones et al. 2018, Web Reference 1.

Table A2 – (continued)

Method	*Advantage*	*Disadvantage*	*Plant species*	*IAPs (selection)*	*Main references*
Alternative methods – Natural products					
Organic acids (e.g. acetic acid, pelargonic acid, caprylic acid, capric acid)	Effective against (young) annual broadleaf plants	Not very effective against grass species and perennials, only “burndown effect”, high dosages needed, high costs.	Annuals	Experimental and/or field tests available (along roadsides), not yet tested on relevant IAPs.	Young 2004, Abouziena et al. 2009, Barker & Prostak 2014, Crmaric et al. 2018.
Essential oils (e.g. clove oil, pine oil, citrus oil)	Effective against (young) annual broadleaf plants, positive image of the product (‘natural‘)	Not very effective against grass species and perennials, only “burndown effect”, high dosages needed, high costs.	Annuals	Experimental and/or field tests available (along roadsides), not yet tested on relevant IAPs.	Young 2004, Boyd et al. 2006, Abouziena et al. 2009, Barker & Prostak 2014.
Plant oils (rape oil, sunflower oil)	Reduces biomass of plants, environmentally friendly.	Herbicidal activity appears low (depends on plant species), more treatments necessary, quantities required may not be economically viable	Annuals, perennials	Experimental and/or field tests available, not yet tested on relevant IAPs	Hodge et al. 2018.
Iron chelate solution	Selective, for broadleaf plants, no residuals.	Repeated treatments necessary, product not available in Europe yet.	Annuals, perennials	Not yet tested on IAPs.	Smith-Fiola & Gill 2014.

Table A2 – (continued)

Method	*Advantage*	*Disadvantage*	*Plant species*	*IAPs (selection)*	*Main references*
Alternative methods – Natural products (continued)					
Corn gluten meal (crude botanical product)	Pre-emergence herbicidal activity, positive image ('natural product').	Grasses and perennial weeds are less sensitive, applicability along roadsides questionable (e.g. high quantities needed).	Annuals	Experimental and/or field tests available (along roadsides), not yet tested on relevant IAPs.	Barker & Prostak 2014, Dayan & Duke 2010.
Plant allelopathy *Festuca rubra*, *Festuca arundinacea,* straw/mulch (crude botanical product)	Can be effective.	Effectiveness depends largely on the weed spectrum, applicability along roadsides questionable (e.g. high quantities needed), more experiments necessary.	Annuals, perennials.	Experimental and/or field tests available, not yet tested on relevant IAPs.	Bertin et al. 2007, Recasens et al. 2018.
Alternative methods – Physical					
Direct flame	Can be effective (on a hard surface 100% reduction of weed cover).	Effectiveness depends on plant age & species, weather conditions; less effect on perennials; high energy consumption (6.82 kg/h, working width 1 m), fire hazard.	Annuals	Experimental and/or field tests available (along roadsides), not yet tested on relevant IAPs.	Ascard 1995, Rask & Kristoffersen 2007, Barker & Prostak 2014.
Hot water	Can be effective, moderate environmental impact.	Effectiveness depends in particular on plant age and species, weather conditions, less effect on perennials.	Annuals	Experimental and/or field tests available, not yet tested on relevant IAPs.	Kurfess & Kleisinger 2000, Rask & Kristoffersen 2007, Web Reference 2.

Table A2 – (continued)

Method	*Advantage*	*Disadvantage*	*Plant species*	*IAPs (selection)*	*Main references*
Alternative methods – Physical (continued)					
Hot foam made from plant oils and sugar	Can be used on any surface, low energy consumption, keep heat on the plant.	Very high impact on environment because palm oil and avocado oil is used.	Annuals	Experimentally tested.	Foamstream available in the US market (Web Reference 3).
Steaming	Can be effective, less water use as than hot water, higher heat transmission	Effectiveness depends in particular on plant age and species, weather conditions; less effect on perennials; higher risk of energy loss during application.	Annuals	*Erigeron annuus, Senecio* sp. Experimental and/or field tests available, not yet tested on relevant IAPs.	Rask & Kristoffersen 2007.
Hot air	Effect similar to other thermal controls.	Effectiveness depends in particular on plant age and species, weather conditions, less effect on perennials; high energy needed, only small machines are available.	Annuals	Experimental and/or field tests available, not yet tested on relevant IAPs.	Rask & Kristoffersen 2007.
Cold water (under high pressure)	Can be effective, machine for practical use available.	Cost intensive	Annuals	Experimental and/or field tests (orchards) available, not yet tested on relevant IAPs.	Bravin & Kuster 2016.

Table A2 – (continued)

Method	*Advantage*	*Disadvantage*	*Plant species*	*IAPs (selection)*	*Main references*
Alternative methods – Physical (continued)					
Infrared/ Radiant	Can be effective	Effectiveness depends in particular on plant age and species, weather conditions; less effect on perennials; high cost, low area output.	Annuals	Experimental and/or field tests available, not yet tested on relevant IAPs, no machine available.	Ascard 1995, Rask & Kristoffersen 2007.
Microwaves		High energy consumption (1000 to 3400 kg diesel/ha), no machine for practical use available, experimental stage.	Annuals	Experimental and/or field tests available, not yet tested on relevant IAPs.	Sartorato et al. 2006, Rask & Kristoffersen 2007.
Laser radiation	Lower energy cost compared to other thermal controls.	Does not kill plants, only retards plant growth, no machine for practical use available, experimental stage for direct targeting of the specific plant species.	Annuals	Experimental and/or field tests available, not yet tested on relevant IAPs.	Rask & Kristoffersen 2007, Mathaissen et al. 2006, Kaierle et al. 2013.
Freezing (i.e. liquid nitrogen and carbon dioxide)		Only destroys upper part of the plants, no machine for practical use available. Treatment is time & cost intensive, can damage road infrastructure.	Annuals, perennials	Experimental and/or field tests available, not yet tested on relevant IAPs, except *Fallopia* sp.	Rask & Kristoffersen 2007, LIFE12 NAT/AT/000321.
Electrical	Effective against (young) annual grass and broadleaf plants.	The deep root system of perennials seems to be not affected sufficiently, experimental stage	Annuals (perennials)	*Ambrosia artemisiifolia*.	

Table A2 – (continued)

Method	*Advantage*	*Disadvantage*	*Plant species*	*IAPs (selection)*	*Main references*
Alternative methods – Biological control (examples)					
Chondrostereum purpureum	Effective	Cultivated and native *Prunus* sp. are also affected, commercially developed, but not on the market.	Trees (*Prunus* sp.)	*Prunus serotina*	De Jong 2000, Hamberg et al. 2017, Web Reference 4.
Verticillium nonalfalfae	Effective, commercially developed and temporarily authorized in Austria.	Labour intensive (stem inoculation), follow-up host range studies are needed.	Tree (*Ailanthus altissima*)	*Ailanthus altissima*	Maschek & Halmschlager 2017, 2018.
Puccinia komarovii var. *glanduliferae*	Effective, already released in the UK, (establishment phase).	Biotypes of *Impatiens glandulifera* seem to be less sensitive	Annuals (*Impatiens glandulifera*)	*Impatiens glandulifera*	Varia et al. 2016.
Grazing (e.g. goats)	Viable option for specific right of way situations (e.g. reclaiming overgrown sites)	High cost (e.g. fence needed), not widely applicable, security concerns	Annuals, perennials, shrubs and trees.	*Robinia pseudoacacia, Ailanthus altissima*, *Fallopia* sp., *Heracleum mantegazzianum, Impatiens glandulifera.*	Popay & Field 1996, Willard 2016.

Frequencies of treatment and duration

Tables A3 to A5 provide an indication of the benefits of different control methods (ControlinRoad WP5.2 2020). The effectiveness is rated as low/medium/high, after 10 years of implementation.

Table A3 – Effectiveness of standard methods of control of Heracleum mantegazzianum

Method	*No. treatments per year*	*Duration of management (years)*	*Duration of monitoring (years)*	*Effectiveness*
Mulching	3	5	8	medium
Mowing + disposal	3	5	8	medium
Hand removal + disposal	1	1	8	high
Glyphosate	2	5	8	high

Table A4 – Effectiveness of standard methods of control of Fallopia spp.

Method	*No. treatments per year*	*Duration of management (years)*	*Duration of monitoring (years)*	*Effectiveness*
Mulching	4-8*	>10	8	low
Mowing + disposal	4-8*	7	8	medium
Hand removal + disposal	8	7	8	medium
Digging + disposal	1	1	8	high
Glyphosate	2	3	8	medium

** A range between 4 and 8 treatments per year is used according to the literature and stakeholders*

Table A5 – Effectiveness of standard methods of control of Ambrosia artemisiifolia

Method	*No. treatments per year*	*Duration of management (years)*	*Duration of monitoring (years)*	*Effectiveness*
Mulching	3	5	8	medium
Mowing + disposal	3	5	8	medium
Hand removal + disposal	1	5	8	high
Glyphosate	1	5	8	high

Cost effectiveness of methods of control

Figures A1 to A3, taken from ControlinRoad WP3&4 2020, provide an overview of the calculated Cost Benefit Ratio per thousand euro, for the following three defined scenarios:

- Minimum scenario: low plant density, 1 m treatment width, upper effectiveness range (between 90% and 100%);
- Main scenario: medium plant density, 3 m treatment width, medium effectiveness range (between 50% and 90%);

- Maximum scenario: high plant density, 10 m treatment width, lower effectiveness range (up to 50%).

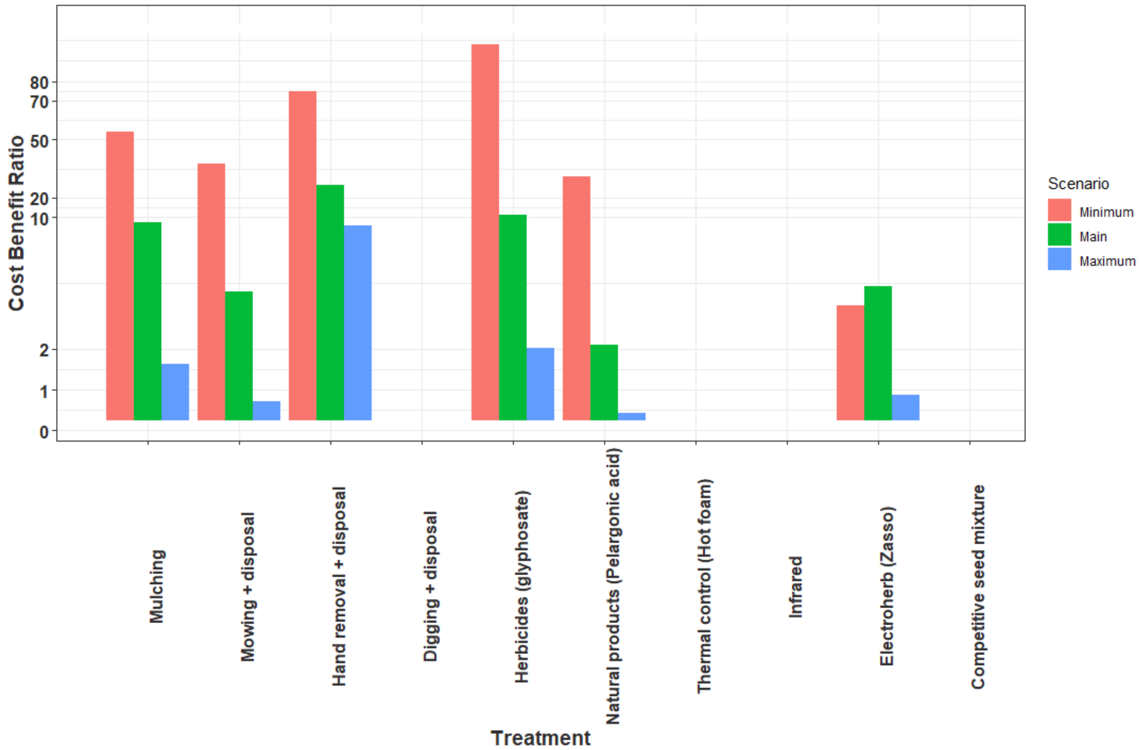

Figure A1 – Cost benefit per thousand euro of various methods of treatment for H. Mantegazzianum for minimum (red), main (green) and maximum (blue) scenarios

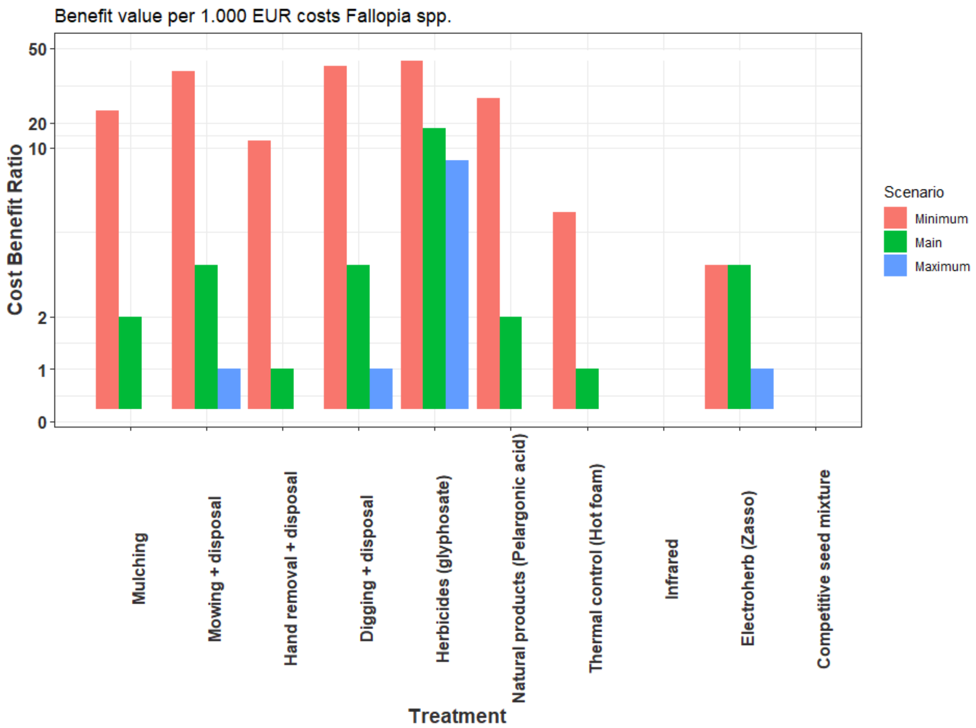

Figure A2 – Cost benefit per thousand euro of various methods of treatment for Fallopia spp. for minimum (red), main (green) and maximum (blue) scenarios

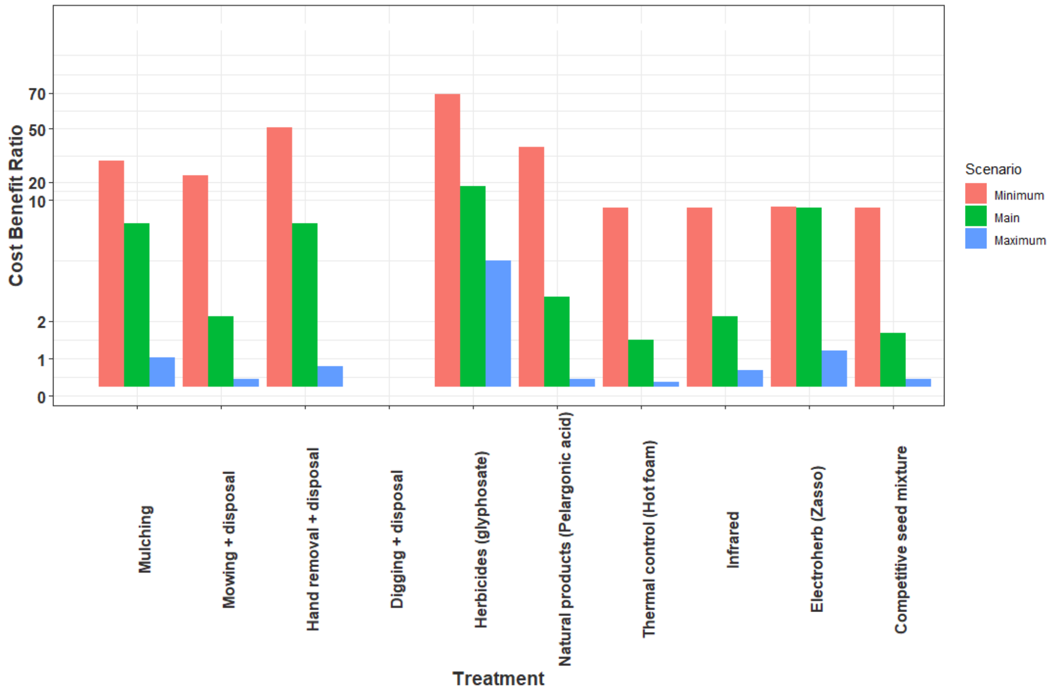

Figure A3 – Cost benefit per thousand euro of various methods of treatment for A. artemisifolia for minimum (red), main (green) and maximum (blue) scenarios

Appendix B – Additional Description and Discussion of Criteria used to Score the Biodiversity Potential of a Roadside

The following are edited extracts taken from EPIC Roads 3.1 2021.

Category: Landscape
Landscape (A) contains the subcategories (A1) *habitat quality* in the surrounding landscape, (A2) *connectivity* to the adjacent habitat, and (A3) the *regional species pool* as a source of biodiversity along roadsides.

Habitat quality in the landscape (A1) also affects the ecological value of a roadside, since the adjacent landscape can accelerate the plant compositional changes towards late-successional stages at the roadside, providing it with diversity and different degrees of landscape resistance. The nearby presence of designated NATURA 2000 protected areas can also positively influence the ecologic development of a roadside via plant and animal dispersal, and therefore should be considered. Thus, the scores are assigned to the increasing numbers of habitats of good ecological quality and protected habitats in the vicinity of a roadside.

Connectivity to the adjacent habitat (A2) is negatively affected by fences, rail tracks, paths, powerlines, or any other barriers. Existing connectivity from one roadside to the other through wildlife crossing structures over or under the road are considered as positive landscape-connecting elements. Increased structural connectivity (e.g., via steppingstones) is positively correlated with biodiversity and ecosystem services, since roadsides may then function as corridors for the movement of plants and animals longitudinally and laterally to the road. The more connectivity present (a) along the road, (b) from the adjacent landscape to the roadside, and (c) from one roadside to the other side of the road through wildlife crossing structures, the higher the connectivity of a roadside.

The regional species pool (A3) of the roadside habitats reflects the *potential* biodiversity at roadsides that for many species are both site- and dispersal-limited. The more regional species there are compared to the area available at the roadside, the greater its ecological value. Therefore, the higher the regional species pool, the greater the score assigned. Clearly the presence of invasive species is recognised as an indicator of reduced ecological value of roadsides, and thus should be considered in the evaluation of the regional species pool as a negative factor.

Category: Area
Area or ecotone (B) contains the subcategories of (B1) *longitudinal* and (B2) *lateral* extent of the roadside, (B3) *steepness and aspect* across and along roadsides, and (B4) degree of *human influence* within the road corridor.

Longitudinal extent (B1) represents the length of a roadside habitat without any interruption by crossroads, bridges, or water bodies. A positive evaluation correlates with the length, ascending from low to intermediate to high, since the longitudinal connectivity of a roadside as an ecotone positively impacts pollinator diversity and enables pollinator movement and thus increases pollination in general. Similar patterns may be seen in other ecosystem services, that are positively correlated with length of a roadside.

Lateral extent (B2) is the width of a roadside up to its adjacent habitats (e.g. crop fields), urban boundary (e.g. service road, separation ditch, fence, building, footpath) or any natural boundary (e.g. river, lake, forest) outside the road corridor. Plant biodiversity can be significantly increased by management methods that implement planting or preservation of different heights of vegetation. For safety reasons, taller vegetation should only be established in ascending order further from the road. Thus, the wider the roadside is, the more differentiated the vegetation can be. The more differentiated the roadside vegetation is, the more differentiated is its animal biodiversity.

Steepness (B3) is the lateral or longitudinal difference between the maximum and minimum height per unit length. This estimate of the slope within a road corridor needs not distinguish between raised or lowered roads. Some steepness is considered as positive, because a steeper roadside increases abiotic gradients and thus the potential for habitat diversity, while habitat area and distance to the road are reduced. However, very steep roadsides may lead to increased contamination and higher road mortality. Moreover, these slopes may be stabilised by engineering measures with metal nets or concrete constructions that reduce ecological habitat quality. Therefore, the positive evaluation ascends from level to intermediate slopes, while very steep slopes have reduced ecological value. Aspect/orientation relative to the sun is important for reptiles and thermophilic insects. South-facing is considered best and East/West facing is of medium value. Combining steepness and aspect gives Table B1 which is summarized in Table B2.

Table B1 – Biodiversity score based on slope and aspect

	Low slope (<5%)	Medium slope (5 – 20%)	High slope (>20%)
North aspect	0	1	0
East or West aspect	0	2	0
South aspect	0	2	1

Table B2 – Summary of biodiversity value based on slope and aspect

<table>
<tr><th>Low value (score 0)</th><th>Medium value (score 1)</th><th>High value (Score 2)</th></tr>
<tr><td>Any aspect with low slope</td><td>North aspect with medium slope (5 – 20%)</td><td rowspan="2">East, West or South aspect with medium slope (5 – 20%)</td></tr>
<tr><td>North, East or West aspect with high slope (>20%)</td><td>South aspect with high slope (>20%)</td></tr>
</table>

Human influence (B4) within and beyond the road corridor relates to all human-made disturbance to wildlife through traffic noise, collision and artificial light (e.g., vehicle headlights, street lighting). Road noise intensity and frequency causes disturbance of animals and streetlights not only artificially illuminate the road, but often the roadsides as well, and therefore interfere with the nocturnal life of animals. The negative evaluation correlates to the overall intensity of the human interference.

Category: Habitat

Habitat (C) comprises the subcategories of (C1) *light* intensity (aspect, angle and shadowing vegetation or other structures), (C2) *water* and (C3) *nutrient availability*, (C4) *soil pH*, (C5) *degree of contamination* and (C6) potential for improvement of *management*. These categories can be estimated based on in-situ measurements or indicator species.

Light intensity (C1): Since sunlight is a limiting factor in most plant species (and high light is beneficial for many ectothermic animals as well) the amount of shade caused by shadowing vegetation or any other shading structures on a roadside, negatively correlates with biodiversity and ecosystem services.

Water availability (C2): Highest plant competition is expected at mesic sites, i.e. those with an intermediate amount of water supply. In these conditions many subdominant and transient species are suppressed by fast and tall growing grasses, forbs and woody species, resulting in low biodiversity. On the other hand, extreme hydric conditions (dry or wet) create suitable habitats for stress-tolerating plants, for amphibia (very wet) or bees and wasps (very dry and warm). Thus, the highest scores are awarded in the extremes: for low water availability, and high water availability.

Nutrient availability (C3): An increased nutrient supply that drives productivity is expected to be negatively correlated with biodiversity of plants and ecosystem services. With an abundance of nutrients, some plants will use them to increase their growing speed and will suppress many competitors via light limitation by growing faster and taller. Thus, increasing nutrient supply is awarded in decreasing point order from low to high.

Soil pH value (C4) is positively correlated to vascular plant richness in most parts of Europe, as explained through eco-evolutionary history and normally only subdivided into low (≤5.5) and high pH (>5.5). However, this recommendation is for a slightly more differentiated evaluation with acidic (pH < 5.0), near-neutral (5.0–7.0) and alkaline soils (>7.0). Experts can either measure soil pH or use indicator plants and animals to evaluate a given roadside.

Degree of contamination with pollutants (C5) is often expensive to measure but closely correlates with traffic volume and road width, since an increased amount of traffic is accompanied by an increased production of exhaust gases, rubber abrasion, heavy metal pollution, noise, and traffic light. Representing a negative linear correlation to biodiversity and ecosystem services, increasing contamination estimated through traffic volume is awarded scores in descending order.

Management (C6): Connell's classical 'intermediate disturbance theory' suggests highest species density of herbaceous plant communities at an intermediate level of disturbance, and in most cases the evidence in empirical studies is consistent with that prediction. Mowing, grazing, pruning, coppicing, fire, herbicides, harrowing, soil disturbance (compaction by road maintenance vehicles), or other management activities represent examples of these ecological disturbances that affect plants and animals in roadside habitats. The scoring is according to the potential for an improved level of disturbance/management from what is currently practiced. For example, a high score is awarded if the current management practice greatly disfavours biodiversity.

Appendix C – References to Original Project Reports

The EPIC Roads reports are listed in Table C1 and the ControlinRoad reports in Table C2.

Table C1 – EPIC Roads Reports

Report No.	Title	Link
D1.1	Dataset	https://www.cedr.eu/docs/view/61b9f489603f9-en
D1.2	Ecological effects of roads – a review of the literature	https://www.cedr.eu/docs/view/61b9f4c62492c-en
D2.2	Roadside habitats and biodiversity conservation – a literature review with focus on vascular plants and insects	https://www.cedr.eu/docs/view/61b9f5834ad5b-en
D2.3 – 2.5	Deliverables 2.3-2.5: Practical guidelines	https://www.cedr.eu/docs/view/61b9f6068dd82-en
D3.1	Deliverable 3.1: Development of a classification system that evaluates roadside habitats in Europe	https://www.cedr.eu/docs/view/61b9f67c76f0b-en

Table C2 – ControlinRoad Reports and Papers (continued on next page)

Report No.	Title	Link
D2.2	Deliverable D2.2: Booklet with IAP and description	http://www.controlinroad.org/sites/default/files/documents/CEDR_Booklet%20with%20IAP%20and%20Description.pdf
D3.1	Deliverable 3.1: Alternative methods in road construction, operation and maintenance in relation to Invasive Alien Plants (IAPs)	http://www.controlinroad.org/sites/default/files/documents/Deliverable%203_1_Evaluation%20of%20alternative%20methods.pdf
D3.2	Greenhouse assays	http://www.controlinroad.org/sites/default/files/documents/CEDR%20Deliverable%203_2_29062019.pdf
D3.3	Field trials	http://www.controlinroad.org/sites/default/files/documents/CEDR_D3_3_results%20field%20trials_4_03_2020.pdf

Table C2 – continued

Report No.	Title	Link
D4.2	Deliverable D4.2: State of the art of legislation, guidelines and best practices in road construction and maintenance for the control of invasive species	http://www.controlinroad.org/sites/default/files/documents/D4%202__State%20of%20the%20art%20of%20legislation%20guidelines%20and%20best%20practices%20in%20road%20construction%20and%20maintenance%20for%20the%20control%20of%20invasive%20species.pdf
WP 3&4	Recommendations and best practice guide based on outcomes of WP3 and WP4	http://www.controlinroad.org/sites/default/files/documents/CEDR_D_5_1_Recommendations_and_best_practice-guide.pdf
D4	List of invasive alien plants along roadsides	http://www.controlinroad.org/sites/default/files/documents/CEDR%20Deliverable%20No%204.pdf
WP5.2	WP5.2: Cost benefit calculations	http://www.controlinroad.org/sites/default/files/documents/CEDR_D5%202_Cost%20Benefit%20Calculation_1.pdf
FR	Final Report: Controlling the spread of invasive species with innovative methods in road construction and maintenance	http://www.controlinroad.org/sites/default/files/documents/Final%20report_30092020.pdf
Paper	Follak, S., Eberius, M., Essl, F., Fürdös, A., Sedlacek, N., Trognitz, F. 2018, 'Invasive alien plants along roadsides in Europe', *EPPO Bulletin*, 48, 256–265.	https://doi.org/10.1111/epp.12465

CEDR Contractor Report 2022-12

Final Programme Report from CEDR Research Programme Call 2016 Biodiversity

Conférence Européenne des Directeurs des Routes

Conference of European Directors of Roads

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