CEDR Transnational Road Research Programme
Call 2016: [Invasive Species and Biodiversity]

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Conférence Européenne des Directeurs des Routes
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ControlInRoad
Controlling the spread of invasive species with innovative methods in road construction and maintenance

Final Report
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CEDR Call 2016: Invasive Species and Biodiversity

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Conférence Européenne des Directeurs des Routes
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The Problem

Invasive alien species (IAS, including plants, animals, microorganisms) are a threat to biodiversity in Europe. The cost related to the damage caused by IAS to the European economy is estimated to amount to at least €12 billion per year in different sectors of the economy (https://ec.europa.eu/environment/pdf/13_07_2016_QA_en.pdf). Many countries are aware of the problem posed by IAS, however, generally appropriate management plans are not in place.

Roads are unique ecosystems that encompass the road, the median strip and the roadsides. Roadsides offer a unique habitat characterized by well-drained soils which often contain high concentrations of heavy metals, salt and nutrients. Due to the anthropogenic disturbance roadsides are more vulnerable to invasion by alien species compared to intact ecosystems. Through road maintenance activities, seeds of invasive alien plants (IAPs) can be easily dispersed to other sites.

In the last years, the need for new and effective methods to control IAPs has become more and more urgent. Roadside vegetation managers rely heavily on mechanical and chemical methods to control weeds and IAPs along roadsides. The use of chemicals has been debated for several years and also finds less and less acceptance by the general public. Moreover, the registration of herbicides is debated at the political level and some active ingredients will be most likely withdrawn from the market within the next few years. Some European countries have already regulated the use of herbicides along roadsides, e.g. in Austria, the use of herbicides along roadsides is prohibited. Furthermore, the most widespread standard methods (i.e. mowing, mulching) for vegetation management along roadsides are often not suitable to achieve adequate control of IAPs.

The Research Project

In 2016 the Call for Proposals entitled CEDR Transnational Road Research Programme Call 2016 was launched on behalf of the Conference of European Directors of Roads (CEDR). The aim of the research programme was to develop a strategy to eradicate or control the spread of IAPs while conserving and promoting indigenous biodiversity. Within subject 1 “Management of alien invasive species” the project ControlInRoad was funded.

ControlInRoad (“Controlling the spread of invasive species with innovative methods in road construction and maintenance”) was structured in five work packages (WPs) dealing with different aspects of IAP management:

- WP1: Management and organisation
- WP2: Compiling a list of relevant roadside IAPs in Austria, Germany, Ireland, the Netherlands, Norway, Slovenia and Sweden and providing a booklet with the description and control methods of the most abundant IAPs.
- WP3: Evaluating treatments of IAPs based on literature reviews as well as field trials
- WP4: Compiling national legislation and regulation referring to the control of IAPs
- WP5: Performing cost-benefit analysis and developing recommendation for road operators to control IAPs

Major Outcomes

All deliverables and relevant information about the project can be found on the website (http://www.controlinroad.org).

A list of relevant roadside IAPs in Austria, Germany, Ireland, the Netherlands, Norway, Slovenia and Sweden was compiled, and a booklet with the description and control methods of the most abundant IAPs was produced (Section 2).

Weed control methods were evaluated and assessed for their suitability for roadside IAP control. The advantages and disadvantages were summarized. Promising alternative (i.e. methods that are not commonly used) methods were the application of natural compounds (such as pelargonic acid), hot foam, infrared and electricity as well as removal of the plant by hand followed by seeding of a competitive seed mixture.
However, for most of the alternative methods for weed control publicly available data on their effectiveness against IAPs on road verges were lacking (Section 3).

In 2018 and 2019, field trials were performed with common ragweed (*Ambrosia artemisiifolia*) and knotweed (*Fallopia* spp.). Common ragweed was used as an example of an annual seed producing plant species and knotweed for a rhizomatous perennial plant species. Both plants frequently occur along roads. The control methods tested were selected based on the latest developments in the field of weed management and machine availability. For the control of common ragweed several of the tested alternative and standard methods, such as the application of hot foam (Weedingtech), electricity (Electroherb™), infrared (Brühwiler), pelargonic acid (product Beloukha) and up-rooting were successful. For knotweed, the plants treated with electricity were smaller than the untreated plants, however, no plants were eradicated. The results obtained indicate trends, which should be further validated in other environments (Section 4).

To evaluate the methods tested in the field trials in terms of costs, a cost-effectiveness analysis was carried out. The benefits of a certain measure were put in relation to routine vegetation management in different scenarios of IAP invasions considering three IAPs, common ragweed, knotweed and additionally, giant hogweed (*Heracleum mantegazzianum*). However, based on the cost-effectiveness analysis no generalization could be made. The most cost-effective method depends largely on the IAP to be treated, its density and the treatment width.

The current control methods as well as the legal regulations for the management of IAPs in the individual countries were collected in the form of an online questionnaire. The knowledge about IAPs, the application of control methods and national legislation and regulation varies greatly between countries. Based on the information gathered, it is proposed that the management of IAPs requires a holistic approach including the following main steps: to raise awareness and provide information, to inventory the occurrence of IAPs, to apply treatment and disposal, to monitor effectiveness and to conduct follow-up monitoring. (Section 5).

Specifically, the following recommendations can be made for the control of IAPs:

- It is highly important to raise awareness among the road operators, decision-makers and the public.
- A national system for the documentation of IAP occurrence along roadsides, size of the infestation, control methods applied and monitoring after the control should be established.

- An automated detection system of IAPs (e.g., aerial photographs, drone technology) to support documentation systems should be developed. Moreover, training of the operational personal to recognize IAPs is needed.
- An inventory of IAPs along planned routes during road construction is also of importance. Excavated soil that contains IAP material must be handled with great care (e.g. stored on site and clearly labelled as hazardous).
- An adequate budget must be guaranteed in order to carry out the control of IAPs over a long and sufficient period of time.
- Development of a management plan for IAPs should be based on a cost-benefit analysis. Priority should be given to IAPs listed as an invasive species of Union Concern.
- The best alternative control method replacing standard methods, such as herbicides, depends on the IAP to be treated (i.e. annual vs. perennial vs. woody species), the infestation size and treatment width. Control includes the safe disposal of plant material by burial or professional composting or combustion.
- Selected sites for treatment should be removed from the routine vegetation management to ensure the application of the selected methods and to avoid spreading of the IAPs to surrounding sites.
- Alternative control methods are suitable to control IAPs, but there are still some obstacles to overcome

    - Hot foam is a better alternative compared to hot water in terms of effectiveness, but application techniques must be further refined for the use along roadsides.
    - The application of electricity to control IAPs was effective on annual plants. This method needs to be further tested, in particular on other annual, but also on perennial plants. Additional tests for the safe application along roadsides are necessary.
    - Greening (i.e. seeding of a competitive seed mixture) has a potential for the suppression of IAPs. An appropriate seed mixture will largely depend on the target environment and its growth conditions. The application of specific plant growth-promoting microorganisms can be useful and needs to be further evaluated.

- In general, research is needed for long-term studies (> 3 years) for the control of IAPs in different environments and for the development of new methods to control IAPs, including biological control.

1 Introduction

Invasive alien species (IAS, including plants, animals, microorganisms) are a threat to biodiversity in Europe. The cost to the European economy is estimated to be at least €12 billion per year in different sectors of the economy (https://ec.europa.eu/environment/pdf/13_07_2016_QA_en.pdf). Horticulture, agriculture, aquaculture and transport/travel are considered as the main pathways for introducing IAS. Some of the most harmful invasive alien plant species (IAPs), such as giant hogweed and Himalayan balsam, were introduced in the 19th century as ornamental plants for gardens, from where they spread into the wild. Others were introduced unintentionally and arrived as contaminants, for example in seed mixes or in bird feed.

Transport infrastructure habitats are complex and diverse and heavily impacted by human activities. They are widespread and still increase in size and length in many countries, resulting in altered landscapes and wildlife communities. Furthermore, roads and their verges create new habitats, alter hydrological dynamics, and disrupt natural processes and habitats. Moreover, because of their unique habitat characteristics, roadsides often function as prime habitats and corridors for IAPs (Figure 1). Roads and adjacent areas are habitats, which are anthropogenically disturbed, mostly well drained, nutrient rich and heavily polluted with heavy metals and de-icing salts often facilitating the growth and spread of IAPs. These characteristics provide a growth advantage to robust plants which are well adapted to harsh conditions. Through road maintenance activities seeds of IAPs can be easily dispersed to other sites, where they may survive for a long period until the conditions for germination become favourable.

Figure 1. *Fallopia* spp. growing along the road

The European Union (EU) Regulation 1143/2014 on IAS aims to control or eradicate priority species, and to manage pathways to prevent the introduction and establishment of new IAS. The regulation is the most important European environmental policy measure to fulfil target 9 of the “Convention on Biological Diversity” and target 5 of the EU Biodiversity Strategy.

Three distinct types of measures are specified in Regulation 1143/2014, which follow an internationally agreed hierarchical approach to combat IAS:

- **Prevention**: a number of robust measures aiming at the prevention of intentional or unintentional introduction of IAS of Union concern into the EU.
- **Early detection and rapid eradication**: putting in place a surveillance system to detect the presence of IAS as early as possible and taking rapid eradication measures when they first appear to prevent their establishment
- **Management**: some IAS of concern are already established in some EU Member States. Concerted management actions are needed to prevent further spreading of IAS and to minimize the harm they cause.

The backbone of the Regulation is a list of species alien to the EU (called Union list). The list is prepared and constantly adapted with the assistance of a committee and a scientific forum. Species added to the Union list are identified as invasive through an evidence-based risk assessment, in accordance with prescribed criteria (Carboneras et al., 2018) The criteria for prioritised species is based on their impact on biodiversity and ecosystem services only and do not consider health and economic cost of IAS, although some species might cause such. At the first release in 2016, 37 species (animal and plants) were listed including the terrestrial plant species *Heracleum persicum*, *Heracleum sosnowskyi, Parthenium hysterophorus, Pueraria lobata*. With the update in July 2017, 12 additional species were added including e.g. the plant species *Asclepias syriaca*, *Gunnera tinctoria*, *Heracleum mantegazzianum*, *Impatiens glandulifera, Microstegium vimineum, Baccharis halimifolia*, *Microstegium vimineum* and *Persicaria perfoliata*. The last update in August 2019 included 17 additional species, such as the plant species *Ailanthus altissima*, *Andropogon virginicus*, *Cardiospermum grandiflorum*, *Cortaderia jubata, Ehrharta calycina*, *Humulus scandens*, *Lespedeza cuneate*, *Lygodium japonicum, Pennisetum setaceum*, *Prosopis juliflora* and *Triadica sebifera*. The Union list covers less than 5% of the more than 1000 established IAPs in Europe with known ecological or economic impact in Europe (Carboneras et al., 2018). Some well-known IAPs are not in the list because either a risk assessment is lacking, the risk assessment did not include some of the information required by the Regulation, or there was insufficient evidence that the species meet the criteria for listing (https://ec.europa.eu/environment/pdf/13_07_2016_QA_en.pdf). The list of IAS of Union concern only contains species that are scientifically proven to be particularly harmful and that can be addressed in a cost-efficient manner.

Many countries are aware of the problem posed by IAPs, but generally appropriate management plans are not in place. In many countries, specific guidelines for the management of IAPs during road construction do not exist. Furthermore, excavated material contaminated with IAPs is often not treated as biological hazard.

In the last years, the need for new and effective methods against IAPs has become more and more urgent. Roadside vegetation managers rely heavily on mechanical and chemical methods to control weeds and IAPs along roadsides. The use of chemicals has been debated for several years and also finds less and less acceptance by the general public. Moreover, the registration of herbicides is debated at the political level and some active ingredients will be most likely withdrawn from the market within the next few years. Some European countries have already regulated the use of herbicides along roadsides, e.g. in Austria, the use of herbicides along roadsides is prohibited. Furthermore, the most widespread standard methods (i.e. mowing, mulching) for vegetation management along roadsides are often not suitable to achieve adequate control of IAPs.

As IAP management is associated with high costs, it is essential not only to address the suitability and effectiveness of a management method, but also to assess costs of the treatment as well as the cost-effectiveness and socio-economic aspects. To evaluate the most suitable method for the control of IAPs, a cost-benefit analysis (CBA) can help to support the decision on which method to choose.

Within the frame of the Project ControlInRoad it was intended to develop guidelines for the management of IAPs and to evaluate the costs for the treatment of IAPs in relation to the effectiveness (Figure 2). The main aims of the ControlInRoad project were to:

- compile a list of invasive alien plants (IAPs) associated with roads
- specify data on their management and related costs to the society
- provide a best practice-guide for the control of IAPs during road construction and maintenance
- provide new and cost-effective methods for the mitigation of IAPs for implementation in road construction and maintenance procedures.

The ControlInRoad project ran from 2017 to 2020 as part of the CEDR Transnational Road Research Programme Call 2016: Biodiversity.

In this final report, key messages and developed guidelines are provided.

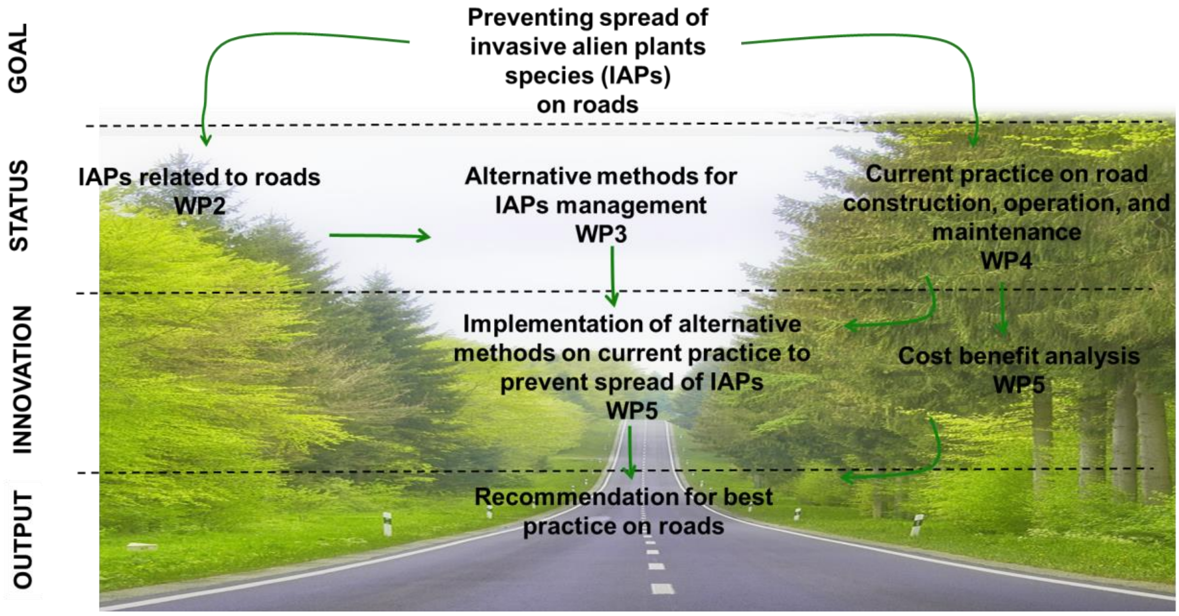

Figure 2. Structure of the ControlInRoad project

2 Invasive alien plants occurring along road infrastructure

The Problem

Road networks play an important role in facilitating the spread of IAPs by providing habitats for their establishment as well as by serving as corridors, which allow them to spread. Within the project, a questionnaire was used to obtain information on the road operators' knowledge of IAPs and their control to which 103 participants from 16 European countries responded. Although most of the participants were aware of the problem related to IAPs, knowledge about which IAPs regularly occur along roadsides and should be monitored, contained and controlled, was rather limited.

Our Approach

We aimed to provide road operators with a comprehensive list of IAPs related to road infrastructure and an identification tool for the most important IAPs. Information was used from the national IAP lists of Austria, Germany, Ireland, the Netherlands, Norway, Slovenia and Sweden as well as from results obtained by a detailed literature search, floristic database queries and expert consultations.

Key Findings

The elaborated document contains IAPs currently found along roadsides in Austria, Germany, Ireland, the Netherlands, Norway, Slovenia and Sweden. In total, 89 IAPs were identified and the complete list of IAPs can be found on the website (http://www.controlinroad.org, use tab “invasive plants”).

In a further step, IAPs from the document were prioritized in terms of impact within Europe based on the following two lists:

- List of IAS of Union concern
- EPPO list of IAPs

Species added to the List of IAS of Union Concern were identified as having a high impact in EU member countries by an evidence-based risk assessment. Species on the EPPO list are considered problematic also in non-EU European countries (https://www.eppo.int/ACTIVITIES/invasive_alien_plants/iap_lists). The EPPO classification is based on expert judgment. EPPO strongly recommends countries, endangered by these species, to take measures to prevent their introduction and spread, and to manage unwanted populations.

Six species from the list established by the project are included in the list of the Union and fifteen on the EPPO list of IAPs (Table 1).

Table 1. The current most problematic IAPs along roadsides and their categorization. EU refers to the List of IAS of Union Concern, EPPO refers to the EPPO List of IAPs

Species	Category
Ailanthus altissima	EU, EPPO
Ambrosia artemisiifolia	EPPO
Amelanchier spicata	EPPO
Asclepias syriaca	EU
Buddleja davidii	EPPO
Cornus sericea	EPPO
Fallopia japonica	EPPO
Fallopia sachalinensis	EPPO
Fallopia x bohemica	EPPO
Gunnera tinctoria	EU
Helianthus tuberosus	EPPO
Heracleum mantegazzianum	EU, EPPO
Heracleum persicum	EU
Impatiens glandulifera	EU, EPPO
Prunus serotina	EPPO
Senecio inaequidens	EPPO
Solidago canadensis	EPPO
Solidago gigantea	EPPO

Recommendations

- Need to raise awareness among road operators regarding the occurrence of IAPs

The developed documents containing IAPs along roadsides can be used to raise awareness among road operators. However, additional IAPs may become relevant for road operators. Thus, there will be a need to update the present list of IAPs along roadsides as new information becomes available (e.g. on the occurrence of specific IAPs along roadsides). Furthermore, certain species must be regulated by law (species are included in the Union list).

- Prioritised monitoring on species included in the list of Union Concern and from national lists

It is recommended that the focus in terms of monitoring and management of IAPs should be primarily on those IAPs, which are included in the List of IAS of Union Concern (*Ailanthus altissima*, *Asclepias syriaca*, *Gunnera tinctoria*, *Heracleum mantegazzianum*, *Heracleum persicum*, *Impatiens glandulifera*), as well as on the well-known invaders such as *Fallopia* spp., *Solidago* spp. and *Ambrosia artemisiifolia*. However, countries may select further IAPs they want to focus on, based on the elaborated document, i.e. species that specifically spread in their country along roadsides.

- Training operating staff on roads to recognize IAPs

Staff in charge of the surveillance of IAPs species should be trained to recognize IAPs at all stages of their lifecycle, even when only small populations occur. Surveys can be carried out during ordinary road maintenance. Photographs (both aerial and from the ground) and the use of drone technology can assist in surveillance. Citizen science projects may be also implemented. Identification keys for the listed IAPs are required. Within the framework of the project, a booklet (Deliverable 2.2) was developed which can be used for this purpose or as a basis for further development . Mobile apps for the identification of IAPs can also be used (e.g. www.plantnet-project.org, Flora Incognita).

- Regular monitoring of IAPs along roadsides

It is recommended to carry out regular surveys to monitor the distribution of IAPs along roadsides and their prevalence. A documentation (mapping) system is necessary. With the help of such a tool, IAPs along roadsides can be widely recorded and distribution maps for further analysis and decision support for suitable control options can be provided. The development of measurement vehicles for the automated mapping of IAPs along roadsides using digital image processing could support monitoring activities in the future.

- Selection of appropriate control methods

Control options for IAPs are evaluated in section 3 and 4. Some of the IAP management strategies can also be retrieved from EPPO PM 9 Standards (https://gd.eppo.int/standards/PM9/) or from the IUCN Technical Notes (https://www.iucn.org/theme/species/our-work/invasive-species/eu-regulation-invasive-alien-species).

Related deliverables and documents

- Deliverable 2.1 – List of IAPs along roadsides
- Deliverable 2.2 – Booklet with IAPs and Description
- Publication – Follak, S., Eberius, M., Essl, F., Fürdös, A., Sedlacek, N. and Trognitz, F. (2018): Invasive alien plants along roadsides in Europe. EPPO Bulletin 48, 256–265. https://doi.org/10.1111/epp.12465
- Website – List of invasive alien plants along roadsides, http://www.controlinroad.org/invasive-plants

3 Assessment of management practices for the road sector

The Problem

In the stakeholder consultation the most applied vegetation management practices along roads, mowing and mulching, were not considered to be effective against IAPs. Therefore, there is a great need to develop new technologies and management practises. However, most of the new technologies for weed management have been developed for the use in agriculture. Currently, only few publications examining different methods in field trials for vegetation management along roads beside the use of herbicides are available.

For the management of IAPs a budget has to be allocated for effective control. It is important for decision-makers to see the benefits of a specific measure in relation to the routine vegetation management. The Cost-Benefit Analysis (CBA) is recognised as an important decision support tool for the management of IAPs in Europe (Courtois et al., 2018; Hanley and Roberts, 2019; Reyns et al., 2018). For the species listed in the EU legislation, Member States are required to put effective management measures in place. Such measures shall be specific to the Member State, be proportionate to the environmental impact and be based on an analysis of the costs and benefits. The CBA including ecological, social and economic aspects is a prominent requirement of the European IAS regulation (Reyns et al., 2018).

For the calculation of the treatment costs the following components were included: Instrument and material costs, running costs like energy and machine maintenance, personnel costs for operating and monitoring, as well as additional costs like transport, disposal and chemicals. The benefits of controlling/eradicating IAPs can be defined as the benefit for the relevant stakeholder compared to the situation without controlling/eradicating IAPs (scenario “do nothing”). It is therefore necessary to assess the potential damage that can be avoided by using the control methods selected.

The following areas were considered in the analysis for possible damage caused by IAPs: road infrastructure, agricultural sector, human health and the environment.

Existing information on relevant costs allows the monetarisation of costs. The data situation to assess benefits of using control methods (equal to costs of doing nothing) enables only a qualitative valuation along an ordinal scale (benefit values). Therefore, the direct connection of benefit values and monetary costs by calculating the cost effectiveness (division of benefit values with monetary cost values) is chosen as the appropriate valuation method. Results of the cost effectiveness analysis (CEA) are benefit values per costs. These values enable the comparison of control methods and a ranking of control methods.

A CEA was performed for three different IAPs common in Europe, *Ambrosia artimisiifolia*, *Fallopia* spp. and *Heracleum mantegazzianum,* and the different treatments were evaluated in terms of cost and treatment effectiveness. The evaluation of the effectiveness of the selected methods was based on literature reports, stakeholder interviews and data from field trials. The three selected species occur regularly along roadsides and were identified as important IAPs that require attention and control (Follak et al. 2018, Deliverable 2.1). Control options (manual, mechanical, chemical) for these species are available, however, their control is still challenging due to their biological and ecological characteristics (Deliverable 2.2., Deliverable 3.1).

Key Findings

Various control methods were evaluated in terms of their advantages and disadvantages for use by road operators. Not all methods are suitable for all IAPs. Most of the alternative methods are still in the experimental stage. Furthermore, no control method exists, which is suitable to control all different IAPs. For most of the alternative methods for weed control publicly available data on their effectiveness on road verges are lacking. In Table 2 the evaluated standard and alternative methods with their advantages and disadvantages are summarized.

For the CEA, three different scenarios were defined. The minimum scenario assumes low plant density and 1 m treatment width. The main scenario assumed a medium plant density and 3 m treatment width, and the maximum scenario assumed high plant density and 10 m treatment width. For every treatment and plant species the efficiency was evaluated based on the results from the field trials performed within ControlInRoad, literature or stakeholder consultations.

For *A. artimisiifolia*, hand removal, and the treatment with pelargonic acid (applied twice) showed the best cost-benefit ratio after the treatment with herbicides in the minimum scenario. In the main scenario, mulching, hand removal and the use of electricity showed the best cost-benefit ratio after herbicide application. In the maximum scenario, assuming high plant density and 10 m treatment width, the treatment with electricity showed after the herbicide application the best cost-benefit ratio.

For *Fallopia* spp., the control method with the best cost-benefit ratio is for all scenarios the use of herbicides. As the best alternative method “digging/excavating and disposal” (minimum and main scenario) and Electroherb™ (maximum scenario) were identified.

With regard to the control of *H. mantegazzianum*, the application of herbicides showed the best cost-benefit ratio in the minimal scenario. For the other scenarios, manual removal and disposal proved to be the method with the best cost-benefit ratio.

Table 2. Summary of methods evaluated in frame of the project

Name of method	Group of method	Description of method	Advantage	Disadvantage	Suitable for IAP
Mulching	Standard Mechanical	Mulching is the standard method for reducing the height of plants and keeping the crop on site to avoid disposal costs. At the same time, the equipment used is very robust and readily available	Low cost 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	Standard Mechanical	In contrast to mulching, the biomass is not finely shredded during mowing, but is actively removed	Low cost 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)*
Hand removal	Standard Mechanical	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	Standard Mechanical	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	Standard Chemical	Chemical substances used to control unwanted plants	Effective, flexible, low costs	Environmental problems, herbicide resistance	**All**
Pelargonic acid	Alternative-natural	This is an organic compound (nine-carbon fatty acid)	Effective against (young) annual broadleaf plants.	Not very effective against grass species and perennials, only “burndown effect”, high dosages needed, high costs	Experimental and/or field tests available (along roadsides), not yet tested on relevant IAPs.
Hot foam	Alternative-physical	The method uses hot water in combination with foam made from natural, non-toxic ingredients including plant oils and sugars.	Can be used on any surface, low energy consumption, keeps heat on the plant	Low working speed	Experimentally tested
Infrared	Alternative-physical	Electromagnetic radiation (EMR) with wavelengths longer than those of visible light	Can be effective	Effectiveness depends in particular on plant age and species, weather conditions, less effect on perennials; high cost, low area output	Experimental and/or field tests available, not yet tested on relevant IAPs.
Electroherb™ (Zasso)	Alternative-physical	The Zasso Electroherb™ process is an electro-technical process for weed control	Effective against (young) annual grass and broadleaf plants	The deep root system of perennials seems to be not affected sufficiently, experimental stage	**Ragweed** *(Ambrosia artemisiifolia)*
Removal + seed mixture	Alternative-mechanical	Removal of IAPs and subsequent sowing of a mixtures of plant species to outcompete IAPs	Sustainable method	Restoration of native vegetation is critical	**Ragweed** *(Ambrosia artemisiifolia)*

Recommendations

- The cost effectiveness analysis is an appropriate method to compare different treatment methods.

Not all sites with IAPs infestation can be treated at the same time. When drawing up an action plan, the costs and benefits of the respective treatment should be taken into account. Based on the available budget, the appropriate plant species and plant density the control method can be selected.

- Herbicides have still the best cost-benefit ratio from the point of view of road administrators in terms of treatment costs without considering costs related to environmental damage.

However, the use of herbicides for weed control in non-agricultural or urban areas may lead to different environmental issues than when they are used in agriculture. Water quality monitoring studies have demonstrated that there is a disproportionate contamination of waters by non-agricultural herbicide use (Kristoffersen et al., 2008). Roads are built so that water can drain quickly, this can result in contamination of nearby ditches, drains, sewage systems or groundwater. In many European countries the use of herbicides in non-agricultural land is prohibited. Based on the CEA there is a need to develop effective and more economic non-chemical weed control methods.

- The best method replacing herbicides depends on the IAP to be treated, the plant density and the treatment width as seen in Table 3.

Based on the cost-benefit analysis no generalization can be made. It may be possible to use the same treatment methods for plants that have a very similar biology.

Table 3. Recommended control methods based on the cost effectiveness analysis

Recommended control methods to be used instead of herbicides based on the calculation of a cost-benefit ratio using a cost effectiveness analysis			
	Minimum	Main	Maximum
	Low plant density, 1 m treatment width	Medium plant density, 3 m treatment width	High plant density, 10 m treatment width
H. mantegazzianum	1. Hand removal + disposal	1. Hand removal + disposal	1. Hand removal + disposal
	2. Mulching	2. Mulching	2. Mulching
Fallopia spp.	1. Digging + disposal	1. Digging + disposal	1. Electricity (Electroherb)
	2. Mowing + disposal	2. Electricity (Electroherb)	2. Digging + disposal
A. artemisiifolia	1. Hand removal + disposal	1. Electricity (Electroherb)	1. Electricity (Electroherb)
	2. Natural products (pelargonic acid	2. Mulching	2. Mulching

- Long-term studies on the effectiveness of treatment methods are needed to improve the quality of the results.

Currently, there are only few studies on the treatment of invasive species in a time frame of more than three years. Long-term studies applying different methods for selected IAPs for at least five years to assess the reliability of the method and its efficacy in various environments are urgently needed.

Related deliverables and documents

- Deliverable 3.1 – Evaluation of alternative methods for the management of invasive alien plants
- Deliverable 5.2 Cost benefit calculation

4 Innovative management practices for the future

The Problem

Based on the feedback from different stakeholders, e.g. road operators, there is a need for new technologies for the management of IAPs, because most of the existing methods are not suitable for road verges. Herbicide application is highly efficient, however, has other drawbacks like environmental pollution and is therefore not permitted in the road sector in many countries. New technologies such as microwaves or electricity are still being tested and only prototypes are available. Other control methods such as thermal treatment methods are not only less effective, but also consume a lot of energy.

For the greening of newly created roadsides, seed mixtures are usually sown that are considered suitable for the respective location. Due to time and resource shortages, this initial planting often has to take place under unfavourable conditions for the seeds to germinate. Poor emergence of the sown plants results in open areas that can be colonized by IAPs. To ensure the growth of the desired plants even under stress conditions, the use of specific plant growth-promoting microorganisms can be advantageous.

Most of the IAPs do not cause damage in their place of origin, because natural enemies keep the population size low. In the classical biological control methods generally, organisms from the native range of the IAPs are used to control them in the invaded range. In Europe such methods are not common and the registration of such an agent is very costly or impossible. In contrast, the bioherbicide approach refers to all forms of biological control in which natural enemies already exist in areas where the target IAP is present. Still very little research is done on the development of bioherbicides for IAPs.

Our Approach

To achieve a fast and efficient vegetation cover on newly constructed roads, locally adapted seed mixtures are sown. This process may be improved in two ways to control and prevent the establishment of IAPs. First, the use of specific plant growth-promoting bacteria can be utilized to promote and facilitate the growth of desired vegetation and thus impede the establishment of IAPs. Second, the application of seed mixtures that contain plants producing allelopathic substances that may suppress the germination of IAPs is promising. Both approaches were tested in greenhouse trials within ControlInRoad.

For the biological control of Himalayan balsam bacteria associated with the plant were isolated. The bacteria were tested *in vitro* for the germination inhibition of lettuce (as a model), as the seeds of Himalayan balsam did not germinate in the lab.

In field trials, not widely used weed control methods were tested and their effectiveness evaluated. One field trial was set up to test different methods like hot foam, pelargonic acid, infrared, electricity, hand removal and mowing on common ragweed. In the second field trial the method applying electricity was tested for two years on knotweed and in one treatment hot foam was applied against knotweed.

Key Findings

Experiments were conducted with common ragweed as this species is a very common IAP along roadsides in many European countries. In the greenhouse trials, bacteria which were isolated and tested in frame of a previous project were tested to find out, if they are able to reduce the germination of ragweed. However, no bacterial strain was able to reduce the germination.

Three different bacteria were tested for plant growth promotion on two different seed mixtures frequently recommended and used for slope greening. None of the treated seeds performed better than the control without any bacterial inoculation.

Festuca rubra commutata produces the potent phytotoxin meta-tyrosine in high concentration (Bertin *et al.*, 2007; Tworkoski and Glenn, 2012). This non-protein amino acid has been proposed as a natural herbicide (Bertin et al., 2007) as it has been shown to strongly suppress the growth of weeds. The level of suppression of broadleaved weeds by fescue and ryegrass was similar to that of chemical herbicides (Tworkoski and Glenn, 2012). ControlInRoad tested different varieties of *Festuca* spp. for their ability to reduce the germination of common ragweed. One variety (Raisa) (Figure 3) significantly reduced the germination of common ragweed.

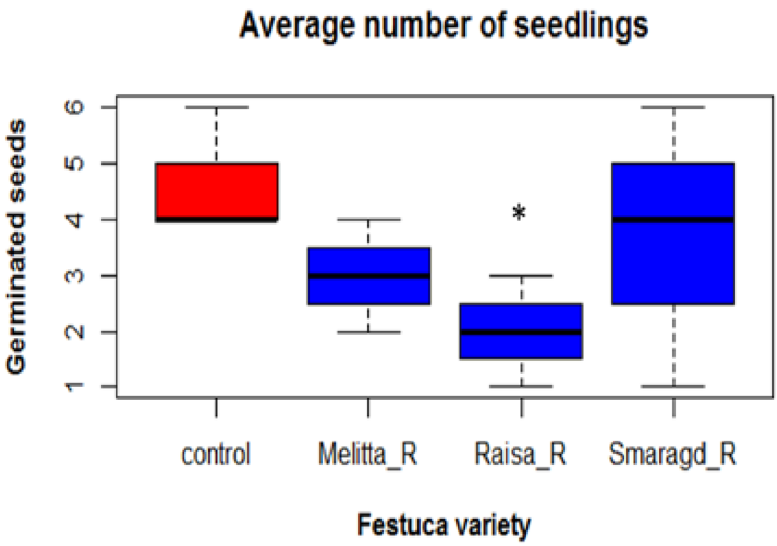

Figure 3. Germination inhibition by three different *Festuca* spp. varieties on *Ambrosia artimisiifolia*

Further research was conducted with Himalayan balsam (*Impatiens glandulifera*), which is listed in the EU regulation 1143/2014. Control measures must be developed to reduce its spread. Currently, contaminated sites are mostly mowed or mulched. One option could be the use of microorganisms to control the plant. During the project about 200 bacterial strains were isolated from Himalayan balsam to test them as control agents. Unfortunately, the collected seeds from Himalayan balsam did not germinate after several attempts to break the dormancy. To test the isolated bacteria lettuce seeds were used as they are often applied as model plants for phytotoxicity tests. The strains, which reduced the germination in lettuce, were tested on non-target plants like Busy Lizzie, rapeseed and wheat. Most of the strains only showed a reduction of germination in lettuce and most of the strains showed dose-dependent effects. The strains that reduces germination need to be further tested on Himalayan balsam seeds to prove the findings from the lettuce assay.

In the field trial on common ragweed the following methods were able to control the plant: hot foam (Weedingtech), electricity (Electroherb™), infrared (Brühwiler) and pelargonic acid (Belouka) applied twice and up-rooting. The measures caused the plants to die and no new shoots were formed. In contrast, the mowing of the plants caused new stems to sprout again and to produce flowers. The use of herbicides was not tested as it is prohibited in Austria, where the field trial was set up.

For the field trial on knotweed the method using electricity (Electroherb™) was tested on three different locations after mulching. Twice, in early summer and autumn, the plants were treated for two consecutive vegetation periods. After the first year, the total number of stems were not different in the treated plots with electricity compared to the only mulched plots. However, the size of the plants was smaller compared to the treatment using only mulching. Fewer plants above 50 cm were observed in the treatment with electricity compared to the control (Figure 4).

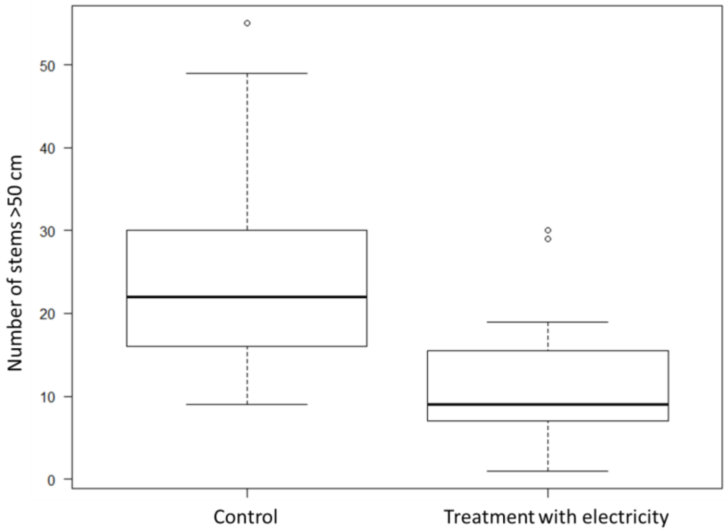

Figure 4. Number of knotweed stems >50 cm between control and the treatment with electricity across all locations

In the second year of field trials against knotweed, hot foam treatment was applied at one site instead of the application of electricity. In the plots treated with hot foam the lowest number of stems was observed ($P<0.01$). The difference between the control and the Electroherb™ method was not significant. The results received were obtained from only one site and one year and requires further testing. The foam is made from a natural blend of plant oils and sugars and it can be used on all surfaces and in all weather conditions. The disadvantage of hot foam is the low working speed, which makes the application very expensive in terms of manpower. The use of hot foam is safe for the operating personnel and for people and animals in the vicinity. The acquisition costs are lower compared to other instruments, like Electroherb™.

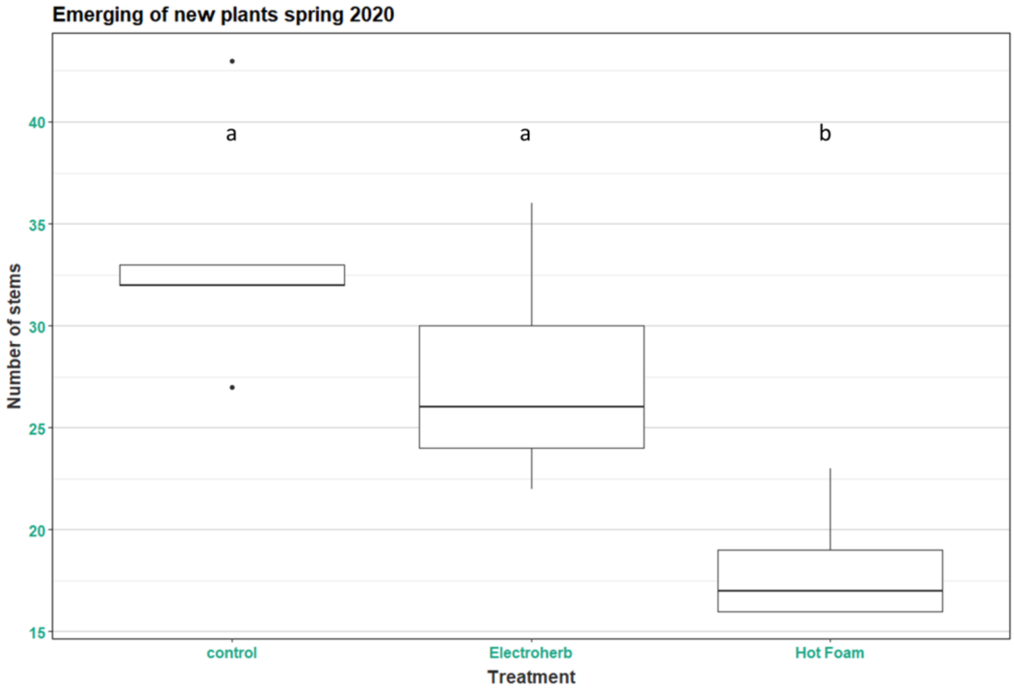

Figure 5. Number of emerging stems of knotweed in 2020 at location 3

Recommendations

- Using appropriate seed mixtures for greening road verges

It is important to establish a vegetation cover as soon as possible after roadside disturbance to avoid the invasion with IAPs. One of the measures would be the use of plant mixtures with a high percentage of plants with allelopathic effects like specific *Festuca* varieties, for example the variety Raisa.

- Management practices to ensure an even growth of the desired plants.

The use of beneficial microorganisms is seen as one of the most promising methods for safe crop management practices in agriculture. Since microorganisms are able to support plant growth even under harsh conditions such as drought, heat and salinity, they are suitable for promoting plant growth even at roadsides. The application of beneficial microorganisms for growth promotion on road verges is not yet explored. More research is needed to find out best combinations of plant species and beneficial microorganisms for the different environments. Since roadsides are planted with a mixture of plant species, the microorganisms should favour the growth of the different plant species. This could be done by a single species with a wide range of hosts or by using a combination of different microorganisms.

When an invasive plant has been removed from a site, the time to reach the desired vegetation should be kept as short as possible. After the removal of IAPs, the desired vegetation should be sown as soon as possible, and it should be ensured that the plants can establish.
A process termed plant–soil feedback should be considered. Here, plants alter the biotic and abiotic qualities of soil they grow in, which then alters the ability of plants to grow in that soil in the future (Bever et al., 1997). Principally, plant-soil feedback processes are often negative, however, in the case of invasive species they are often positive (Klironimos et al., 2002). Therefore, invasive plants usually have a growth advantage, however, plant-soil feedback can be mitigated by soil amendments or topsoil removal.

The following management techniques are summarized by Hess et al. (2019) to overcome the priority effects of IAPs:

- Herbicide application and mechanical removal to reduce IAPs early in the season to minimize the impact on native plants
- Removal of topsoil to reduce the seed load
- Effective mowing management
- Artificial flushing of IAPs may induce the germination, and the small seedling can be treated at early stage by herbicides or other suitable methods
- Planting or sowing of native plants that germinate earlier than the respective IAPs in order to successfully compete with IAPs.
- Development of bioherbicides against IAPs

The use of bioherbicides has the advantage that only the target weed is damaged and the native vegetation is protected. Currently, only two bioherbicides are commercially available from the 15 bioherbicides registered worldwide (Morin, 2020). One product (Di-Bak® Parkinsonia) is produced in Australia against *Parkinsonia aculeata* which is one of the worst invasive plants in Australia. The second product is SolviNix™ to control the herbaceous weed *Solanum viarum* in the United States. In Austria the use of *Verticillium nonalfalfae* to control *Ailanthus altissima* is currently being tested. During the test phase of Ailantax® the fungus efficiently and sustainably controlled the tree without causing damage to other trees (Maschek and Halmschlager, 2017). For the control of *Impatiens glandulifera* the rust fungus (*Puccinia komarovii* var. *glanduliferae* var. *nov)* is studied in the UK (Ellison et al., 2020). However, environmental conditions and the genetic constitution of the weed play a major role in determining rust establishment. In the Netherlands Koppert Biologicial Systems and the Leiden University and the company Probos together with CABI test the sap-sucking psyllid *Aphalara itadori* and the leafspot fungus *Mycosphaerella polygonicuspidati* against *Fallopia* spp. (https://www.cabi.org/news-article/cabi-teams-up-with-colleagues-to-pioneer-the-biological-control-of-japanese-knotweed-in-the-netherlands/). Koppert Biological Systems investigated the fungus *Chondrostereum purpureum* against black cherry in the late 1990s (De Jong, 2000). In Canada and the USA this fungus is registered as bioherbicide against poplar, birch and alder. In a small experiment carried out as part of the project, the fungus applied to freshly cut *Rhus typhina* trees prevented the tree from re-sprouting.

Due to the high cost of registration and low revenues, companies do not invest in the development of bioherbicides. Social drivers and legislation change toward sustainable control of invasive species may open the opportunity for future research on biological control methods. However, stakeholders must be involved in the development process to make development and sales attractive to trading partners.

- Development of new methods for the control of IAPs

Different alternative methods were tested against selected IAPs. Most alternative methods have the disadvantage that they are very labor-intensive and therefore the cost-benefit ratio is low. Devices coupled to a vehicle improve the working speed and reduce the costs.

The start-up company Growave in Australia developed a device for weed control using microwave technology. The company demonstrated that the Growave technology will be as cost-effective and potentially less expensive than current approaches in weed management. It must be shown whether this technology can also be applied to roadsides. The development of new technologies combined with image processing for the detection of IAPs may make it possible to protect natural vegetation in the future.

Relevant deliverables and documents

- Deliverable 3.2 – Greenhouse assays
- Deliverable 3.3 – Results from the field trial

5 Major recommendations

In frame of a Stakeholder workshop (28th November 2019, Vienna, Austria) some important issues were discussed, which are essential for a successful control of IAPs, namely:

- Lack of (long-lasting) funding to control IAPs
- Cross-sector efforts are needed between road, waterways and railway infrastructure
- For an efficient control, better knowledge of the ecology of the plants is required
- Early warning systems for an efficient control of IAPs are needed at an early stage of the invasion
- Early management of IAPs to prevent the establishment and spread of IAPs which reduces the cost
- In many European countries different stakeholders are involved and there is often disagreement about responsibilities
- It is of particular importance to increase awareness about IAPs through information and training
- In some countries no regulations for the use of contaminated soil exist (for example in Germany and Austria), thus there is an urgent need for legislations in all countries
- In general, there is an urgent need for legal obligations to deal with IAPs in all sectors and in all transmission pathways

Most of the points are addressed in the guidelines which were elaborated in frame of the project. Vegetation control methods differ from each other in many variables (e.g. effectiveness, costs, availability, applicability in practice, effects on health and the environment, etc.) which makes it impossible to give generalized recommendations.

Due to different organizational forms, responsibilities and local infrastructures and environments, it is hardly possible to make specific recommendations, which suit all countries or regions. Therefore, only generally applicable principles are recommended for measures to be incorporated into country specific guidelines.

1. General recommendations for the development of an action plan:

For an effective treatment of invasive plants different measures have to be considered. One of the key guidelines is that a clear management plan must be developed for effective control of IAPs for a specific site and a specific plant species. The infested areas should not be included in the regular vegetation management to prevent further spread of plant parts and seeds. An effective management plan should consider the following points:

- Clear competencies and responsibilities

Important are clear competencies and responsibilities for IAP management in the respective road administrations. Responsible bodies, with appropriate knowledge and organizational authority, should be installed at national and regional/local levels. Overall, the issue of IAP control requires a higher-level national coordination. It is recommended that the responsible national body (e.g. ministry) is responsible for providing the basic principles for the management of IAPs on the national level and also actively supports regional road administrations. A good example is Ireland, where the national road authority has taken the lead for IAPs management and supports the local authorities with knowledge and external resources.

- Adequate, sustainable budgeting

In addition to clear competencies, responsibilities and appropriate knowledge in road administrations, financial resources must be made available for the management of IAPs. A regular budget is required to cover costs for inventory, treatment, disposal and monitoring. Furthermore, financial resources are needed to raise awareness and for training. A financial plan should also consider costs related to a national survey and documentation system.

For example, Transport Infrastructure Ireland (TII) is currently engaged in a long-term treatment approach of tackling IAPs with a view to mitigating the risks on construction projects in the future. The Management of Invasive Alien Plant Species Project, led by TII, is a €5.5 million project aiming at managing invasive knotweed and other non-native invasive plant species in the national road network and its interactions with regional roads. The key objective of this project is to develop, implement and monitor a comprehensive national approach to the control and treatment of IAPs in the road network (http://www.sligococo.ie/Services/RoadsandParking/Roads/InvasiveAlienPlantSpecies/).

- National survey and documentation system (Survey & Documentation Tool)

Successful management of IAPs requires national survey and documentation systems. With the support of such a tool, (which main functionalities should be standardised on a European level to ensure cross-border compatibility) IAPs can be comprehensively recorded (and controlled). Treatments and post-treatments can also be documented facilitating the control of IAPs. Such a tool can be also used to document the effectiveness of control methods. Based on this information, spatial and temporal treatment strategies can be developed.

- National guidelines for the management of IAPs in the road sector

National guidelines are an established instrument for the definition of processes and measures in the road sector. These national guidelines for IAPs management in the road sector should include:

  - Description of the national survey and documentation system

- Process flows for inventory, treatment, disposal and monitoring
- Description of control methods
- Cost-benefit considerations

- Prioritizing the treatment

As a rule, not all sites that have been invaded by IAPs can be treated at the same time. It is therefore necessary to establish criteria to determine which sites will be treated with the highest priority. One criterion is the size of the IAP population, as small populations can still be eradicated at low cost. Another criterion for priority setting is the risk of IAPs, such as being harmful to humans or that they alter the ecosystem. Furthermore, any IAPs that are on the EU list or are of regional interest should be treated.

- Choosing appropriate control methods

The following points should be considered when selecting a control method. Firstly, the applicability of the method at the particular site is an important criterion. In addition to the geographical conditions, the proximity to water resources also plays an important role. Secondly, a control measure must be applicable to the treatment of a particular IAP, and here the different plant species - annual, perennial and woody plant species - can provide a good indication, as they require different types of treatment. The control method should also be selected on the basis of the size of an infested area (individual plants/few plants, small or large populations), as large infested areas may require different treatments. The cost-benefit assessment also depends on the size of the area to be treated.

- Choosing the possibility of eradication or containment of the plant species

Complete removal of an invasive species may be possible if the invasive species is detected soon after introduction and immediate measures are taken to eradicate it. If IAPs are already established, complete eradication is unlikely. Intensive efforts are needed to contain the core population of a species and to eradicate it from new areas. Furthermore, the plant species plays a role in control, with annual plants being easier to treat than perennial plants and trees.

- Scheduling the timing of the control

When treating the plant, the timing of the treatment is very important. The plant should be treated when it has used up as many nutrients as possible and before new nutrients are transported in the storage organs. Seed producing plants should be treated before flowering to prevent seed formation. If seeds have already been formed, the plants should not be mowed to prevent the seeds from spreading. After each treatment the machines must be cleaned to prevent spreading.

- Retaining the existing desirable vegetation and canopy where possible

The disturbance of the soil and the native vegetation should be minimized. When selecting the method of treatment, a gentle treatment should be used above all in order to protect the non-target native vegetation. The native vegetation can prevent the introduction of new IAPs. If the vegetation is completely destroyed, natural vegetation should be established as soon as possible.

- Plant disposal

If plant residues cannot be disposed of and are disposed of on site, it is necessary to ensure that the plant material is not viable. One of the common methods of safe disposal is burial of material. The burial depth depends on the plant species. Another possibility is to compost the waste. However, composting has not been shown to consistently break down weed seed. For other plants like *Fallopia* spp. strict protocols have to be carefully followed.

2. Recommendation for the control of IAPs

Successful management of IAPs requires a holistic approach and shall follow some basic principles. The following scheme (
Figure 6) describes the main steps, which should be followed in frame of a comprehensive, uniform IAPs management.

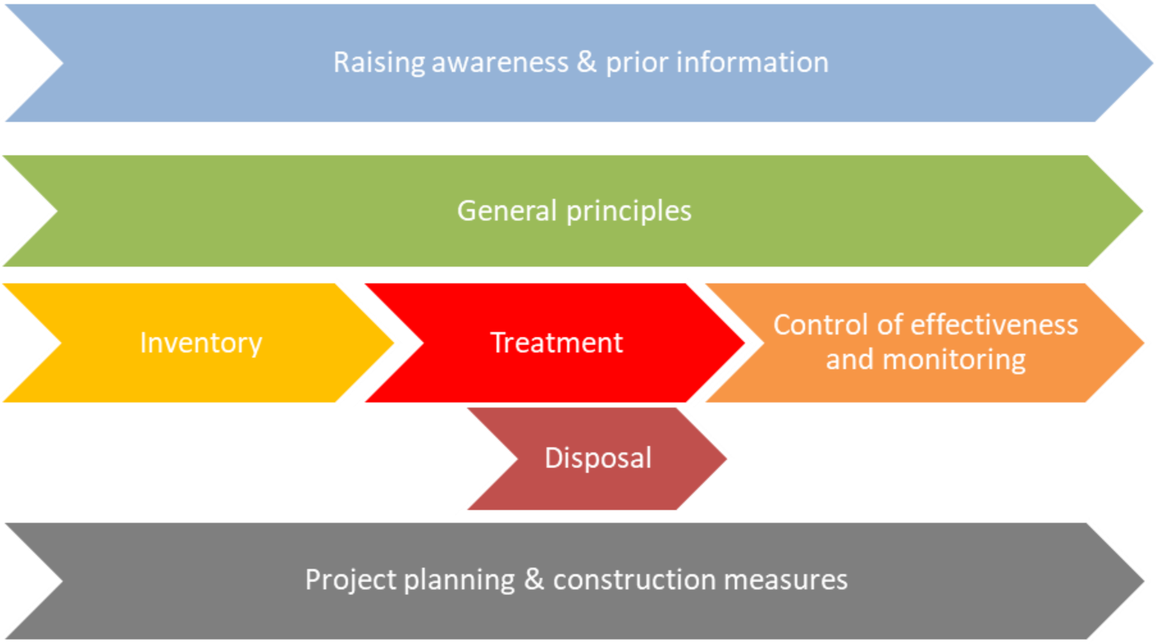

Figure 6. Overview of processes for the management of IAPs

The main process steps for a comprehensive, uniform IAPs management can be described as follows:

- Raising awareness & prior information

The problem of "IAPs in the road sector" is recognized in most countries, but targeted measures are rare. In addition, some IAPs are used for afforestation, whereas other IAPs are still available as ornamental plants. To prevent further spread of IAPs, it is highly important to raise awareness among the general public and decision-makers.

It is also recommended to collect important information (e.g. laws, guidelines, distribution maps, descriptions of plants, experience with control methods, etc.) that are already available at the national level, to regularly update the various documents and to disseminate them, e.g. to road operators.

General principles

The most important common principles are:

- Work and traffic safety

Work and traffic safety are important aspects when treating IAPs along roads. If measures have to be carried out during routine road operation, the protection of the road operators must have top priority. Depending on the choice of the treatment method and depending on the target plant further specific protective measures might be necessary (e.g. special clothing, suitable respiratory protection). Some methods furthermore require special knowledge, permits and training.

- Biosafety

To avoid the spread of plant parts and seeds, equipment (e.g. machines, tools) and clothing/shoes have to be carefully cleaned. This must be done before the equipment or clothing/shoes are used again elsewhere (implementation of biosafety plan).

- Uniform documentation tools

In order to be able to control IAPs successfully, it is essential that the documentation (e.g. of inventory, treatment, etc.) is as comprehensive and uniform as possible. Modern technologies shall be used (e.g. develop professional Apps, real-time connection to a central database, etc.).

- Inventory

It is recommended to develop country-specific strategic plans for inventory (i.e. location, time of occurrence, population size, etc.) for the purpose to get an overview of relevant IAP occurrences near road infrastructures. Important goals in this context are the precise collection of IAPs and their spread along roads, a long-term, complete collection of IAPs in the road network and the collection of data in a central database (which is part of the uniform documentation tool) to be able to document the development and spread of IAPs over time.

- Treatment and disposal

To actively control IAPs, a variety of mechanical, chemical and biological methods is available for treatment on site. A treatment must ensure sustainable removal of IAPs, avoid the spread of IAPs and – so far as possible – to do so by avoiding the use of herbicides. An important role in this context also plays the disposal of plant material. It has to be clarified whether the disposal of plant material is necessary. If so, clear rules must be followed (e.g. prohibition for dumping of mowing/cutting waste into waterbodies, rules for composting and burning).

- Control of effectiveness and monitoring

The objectives of monitoring are the systematic collection, recording and analysis of observations over time which must be done continuously (repeatedly) and comprehensively. The effectiveness must be checked after the treatment for several years (depending on the IAP and the control method). If individual IAPs are found during the follow-up inspection, it is recommended to remove them immediately and dispose them properly.

1. Project planning & construction measures

When constructing new road infrastructure preventive measures must be taken to prevent an uncontrolled or unconscious spread of IAPs. Construction measures, e.g. thicker beds of gravel, growth locks / plant barriers, special seed mixtures should also be considered at exiting roads when special IAP hotspots appear. This is important in order to prevent or minimize additional costs for construction. An inventory of IAPs along the planned route should therefore be carried out during project planning and building preparation. If IAPs are found at the site, the excavated material has to be handled with care to avoid any spread of plant parts and seeds. The excavated material should be stored if possible on site and clearly labelled as hazardous material to avoid any spread during transport.

3. Recommendations for a regulatory framework

Some norms are defined by law, such as legally binding conventions, while others are based on non-legally binding guidelines or directions (that are applied on a voluntary basis). National guidelines and standards are a good alternative to binding legislation to establish controlled technologies, processes and methods in the road sector.

The main chapters of such a guideline may follow the here outlined scheme (based on the main process steps for IAPs management):

- Title, date, numbering, authors
- Statement of obligation
- Table of contents
- Scope of application
- Introduction and background
- Definitions (Glossary - definitions)
- Management strategy
- Raising of awareness and prior information
- General principles (working and traffic safety, cleanliness (biosafety policy, standardized survey and documentation for effectiveness and development control, cost-benefit considerations)
- Inventory (methods, planning, collection of environmental parameters, carrying out the inventory, documentation)
- Treatment on site
- Disposal
- Effectiveness control and monitoring
- Project planning and construction measures
- Attachments

Relevant deliverables and documents

- Deliverable 4. 2 – State of the art of legislation guidelines and best practices in road construction and maintenance for the control of invasive species
- Deliverable 5.1 – Recommendation and best practice guide

6 Dissemination Plan

6.1 Website

www.controlinroad.org

6.2 Conferences and Workshops

Stakeholder Workshop

The stakeholder workshop was held on 28th November 2019 in Vienna. The workshop was organized by AIT with additional support of FFG, ÖBB and Lower Austria. The project partners presented the obtained results to the stakeholders.

Talks:

Friederike Trognitz: Bekämpfung invasiver Pflanzen am Straßenrand - Testergebnisse, Fachkräfte für Neophytenmanagement, 6th November 2019, Graz, Austria

Friederike Trognitz, Lisa Lutz, Angela Sessitsch: Plant associated bacteria for the control of *Impatiens glandulifera*", miCROPe 2019, 2nd to 5th December 2019 Vienna, Austria

Swen Follak, Alexander Fürdös, Matthias Eberius, Norbert Sedlacek, Friederike Trognitz: Controlling the spread of invasive species with innovative methods in road construction and maintenance. EPPO Panel on Invasive Alien Plants in Wageningen, the Netherlands, 6th to 8th June 2018,
https://www.eppo.int/MEETINGS/2018_meetings/invasive_alien_plant_wageningen

Transport Research Arena (TRA)
Presentation of the project ControlinRoad at the Transport Research Arena in Vienna, 16th to 19th April 2018, https://2018.traconference.eu/.

6.3 Publication

Follak, S., Eberius, M., Essl, F., Fürdös, A., Sedlacek, N. and Trognitz, F. (2018), Invasive alien plants along roadsides in Europe. *EPPO Bulletin*, 48: 256–265. https://doi.org/10.1111/epp.12465

6.4 Poster

Friederike Trognitz, Alexander Fürdös, Matthias Eberius, Norbert Sedlacek, Swen Follak: Management of invasive alien plants along roadsides, NEOBIOTA 2018 10th International Conference on Biological Invasions New Directions in Invasion Biology, www.neobiota2018.org, 3rd – 7th September 2018, Dún Laoghaire, Dublin, Ireland P248

Swen Follak, Alexander Fürdös, Matthias Eberius, Norbert Sedlacek, Friederike Trognitz: Controlling the spread of invasive alien plants along roadsides with innovative methods. 18th European Weed Research Society Symposium in Ljubljana, Slovenia, 17th to 21st June 2018, Book of abstracts, p. 80, http://www.ewrs.org/publications.asp.

7 List of Deliverables

D 1.2 Stakeholder meeting (summary included in the final report)
D 1.3 website online (www.controlinroad.org)
D 1.4 Final report
D 2.1 List of invasive alien plants along roadsides
D 2.2. Booklet with IAPs and Description
D 3.1 Alternative methods in road construction, operation and maintenance in relation to Invasive Alien Plants (IAPs)
D 3.2 Results from the greenhouse trials
D 3.3 Results from the field trials
D 4.1 Questionnaire
D 4.2 State of the art of legislation, guidelines and best practices in road construction and maintenance for the control of invasive species
D 5.1 Recommendations and best practice guide based on outcome of WP3 and WP4
D 5.2 Cost Benefit Calculations

8 Acknowledgements

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9 References

Adriaens, T., Branquart, E., Gosse, D., Reniers, J., Vanderhoeven, S. 2019. Feasibility of eradication and spread limitation for species of Union concern sensu the EU IAS Regulation (EU 1143/2014) in Belgium. Report prepared in support of implementing the IAS Regulation in Belgium. Institute for Nature and Forest Research, Service Public de Wallonie, National Scientific Secretariat on Invasive Alien Species, Belgian Biodiversity Platform. DOI: https://doi.org/10.21436/17033333.

Bertin, C., Weston, L.A., Huang, T., Jander, G., Owens, T., Meinwald, J., Schroeder, F.C., 2007. Grass roots chemistry: meta-Tyrosine, an herbicidal nonprotein amino acid. Proceedings of the National Academy of Sciences 104, 16964–16969. https://doi.org/10.1073/pnas.0707198104

Bever, J. D., Westover, K.i M., Antonovics, J., 1997. Incorporating the Soil Community into Plant Population Dynamics: The Utility of the Feedback Approach. The Journal of Ecology 85, 561. doi:10.2307/2960528

Carboneras, C., Genovesi, P., Vilà, M., Blackburn, T.M., Carrete, M., Clavero, M., D'hondt, B., Orueta, J.F., Gallardo, B., Geraldes, P., González-Moreno, P., Gregory, R.D., Nentwig, W., Paquet, J.-Y., Pyšek, P., Rabitsch, W., Ramírez, I., Scalera, R., Tella, J.L., Walton, P., Wynde, R., 2018. A prioritised list of invasive alien species to assist the effective

implementation of EU legislation. Journal of Applied Ecology 55, 539–547. https://doi.org/10.1111/1365-2664.12997
Courtois, P., Figuieres, C., Mulier, C., Weill, J., 2018. A Cost–Benefit Approach for Prioritizing Invasive Species. Ecological Economics 146, 607–620. https://doi.org/10.1016/j.ecolecon.2017.11.037
De Jong, M.D., 2000. The BioChon story: deployment of *Chondrostereum purpureum* to suppress stump sprouting in hardwoods. Mycologist 14, 58–62. https://doi.org/10.1016/S0269-915X(00)80005-1
Ellison, C.A., Pollard, K.M., Varia, S., 2020. Potential of a coevolved rust fungus for the management of Himalayan balsam in the British Isles: first field releases. Weed Research 60, 37–49. https://doi.org/10.1111/wre.12403
Hanley, N., Roberts, M., 2019. The economic benefits of invasive species management. People and Nature 1, 124–137. https://doi.org/10.1002/pan3.31
Klironomos, J. N., 2002. Feedback with soil biota contributes to plant rarity and invasiveness in communities. Nature 417, 67–70. doi:10.1038/417067a. PMID 11986666
Kristoffersen, P., Rask, A.M., Grundy, A.C., Franzen, I., Kempenaar, C., Raisio, J., Schroeder, H., Spijker, J., Verschwele, A., Zarina, L., 2008. A review of pesticide policies and regulations for urban amenity areas in seven European countries. Weed Research 48, 201–214. https://doi.org/doi:10.1111/j.1365-3180.2008.00619.x
Maschek, O., Halmschlager, E., 2017. Natural distribution of *Verticillium wilt* on invasive *Ailanthus altissima* in eastern Austria and its potential for biocontrol. Forest Pathology 47, e12356-n/a. https://doi.org/10.1111/efp.12356
Morin, L., 2020. Progress in Biological Control of Weeds with Plant Pathogens. Annual Review of Phytopathology 58, https://doi.org/10.1146/annurev-phyto-010820-012823
Reyns, N., Casaer, J., De Smet, L., Devos, K., Huysentruyt, F., Robertson, P.A., Verbeke, T., Adriaens, T., 2018. Cost-benefit analysis for invasive species control: the case of greater Canada goose Branta canadensis in Flanders (northern Belgium). PeerJ 6. https://doi.org/10.7717/peerj.4283
Tanner, R.A., Ellison, C.A., Seier, M.K., Kovács, G.M., Kassai-Jáger, E., Berecky, Z., Varia, S., Djeddour, D., Singh, M.C., Csiszár, Á., Csontos, P., Kiss, L., Evans, H.C., 2015. *Puccinia komarovii* var. *glanduliferae* var. nov.: a fungal agent for the biological control of Himalayan balsam (*Impatiens glandulifera*). European Journal Plant Pathology 141, 247–266. https://doi.org/10.1007/s10658-014-0539-x
Tworkoski, T.J., Glenn, D.M., 2012. Weed Suppression by Grasses for Orchard Floor Management. Weed Technology 26, 559-565.

10 Annex

10.1 Stakeholder Meeting

STEAKHOLDER MEETING
CONTROLINROAD 2019

FFG Forschung wirkt. ÖBB INFRA eco plus EFRE

The stakeholder meeting took place on 28th of November 2019 in Vienna. More than 50 participants from 12 European countries attended the workshop.

In the **first part** of the workshop, the results of the ControlInRoad project were presented by the project team members and discussed with the participants. Feedback on the results were discussed and specific points were addressed.

- **Safety using Electroherb™ on roadsides**

Roadside safety in the use of electricity with Electroherb™ to combat IAPs was questioned. Especially whether the wires laid in the ground along the road are affected by the electrical currents. A definitive answer could not be given as the necessary studies have not yet been carried out by Zasso, but the company will look into this issue in more detail in the future. The method cannot be used for road maintenance at present, but the company is working on the development of suitable equipment.

- **Cost and efficiency of different methods**

It was discussed that no costs for damages can be calculated that are included in cost-benefit analysis, as no cost data for damages are available. The question was discussed whether treating the knotweed population by mulching would lead to an increase in the population. In many countries mulching for vegetation management is not known. Mulching is a similar process to mowing, but the cut parts of the plant are crushed into very small pieces, like a flail mower. With this method, the nodes of *Fallopia* spp. are damaged and the spread is minimized in this case. Plant parts from mulching that remain in place dry out quickly. In contrast to mowing, where whole stem parts are cut with nodes, new plants can grow back from the nodes.

In the **second part** of the workshop, several experts presented their experiences with the management of IAPs.

Katrin Schneider (KORINA, Koordinationsstelle Invasive Neophyten in Schutzgebieten Sachsen-Anhalts beim UfU e.V., Germany) presented the state-wide data collection system for IAPs in Saxony-Anhalt. The database contains images, bibliographic data, occurrences and the corresponding control measures of the different IAPs. The information is available on the website www.korina.info. Newly discovered locations of IAPs can be recorded via a mobile phone application. With this system the information can be transmitted to the authorities so that they can react as quickly as possible to prevent the spread. Within the ENVISAGE project, the possibility of using satellite images was investigated. The time at which the satellite images were taken is crucial for reliable identification of the plants. The images must be taken when the IAPs can be distinguished from other plants. The project tested different control methods against *Fallopia* spp., *Heracleum mantagazzianum* and *Bunias orientalis*. Mowing *Fallopia* spp. several times per year had no effect in terms of population reduction. Grubbing and chemical treatment with Garlon and Roundup showed the best results in controlling *Fallopia*.

Wolfgang Lanner (Styrian provincial government, Austria) presented his experiences in daily road maintenance work. In Styria, 113,000 hours/year are spent mowing roadsides. Around the road maintenance station at Gleisdorf near Graz, the total road embankment length is about 335 km, and 6850 hours per year are spent on mowing. In the months of April, July and November the mowing effort is higher due to the presence of IAPs. He calculated the effort with a 5 to 10% higher workload due to IAPs. For example, an area of 1000 m2 of knotweed-contaminated terrain means that 150 additional hours per year must be spent on maintenance. An additional problem is the cuttings remaining on the site, which increase the supply of nutrients and allow vegetation to grow faster.

Vincent O'Malley (Transport Infrastructure Ireland) pointed out that a new standard for the management of IAPs on national roads in Ireland has been in place since September 2019. The document contains advice on the identification, ecology and control of the different IAPs. Important points focus on design, construction and maintenance. In planning, early detection is one of the key points for success. Only qualified personnel are authorised to handle IAPs. To ensure treatment, the land is purchased. A management plan is drawn up before a road is built. Compliance with the action plan is constantly monitored during the construction phase. The management plan includes a biosecurity plan. It must be ensured that the imported soil is checked to be free of IAPs as well as any excavated soil. The biosafety plan contains strict rules on the deposition of contaminated soil. For the treatment of IAPs, more cost-effective approaches must be implemented to reduce the use of pesticides. In recent years, control measures against IAPs have been implemented on 53 national roads with a total area of 202,000 m2 at a cost of €5 million. Due to the continuous treatment, a reduction in plant density was achieved, which means a reduction in the amount of work required. Thus, costs could be reduced and additional sites could be treated.

Kathrin Fischer (Zurich Cantonal Public Works Office, Switzerland) explained her experiences with the management of IAPs in Zurich. In Switzerland, there are several legal bases regulating the management of IAPs. Different IAPs are listed for the elimination or reduction of populations. Ragweed and *Heracleum mantegazzianum* should be eradicated and populations of *Ailanthus altissima* and *Senecio inaequides* reduced. To control IAPs during the construction phase there is an action plan for the correct handling of contaminated soil to minimize the spread of IAPs on construction sites. For this purpose, at least four surveys per year are carried out, with a focus on Himalayan balsam. For road maintenance, ragweed is removed by hand and the giant hogweed cone root is cut off below 15 cm. Both plants are rare on roads in Switzerland, and efforts are being made to eradicate them. For *Fallopia* spp., the aim is to stabilize and reduce populations by mowing at least twice a year. In the case of the trees *Rhus typhina* and *Ailantus altissima*, the aim is to prevent their spread and reduce population size. The trees are treated with trunk girdling, curling and mowing of the root runners. For the annual plants *Solidago* spp., *Erigeron annuus* and *Senecio inaequides* mowing plans exist to minimize the spread via seeds.

Thomas Schuh (ÖBB, Austria) presented the efforts of the Austrian Federal Railways against IAPs. Several projects are being carried out, for example, as part of a master's thesis, various films to cover *Fallopia* spp. tested. The ÖBB faces higher costs for the management of the rail system due to IAPs.

Mariana Pucarinho Fernandes (University of Evora, Portugal) presented the results of the LIFE LINES project Linear Infrastructures Networks with Ecological Solutions.

Erhard Halmschlager (University of Natural Resources and Life Science, Vienna, Austria) presented the results from field trials with the biocontrol agent *Verticillium nonalfalfae* to control *Ailanthus altissima.* In Austria, the control agent showed promising results as all treated plants died off after inoculation. In the next year, the biocontrol agent will be tested in Switzerland under an emergency permission.