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Assessment of Invasive Alien Species in Latvia

Part 1: A Cost-Effiency Analysis of Piloted Control Methods for Five Invasive Species

Latvia Nature Conservation Agency

Green Assist Advisory Assignment - Final Report

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Abbreviations and Acronyms

CBA	Cost-Benefit Analysis
CEA	Cost-Efficiency Analysis
CER	Cost-Efficiency Ratio
ER	Effectiveness Rate
EU	European Union
EUR	Euro
Ha	Hectare
IAS	Invasive Alien Species
LIFE-IP	LIFE Integrated Project
LNCA	Latvia Nature Conservation Agency
NP	National Park
PA	Protected Area
SGR	Species Growth Rate

Executive Summary

The Latvia Nature Conservation Agency (LNCA), under the LIFE-IP LatViaNature project, conducted a cost-efficiency and cost-benefit assessment of invasive alien species (IAS) management methods in Latvia. For five high-impact plant species, i.e., Impatiens glandulifera (Himalayan balsam), Solidago canadensis (Canadian goldenrod), Amelanchier spicata (dwarf serviceberry), Acer negundo (box elder), and Rosa rugosa (beach rose), eradication measures were piloted across multiple sites to evaluate control interventions, with the aim of developing effective and scalable strategies for national implementation.

These species were selected due to their known ecological impacts and prevalence in Latvian ecosystems, particularly in Natura 2000 sites and other protected areas. A cost-efficiency and effectiveness analysis were conducted for various control methods, drawing on field data collected in 2023 and 2024 across 75 sample plots. It combines a Cost-Efficiency Analysis (CEA), which measures the cost per hectare per percentage reduction in IAS cover, with a Cost-Benefit Analysis (CBA), which assesses broader ecological and socio-economic impacts.

1. **Impatiens glandulifera** was found to be highly invasive along riverbanks and wetland areas, with mechanical methods such as milling and mulching achieving the best balance of effectiveness and cost. Although hot steam treatment was the most cost-efficient in narrow terms, its lower effectiveness suggests it is best suited for use in sensitive or inaccessible areas.
2. **Solidago canadensis** emerged as one of the most impactful species in Latvia, forming persistent monocultures that suppress native plant diversity. The most successful control approach combined mechanical disturbance with the sowing of competitive native species like white clover and orchard grass, significantly reducing goldenrod coverage while promoting biodiversity restoration.
3. For **Amelanchier spicata**, a species that invades sandy pine forests and alters forest structure, mechanical and chemical treatments yielded better results than manual trimming, which proved largely ineffective. Long-term control is expected to require repeat interventions due to regrowth from root suckers.
4. In the case of **Acer negundo**, a fast-growing riparian tree, chemical stump treatment and trunk girdling showed promise, though chemical use may be restricted in certain habitats. The report recommends integrated mechanical-chemical strategies where feasible and notes the importance of targeting younger trees for removal to prevent seed spread.
5. Although **Rosa rugosa** control trials only began in 2024, literature and baseline assessments confirm it as a severe threat to coastal ecosystems. The species forms dense, thorny thickets that exclude native dune vegetation. Mechanical excavation combined with soil sieving and follow-up monitoring is expected to be the most effective approach, although labour-intensive and costly.

Across all species, the findings underscore that no single method is universally superior; rather, effectiveness depends on ecological context, infestation size, and terrain. Mechanical methods with native replanting often offer the best combination of ecological impact and long-term resilience.

It is acknowledged that all findings are preliminary, based on just one year of post-treatment data. Continued monitoring through 2027 is essential to assess regrowth patterns, seed bank depletion, and broader ecological recovery. Nonetheless, early results suggest that integrated, ecosystem-sensitive approaches can yield promising outcomes for IAS control in Latvia. Continued data collection through 2027 will be crucial for validating results and informing large-scale IAS management frameworks.

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1. Introduction

1.1 Background and context

In today's globalized world, the extensive movement of people and the transportation of goods—whether by land, sea, or air—create numerous pathways for the unintentional spread of plant and animal species at various stages of their life cycles. While some of these movements are strictly regulated and controlled, others remain poorly managed or entirely unmonitored. As a result, the risk of introducing plant and animal species to ecosystems beyond their native ranges has increased significantly.

Historically, before the ecological consequences of species introductions were fully understood, exotic plants and animals were frequently transported across continents. Botanical collections, ornamental gardens, and economic enterprises often introduced non-native species without consideration of their long-term ecological impact. Fish, crayfish, birds, ruminants, and fur-bearing animals, among others, were intentionally released into new environments for commercial or recreational purposes. Today, many countries face the unintended consequences of these introductions, as some of these species have become highly invasive, causing significant economic losses, declines in native biodiversity, and even pose a risk to human health.

For non-native species, survival in a new environment depends on finding favourable ecological conditions. When these conditions are met, invasive species often thrive due to the absence of their natural predators, competitors, or pathogens that regulate their populations in their native habitats. This ecological imbalance gives them a competitive advantage over native species occupying the same ecological niche, leading to rapid and uncontrolled population growth.

Once invasive alien species (IAS) establish and spread, they can outcompete native species for essential resources such as light, nutrients, food, and shelter. In some cases, invasive animals directly prey on native species, further disrupting local food webs and ecological stability. The resulting impacts can be severe, including:

- **Ecosystem Degradation**: IAS can alter ecosystem dynamics by modifying vegetation cover, soil composition, and hydrological cycles, which in turn affects erosion patterns and nutrient availability.
- **Loss of Biodiversity**: IAS often displace or outcompete native flora and fauna, leading to reduced species diversity and, in some cases, local extinctions.
- **Economic Damage**: The spread of IAS can negatively affect agriculture, forestry, fisheries, and infrastructure, leading to increased maintenance costs and economic losses.
- **Public Health Risks**: Some IAS act as vectors for diseases or introduce allergens and toxins that impact human health.

Climate change further exacerbates the challenges posed by IAS by creating more favourable conditions for their expansion into new regions. Rising temperatures, changing precipitation patterns, and increased habitat disturbance can enhance the ability of invasive species to establish and spread. In Europe, for example, the free movement of people and goods within the Schengen Area has facilitated the unintentional dispersal of IAS across borders, complicating management efforts.

There are numerous historical examples of species introductions that have led to ecological and economic disasters. The release of rabbits in Australia, the introduction of muskrats and raccoon dogs to Northern Europe, and the spread of giant hogweed in Eastern Europe illustrate how invasive species can quickly become unmanageable when introduced to ecosystems without natural checks and balances.

As general awareness of the risks associated with IAS is growing, societies are increasingly recognizing the high costs of prevention, control, and eradication efforts. However, individual actions—whether due to lack of awareness, economic interests, or negligence—continue to contribute to the spread of IAS, further escalating management costs.

1.2 Objectives and scope

Across Latvia, invasive alien species have been observed to spread throughout the country, with varying degrees of establishment and impact on local ecosystems, depending on the species. To curb the spread of Invasive Alien Species (IAS), the Latvia Nature Conservation Agency (LNCA) has established a shortlist of twelve species that will be targeted for potential scaling up of eradication measures and control programmes. Initial testing of selected eradication methods is included as interventions as part of the wider LIFE-IP LatViaNature Integrated project "*Optimising the Governance and Management of the Natura 2000 Protected Areas Network in Latvia*".

Table 1: Invasive species targeted through the LIFE-IP LatViaNature project

#	Name	Common Name	Type	Pilot	Baseline Data	Monitoring Data	CEA?
1.	Impatiens glandulifera	Himalayan balsam	Plant	Yes	Yes	Yes	Yes
2.	Solidago canadensis	Canadian goldenrod	Plant	Yes	Yes	Yes	Yes
3.	Amelanchier spicata	Dwarf serviceberry	Plant / Shrub	Yes	Yes	Yes	Yes
4.	Acer negundo	Box elder	Plant / Tree	Yes	Yes	Yes, partly	Yes, partly
5.	Rosa rugosa	Beach rose	Plant	Yes	Yes	n/a	n/a
6.	Heracleum Sosnowskyi	Sosnowsky's hogweed	Plant	No	n/a	Sigulda	Literature
7.	Nyctereutes procyonoides	Common raccoon dog	Mammal	No	-	-	Literature
8.	Pacifastacus leniusculus	Signal crayfish	Freshwater Crayfish	No	-	-	Literature
9.	Orconectes limosus	Spinycheek crayfish	Freshwater Crayfish	No	-	-	Literature
10.	Percottus glenii	Amur sleeper, or Chinese sleeper	Freshwater Fish	No	-	-	Literature
11.	Ondatra zibethicus	Muskrat	Mammal, semi-aquatic	No	-	-	Literature
12.	Arion vulgaris	Spanish slug	Pulmonate snails / slugs	No	n/a	SGP	Literature

For five plant species (*Impatiens glandulifera, Solidago canadensis, Amelanchier spicata, Acer negundo, and Rosa rugosa*) pilot activities have been set up by the LNCA to test different eradication methods in a "controlled" field environment. For each of the five plant species, different testing locations have been selected representing a variety of habitats. The eradication methods tested are either implemented by the IAS team of the LNCA or with the assistance of external operators who are contracted to provide specialised services (for example for milling, mowing, cutting, pulling, weeding, etc.).

As part of the overall assessment of the effectiveness of the different methods tested, and to enhance decision-making on what methods may be best suitable and feasible for the LNCA to scale up, the costs associated with applying different eradication methods would need to be considered in analysis.

Four of the listed invasive alien plant species (*Impatiens glandulifera, Solidago canadensis, Amelanchier spicata, Acer negundo*) have currently undergone a first cycle of treatments, and monitoring data is (partly) available from one year (2024) after the last treatment. As the project will evolve in the coming years, the monitoring data for the next cycles of treatments will further enrich the analysis and make it more robust.

At this stage, a preliminary cost-efficiency assessment can be made for these four species of plants, covering a total of **18 different eradication methods** (***plus six methods*** for which no data is readily available yet or treatment has stopped due to damage to pilot sites) with the most complete monitoring data and available cost information. Observations regarding the effectiveness of the different methods are drawn from baseline and monitoring data collected from a total of **75 sample plots** spread across several pilot areas in key sites across Latvia, including Vecdaugava, Kemeri National Park, Beitāni, Krustkalni Nature Reserve, Ķemeru National Park, Daugavpils, Jēkabpils, Ragakāpa Nature Park, and Ziemupe Nature Reserve.

1.3 Methodology

The study consists of two main components. First, a **Cost-Efficiency Analysis (CEA)** is conducted to determine which interventions provide the greatest reduction in IAS populations or ecological restoration outcomes for the lowest cost. Secondly, based on an extensive literature review, a **Cost-Benefit Analysis (CBA)** is conducted to assess the potential negative impact of IAS on different socio-economic dimensions, using a ranking framework (see Annex 1).

1.3.1 Cost-Efficiency Analysis (CEA)

The cost-efficiency analysis (CEA) conducted for invasive alien species (IAS) control in Latvia follows a structured, multi-step methodology, with the objective to assess and compare the effectiveness and associated costs of various eradication and control methods for five IAS.

The methodological approach consists of the following components:

1. **Baseline Assessment and Site Selection:** Field visits were conducted to observe activities and conditions at sample plots across multiple nature reserves and pilot sites where invasive species interventions were tested. Baseline data were collected in 2022/2023 by the Latvia Nature Conservation Agency's team on IAS population density and ecological conditions to enable comparison against post-intervention outcomes.
2. **Identification of IAS and Control Measures**: A total of twelve invasive species were selected for the analysis, with pilot control methods tested for five key species ((*Impatiens glandulifera, Solidago canadensis, Amelanchier spicata, Acer negundo, and Rosa rugosa*). For each of these species a range of control methods is being tested by LNCA, ranging from hot steam application and mechanical removal to grazing and chemical treatment.
3. **Data Collection and Estimation of Costs**: For the different interventions, LNCA recorded different types of cost data, both fixed (e.g., equipment, infrastructure, etc.) and variable (e.g., labour, materials, fuel, monitoring). Where possible, ***cumulative expenses were normalized per hectare and over multiple years to reflect realistic implementation conditions***. Cost data were consolidated from available project documentation.
4. **Effectiveness Measurement**: Based on monitoring data collected by LNCA about IAS population coverage in the pilot sites, one year post-treatment (and before the 2nd cycle of treatment), the effectiveness of each intervention was ***quantified as the percentage reduction in IAS cover or targeted IAS population within the treated plots***. These outcomes were then extrapolated to represent effectiveness across the full area under treatment by the same method.

5. **Calculation of Cost-Efficiency Ratios**: For each intervention, a cost-efficiency ratio (CER) was calculated as the cost per hectare per percentage of IAS reduction, combining the rate of effectiveness of each method piloted with the cost of the intervention calculated per hectare. This metric enabled direct comparison across different species and treatment approaches. [***CEA calculation tool available as excel spreadsheet***].
6. **Ranking and Comparative Analysis**: Eradication methods were ranked according to their CERs (lowest CER representing the most cost-efficient method within the experiment), with additional contextual factors into account (when available), such as ecological impact, scalability, and feasibility in protected areas. In some cases, preliminary results showed high variability due to differences in initial investment costs and monitoring duration (*only one cycle of monitoring data is available from year 2024, which is not sufficient for making conclusive recommendations*).

Based on available literature, project documentation, field observations, monitoring data and cost information, the different interventions are reviewed, including a preliminary assessment on their applicability and effectiveness. Experiences with eradication of IAS in other EU countries supplement the analysis, providing general direction for a suitable control approach. The CEA supports the identification of the most economically viable strategies for IAS management and can inform future decision-making by aligning conservation goals with budgetary constraints within the context of Latvia.

1.3.2 Cost-Benefit Analysis (CBA)

The Cost-Benefit Analysis (CBA) undertaken in this study evaluates the broader ecological, economic, and social benefits of eradicating invasive alien species (IAS) in Latvia. The analysis complements the Cost-Efficiency Analysis by focusing not on implementation costs, but on the ***potential value of avoided damages resulting from successful IAS control***. These avoided impacts are used as a proxy for the societal and environmental benefits that would accrue through effective intervention.

To structure the assessment, a categorization framework was applied that groups IAS-related impacts into key domains: ecosystem services (supporting, regulating, provisioning, and cultural), biodiversity conservation, infrastructure and public health, and socio-economic values including recreation and land use. These domains reflect the multifaceted ways in which invasive species degrade ecosystems, alter services, or impose management burdens on landowners and public authorities.

For each IAS, an ordinal scoring system was applied across the relevant impact categories. Scores range from 0 (no negative or negligible impact) to 4 (severe and irreversible impact), based on the species' known or expected effects in Latvia and similar European contexts. The scoring process draws on a mix of scientific literature, project documentation, pilot method monitoring data, and expert judgment. This allows the analysis to capture both direct and indirect effects—such as biodiversity loss, erosion risks, or declines in aesthetic and recreational quality.

To facilitate prioritization, the results were integrated into a structured CBA matrix tool (see Annex 1). This tool compiles the impact scores into a cumulative ranking for each species, offering a comparative overview of which IAS pose the greatest threats across multiple domains. It supports decision-makers in identifying species and control strategies with the highest return in avoided ecological or economic harm, thus guiding investment and policy focus for IAS management.

It should be noted that the CBA approach presented is qualitative to semi-quantitative in nature. It does not assign monetary values to benefits, but rather provides a relative ranking of IAS based on the severity and breadth of their negative impacts. While this limits direct financial comparisons, it provides a practical and evidence-based framework for informing management priorities where full economic valuation is not feasible.

1.4 Limitations of the study and implications for IAS management recommendations

While this study aims to provide evidence-based recommendations for the management of the invasive alien species (IAS) under investigation, several limitations hindered the ability to offer definitive conclusions. These constraints stemmed from both the availability and quality of field data, the scope of experimental trials, and gaps in existing literature. The key limitations identified are as follows:

1.4.1 Limited scope of field trials

At the time of this study, field trials had been initiated in Latvia for only five of the six targeted plant species. Notably, there were no experimental trials available for *Heracleum* spp. (hogweed) or for any of the six invasive animal species included in the study. The absence of direct, location-specific experimental data for these species restricted the ability to develop robust, empirically validated management recommendations. Instead, insights were drawn primarily from literature reviews, which, while informative, do not always reflect local ecological conditions or provide the level of specificity required for effective IAS management.

1.4.2 Insufficient field data for plant species

The existing field trials for invasive plant species have been initiated relatively recent, with establishing a baseline (for monitoring), followed with a first cycle of one year of treatments and one cycle post-treatment monitoring. Therefore, the current study can only use one year of monitoring data, while additional cycles are being planned up to 2027. Given that effective IAS management often requires long-term, multi-year interventions, the currently available datasets are still in their preliminary stages. Consequently, the results obtained thus far offer only early-stage indications of potential management efficacy. As multiple-year treatments will be required to assess long-term effectiveness and ecological impacts, conclusive recommendations cannot yet be formulated. The limited temporal scope of available data also restricts the ability to assess the resilience of IAS populations post-treatment, which is a critical factor in determining sustainable management strategies.

1.4.3 Reliance on literature for animal species and hogweed management

Due to the absence of field trials for the six invasive animal species and for the *Heracleum Sosnowskyi* (Sosnowsky's hogweed), recommendations for their management are based on existing literature. While a range of alternative management methods is documented for some of these species, the information available is often incomplete, outdated, or lacking in detail regarding practical implementation and cost-efficiency. Economic analyses of management methods remain sparse, which limits the ability to conduct comprehensive cost-benefit assessments of different control strategies. Furthermore, existing studies often do not provide standardized metrics for measuring the effectiveness of IAS control, which is often context specific, making cross-study comparisons challenging.

1.4.4 Need for ecosystem-specific field trials

A key limitation of existing field trials is their lack of differentiation across ecosystem types and terrain conditions. The effectiveness of IAS management methods can vary significantly depending on habitat characteristics such as soil composition, hydrology, and vegetation structure. However, current field trials have not been specifically designed to assess these variations. To improve the applicability of findings, future experimental designs should incorporate stratified sampling across diverse ecosystem types, with sufficient replication to allow statistical comparisons. This would enable a more nuanced evaluation of management methods under different environmental conditions and facilitate a sensitivity analysis to determine the most effective approaches for specific habitat types.

1.4.5 Lack of systematic data collection and monitoring

One of the challenges encountered in evaluating IAS management strategies is the inconsistent documentation of prior experiences, particularly with regard to the management of hogweed in Latvia. Many past control efforts lack clearly defined baseline data, making it difficult to assess the initial severity of infestations or to quantify changes in population dynamics over time. Additionally, standardized monitoring data—particularly regarding management costs—are often unavailable or based on anecdotal evidence, which restricts the ability to conduct a rigorous economic assessment of different control approaches. This lack of systematic data collection significantly weakens the ability to draw evidence-based conclusions on management effectiveness.

1.4.6 Application of overlapping management methods and confounding effects

In some cases, multiple control methods for *Heracleum Sosnowskyi* have been applied concurrently or sequentially within the same management sites, without clear documentation of intermediate treatment effects. This makes it impossible to isolate the impact of individual management strategies. As a result, while it is possible to observe a general reduction in hogweed abundance over time, it is not possible to attribute this suppression to any specific treatment with confidence. A more structured approach to experimental design, involving **clear documentation of treatment sequences and intermediate monitoring**, is necessary to accurately determine the relative effectiveness of different control methods.

1.4.7 Implications for future research and management strategies

Given these limitations, the design and implementation of future IAS control trials and studies should consider the following actions to enhance the robustness of the analysis and recommendations:

- **Expanding field trials** to include all target species, particularly invasive animal species and hogweed, to develop location-specific management strategies.
- **Long-term monitoring** to assess the sustained effectiveness of control measures using multiple cycles of treatment and monitoring, including post-treatment population dynamics and habitat recovery.
- **Comparative studies across different ecosystems and terrain types**, ensuring that findings are applicable across a range of environmental conditions.
- **Standardized data collection** for management costs and effectiveness metrics, enabling more robust economic analyses and cross-study comparisons.
- **Sequential and controlled testing of management methods**, avoiding confounding effects caused by overlapping treatments and ensuring that each method’s efficacy is accurately assessed.

By addressing the above-mentioned gaps, future research and management initiatives can develop more precise, evidence-based recommendations for the control of IAS, ultimately improving the efficiency and sustainability of invasive species management efforts. When the IAS pilot project progresses for the current five plant species under trial, new monitoring data will become available year on year, which can be used to conduct more robust calculations for the cost-efficiency analysis.

2. Impatiens glandulifera [Himalayan balsam]

2.1 Species characteristics

Impatiens glandulifera (Himalayan balsam) is a tall, fast-growing annual, herbaceous plant, native to the Himalayas (India, Pakistan, Nepal, and Bhutan), where it grows in the submontane and montane regions, typically at altitudes ranging from 2,000 to 4,000 meters. The plant is known for its striking, pink to purplish, orchid-like flowers. This species can grow up to 2–3 meters tall and is characterized by hollow, reddish stems, lance-shaped leaves, and explosive seed pods that can disperse seeds over several meters.

Although the plant is valued for its ornamental beauty due to its colourful flowering, Himalayan balsam is a highly invasive species in many regions outside its native range, including in Europe and North America. It thrives in moist, nutrient-rich soils, especially along riverbanks and in wetlands. Himalayan balsam outcompetes native vegetation and disrupts ecosystems. In many of the countries where the plant has become invasive, efforts are made to control its further spread to preserve biodiversity in affected areas.

Photograph 1: Impatiens glandulifera flowering

Source: Consultant

2.2 Habitat and ecological characteristics

Impatiens glandulifera thrives in a variety of habitats. It can be found in areas that provide moist and nutrient-rich growing conditions. It thrives best in waterlogged or seasonally inundated soils but can tolerate drier conditions temporarily. While it grows best in sunny to partially shaded conditions, it can tolerate light shade, enabling it to colonize a variety of environments. The species is adaptable to a range of temperate climates, contributing to its invasiveness in non-native regions.

The plant's preferred habitats and ecosystems include:

1. **Riparian Zones:** Riverbanks, stream edges, and floodplains are prime habitats for Himalayan balsam. The plant benefits from the high moisture levels and nutrient deposits found in these areas.
2. **Wetlands:** Marshes, swamps, and other wetland ecosystems provide the damp conditions it requires for optimal growth.
3. **Grasslands:** In wetter meadows and pastures, particularly those near water sources, the plant can establish dense populations.
4. **Forest Margins:** The *Impatiens glandulifera* often grows at the edges of woodlands, where there is partial sunlight and adequate moisture.
5. **Disturbed and Open Areas:** It flourishes in disturbed soils, such as those found in urban or rural areas, roadside verges, abandoned fields, and construction sites.

In areas where the plant becomes invasive, *Impatiens glandulifera* often displaces native vegetation by forming dense monocultures, which can alter soil conditions, reduce biodiversity, and impact water flow in riparian ecosystems.

2.3 Introduction and spread in Europe

Impatiens glandulifera was introduced to Europe in the early 19th century for ornamental purposes due to its attractive flowers and ease of cultivation (Tanner, 2017). Since its introduction, Himalayan balsam has rapidly naturalized and spread across most European countries. The plant thrives in moist, disturbed environments, particularly along riverbanks, wetlands, ditches, railway embankments, and damp woodlands, which has facilitated its extensive distribution throughout the European continent (Razak et al., 2023).

The spread of Himalayan balsam is primarily driven by its highly effective seed dispersal mechanisms. Each plant can produce up to 2,500 seeds, and in dense stands, seed production can reach up to 6,000 seeds per square meter (Tanner, 2017). The plant's seedpods are explosive and can project seeds up to seven meters away from the parent plant. Additionally, the seeds are buoyant, allowing them to be transported by water currents, often dispersing as far as 10 kilometres downstream, thus colonizing new areas efficiently (Leblanc and Lavoie, 2017).

Himalayan balsam is now established in most European countries, with significant populations in the United Kingdom, Ireland, Germany, Latvia, Estonia, and Slovenia, among others (Coakley and Petti, 2021; Šabić and Jogan, 2022). Its ability to outcompete native vegetation for light, nutrients, and space has led to concerns about its impact on biodiversity and ecosystem functions. Furthermore, the plant dies back in winter, leaving riverbanks bare and vulnerable to soil erosion, exacerbating its ecological impact (Gaggini, Rusterholz, and Baur, 2017).

2.4 Baseline situation in Latvia

Across Latvia, dense stands of Himalayan balsam have been observed in various locations, such as Vaive, Vecdaugava, Beitān Hillfort, Svente Lake, and Krustkalni Nature Reserve. These locations represent a diverse mix of ecological and land-use contexts, including floodplains, forested areas, and former agricultural sites. In many of these sites, the plant forms monocultures, suppressing native vegetation, reducing plant diversity, and altering habitat structures. Notably, in wetter regions, Himalayan balsam frequently coexists with other invasive species, like *Heracleum Sosnowskyi* (Sosnowsky's hogweed), compounding its environmental impact.

The baseline study conducted in 2022 as part of the LIFE-IP LatViaNature Project found that Himalayan balsam's dominance varies significantly across identified pilot sites, with coverage ranging from 25% to 88% in surveyed plots. The study also observed that species diversity in these areas is generally low, with a few co-dominant plants such as *Urtica dioica* (*Stinging nettle*) and *Aegopodium podagraria* (*Goutweed*). In forested regions, where recent thinning has increased light availability, the Himalayan balsam was able to further spread, underscoring its adaptability to disturbed environments.

The environmental context of the selected areas is critical, as many of the pilot sites include or border ecologically sensitive zones, including Natura 2000 sites. The dense monocultures of Himalayan balsam pose a significant threat to these areas by outcompeting native plant species and thereby decreasing species richness, degrading habitat quality and undermining the integrity of protected ecosystems.

In the baseline study, sample plots (of 5x5 meters) were set up to record vegetation data to understand the species' spread and dominance. The monitoring of the sample plots includes among others photographic documentation and quantitative assessments (e.g., species counts, coverage percentages) to assess the spread of the species under different management and control methods.

2.5 Eradication methods (pilot project)

The invasive plant species *Impatiens glandulifera* [Himalayan balsam] has found its way into Latvia and is now present in a variety habitats and locations, including in and around protected areas and Natura 2000 sites. To test a selection of eradication methods, several sample plots (generally 5x5 m in size) were set up by the LNCA:

Table 2: Eradication methods piloted for Impatiens glandulifera

	Method	Locations	Sample Plots	Description
A.	Hot steam	Vecdaugava	IMP_VECD1, IMP_VECD2	Wet, open small field
		Kemeri National Park	IMP_KNP3, IMP_KNP4	Around energy / gas cable infrastructure
		Beitāni	IMP_BEIT1, IMP_BEIT2	Forest, open field in forest area
B.	Milling and mulching	Krustkalni Nature Reserve	IMP_KDR1, IMP_KDR2	Abandoned ruderal area
C.	Milling and sowing native competitive plants	Krustkalni Nature Reserve	IMP_KDR3, IMP_KDR4	Abandoned ruderal area
D.	Grazing with horses	Vecdaugava	IMP_VECD3, IMP_VECD4	Stand with grasses, bushes, black elder

2.5.1 Method A: Hot steam treatment

Combatting *Impatiens glandulifera* (Himalayan balsam) with hot steam treatment is an innovative approach focused on utilizing thermal energy to damage and kill the plant tissues. This method is considered environmentally friendly compared to other eradication measures, as it reduces reliance on herbicides and minimizes disruption to soil and surrounding ecosystems.

Photograph 2: Hot steam application to Impatiens glandulifera

Source: Latvia Nature Conservation Agency

The application requires specialized steam-generating machines, either mounted on vehicles or portable devices. The machines produce superheated steam (around 90–100°C or higher) delivered through a nozzle or applicator wand. The steam is applied to the plant stem, leaves, and root crown (where the plant meets the soil), which are critical growth points. The steam penetrates the plant tissues, causing cellular damage by denaturing proteins, rupturing membranes, and dehydrating the plant. Soil in the target area may also be treated lightly around the base of the plant to target emerging seedlings or shallow root structures.

The most effective time to do hot steam treatments is during the early stages of growth of the plant (from spring to early summer), typically from March to June, when plants are actively growing but have not yet set seed. The best timing to treat the plants is before the flowering period (and especially before seed pods form) to prevent seed dispersal, which is a key factor in controlling their spread. If plants have already reached maturity and produced flowers, steam can still damage the plant, but there is a higher risk of seeds being dispersed before the plants die. Steam treatments may need to be repeated over several seasons, as Himalayan balsam has a persistent seed bank in the soil that can germinate for up to 2–3 years.

The hot steam treatment will cause immediate damage to the exposed plant tissue (leaves, stems, and flowers), and the plant wilts and collapses within hours to days after the treatment. The root crowns will die off, preventing regrowth from the same plant. When steam is applied to the plant flowers, it can kill seeds before they mature, reducing the seed bank for subsequent years. The hot steam does not generally harm dormant seeds or nearby plants with thick bark or underground rhizomes, allowing for more targeted control of the Himalayan balsam. As there are no chemical residues left in the soil or water, non-target species in the surrounding environment are less likely to be affected.

Hot steam treatment can be applied in densely populated areas. Application with portable equipment may be an advantage in areas less accessible with heavy equipment (such as tractors). Hot steam treatment is an effective non-chemical method for controlling Himalayan balsam, especially in ecologically sensitive areas such as Natura2000 sites and its borders. When timed correctly and applied systematically, it can significantly reduce the plant's spread and contribute to long-term eradication efforts. In water catchment areas (for example near rivers and streams, riverbanks), hot steam treatment is considered a better option than chemical treatment. However, repeat treatments and long-term monitoring are required to ensure that the seedbank is depleted.

The hot steam method can be labour and time-intensive and is considered generally slower compared to mechanical or chemical methods, especially when managing large areas that are invaded by the plant. The cost of fuel for the steam generating equipment can be resource-intensive compared to other methods. With steam treatment, several repeat treatments will be required due to the persistence of the seed bank, implying the need for long-term monitoring and re-application of the method to ensure effective control of the infested area and prevention of its further spread. Operators of the steam-generating equipment will require specialized training on how to apply the treatment and take safety precautions

2.5.2 Method B: Milling and mulching

Milling and mulching is an eradication treatment that involves mechanical techniques to suppress the growth of the Himalayan balsam, prevent seed production, and reduce its further spread.

A milling machine (or forestry mulcher) uses heavy-duty blades or hammers to grind and pulverize vegetation, including shrubs, small trees, and the upper layer of the soil if necessary. The primary goal is to clear overgrown areas, reduce large vegetation to mulch, and prepare the land for further use or restoration. Compared to mowing, milling affects the vegetation more drastically. It not only cuts but also grinds down plants, shrubs, and sometimes small trees, reducing them to mulch. This process may disturb the soil surface to some extent and can significantly alter the landscape.

In using milling as control technique, a mechanical mower or flail-type machine is used to cut and shred the Himalayan balsam. The milling process breaks the plant stems down into smaller fragments. The shredded plant material is then left on-site as a layer of mulch to suppress regrowth by limiting light penetration to the soil and hindering seed germination of remaining Himalayan balsam or other opportunistic species.

In using milling and mulching as control treatment, it is critical to mill the plants before they begin to set seeds, as this prevents seed dispersal. The optimal time to apply milling and mulching is during the early summer to mid-summer, before flowering or seed formation, which typically occurs between May and July. By targeting the plants early in their life cycle, the method prevents seed production, which is critical to long-term control. In flood-prone areas, early-season interventions may be preferred to minimize soil disturbance during high-flow periods. Follow-up treatments may be necessary in subsequent years to deal with regrowth or missed plants.

By milling the affected site, the above-ground biomass of Himalayan balsam is reduced immediately, while the mulch suppresses light penetration to the soil, reducing the germination and growth of seeds in the treated area. When applied in the right period of the year and depending on growth cycles of native vegetation, the native vegetation can recover due to the removal of competition and improved soil conditions under the mulch layer. In riparian zones, a decrease in soil erosion can be observed, as the mulch stabilizes the soil previously destabilized by Himalayan balsam monocultures.

Depending on the machinery used, non-target damage to native plants may be possible if the equipment is not used carefully. Before applying mechanical milling and mulching, it is necessary to first evaluate access routes for (heavy machinery such as tractors, mowing machines) equipment and plan to avoid collateral damage to native vegetation and disturbance of critical ecosystems and habitats (especially in protected areas such as Natura 2000 sites). Educating personnel on plant identification and proper equipment use is crucial for reducing off-target impacts.

The milling and mulching treatment is considered an effective management method for controlling Himalayan balsam in large densely populated sites where access is relatively easy. This method is both eco-friendly and cost-effective when timed and executed properly, leading to significant reductions in the spread of Himalayan balsam. However, if seeds are already present in the soil, the seed bank may persist for several years, requiring ongoing multi-year treatment and monitoring. Monitoring for recolonization and regenerating the area with native plant species can further increase the effectiveness of the method and ensure long-term habitat restoration. Milling and mulching should be used as part of an integrated management strategy, complementing manual removal or herbicide treatments (preferably not in protected areas or watershed areas) as needed.

2.5.3 Method C: Milling and sowing native competitive plants

The milling and sowing native competitive plants treatment is a targeted approach that involves mechanically removing the Himalayan balsam and immediately re-establishing native flora to suppress regrowth and restore the ecological balance.

Milling the site is done mechanically, either with brush cutter, flail mower, or similar equipment to cut down the Himalayan balsam at the base. It is important to collect and dispose of the biomass in a controlled manner to minimize the spread of seeds, and allow for growing conditions of native plants. After milling and removing the mulch, the soil surface can be raked with harrows to remove remnants of Himalayan balsam roots and to create an ideal bed for sowing seeds of selected native plants. For the sowing, it is best to select a seed mix of fast-growing and competitive native plants (e.g., grasses, wildflowers) suited to the habitat. Once seeds are sowed, the surface should be covered with a light layer of soil or compost to improve germination rates.

Ideally this method is applied from late spring to early summer (May to July), when Himalayan balsam plants are actively growing but before seed pods have formed and matured to prevent inadvertent seed dispersal. An optimal timing should be chosen considering the best time when native plants should be sown (or come back to the site at a later time after milling when it is the best time to sow native plant seeds). It is important to reassess the treated area in subsequent years during the growing season to address any regrowth and reinforce the native plant cover.

With milling, a significant reduction in the standing biomass of Himalayan balsam can be achieved in targeted sites. The open spaces created by the milling process can be re-populated by the rapid germination of sown native plants, and native plants may begin to outcompete any regrowth of Himalayan balsam. In the immediate short-term, the method could lead to some soil erosion, until native plants start to establish themselves, which will improve soil stability as native root systems take hold.

This method can be subject to some challenges, such as for example ineffective seed germination of native plants due to drought or poor soil conditions, and by competition from remaining Himalayan balsam seedlings. In addition, the seed bank of Himalayan balsam may persist for another 2-3 years after removing the plant, which requires follow-up treatments for 2-3 years and monitoring of the targeted sites.

Milling and sowing native competitive plants is considered an effective method when combined with long-term monitoring and adaptive management strategies. It not only removes the invasive species but also restores the ecological balance of the habitat, offering a sustainable solution to Himalayan balsam control.

2.5.4 Method D: Grazing with horses

Grazing with horses can be an effective and eco-friendly method for controlling Himalayan balsam, especially in areas where mechanical or chemical controls are impractical. Generally, applying this method starts with identifying heavily infested areas that are suitable for horse grazing. This involves ensuring access to water, proper fencing, and an environment where horses can graze safely. Once the area is prepared, horses should be introduced during late spring to early summer (typically May to June) when the plants are young in their early growth stage, and before flowering begins. Grazing should continue throughout the growing season, from late spring to early autumn (September), to maximize the suppression of Himalayan balsam.

When the identified site is prepared, horses are allowed to graze in a controlled manner, applying consistent pressure to the Himalayan balsam without causing soil compaction or erosion. However, grazing areas should be rotated to prevent overgrazing and allow native vegetation to recover. Monitoring the site regularly is therefore crucial to assess the grazing impact and ensure the desired control of Himalayan balsam. Once the flowering period ends, or native plants have recovered sufficiently, the horses can be removed. Follow-up monitoring and grazing in subsequent years may be necessary to address any regrowth or resurgence of the invasive species.

The primary benefits of horse grazing include a significant reduction in Himalayan balsam density and prevention of seed production by suppressing flowering. Grazing reduces the above-ground biomass of Himalayan balsam, giving native plants a better chance to compete. Over time, this control method could support the recovery of native vegetation, enhancing biodiversity in the area. Grazing also avoids the soil disturbance associated with some mechanical methods and can improve soil health by integrating organic matter and reducing erosion if managed properly. However, horses might not uniformly graze the entire area, leading to patchy control. Supplementary methods (like manual removal) might be necessary in denser patches. Overall, care must be taken to prevent overgrazing, which could harm native plants and lead to soil degradation. In addition, the horses will not be able to graze beyond the borders of the fencing, so any Himalayan balsam on the other side of the fence will still be able to spread and maintain the seed bank. Care should be taken as well to clean the horses when transporting them to new locations, as seeds could be transported on the horse's coat and manes, which should be avoided.

Grazing with horses provides a natural and sustainable way to control Himalayan balsam infestations, but success requires careful management. By starting early in the growing season, maintaining grazing pressure throughout the summer, and regularly monitoring the site, this method can effectively suppress the invasive plant while fostering the recovery of native ecosystems.

2.6 Preliminary Cost-Efficiency Assessment

For *Impatiens glandulifera*, four control methods were piloted across various habitat types, each evaluated based on their implementation costs and the observed reduction in plant cover one year after treatment. The cost-efficiency ratio (CER) was calculated to compare the relative effectiveness of each method per unit cost. While the findings offer early insights into method performance, they are based on a single cycle of monitoring using 2024 data and should be interpreted as indicative rather than definitive. Continued data collection over multiple treatment cycles will be essential to confirm these trends and inform long-term management decisions.

Table 3: Preliminary cost-efficiency assessment Impatiens glandulifera

#	Year = 2024 Method	Costs [EUR per Ha]	% Reduction [Effectiveness]	CE Ratio	Remarks
A.	Hot steam	1,091.20	51.65	**21.12**	Most cost-efficient method, but overall moderate effectiveness as a method, likely multiple treatments needed to achieve same results as with Method B (milling and mulching) or C (Milling and sowing native competitive plants)
B.	Milling and mulching	1,898.24	81.18	23.38	Effectiveness of method is relatively high, and costs per hectare are moderate. Overall best option to consider.
C.	Milling and sowing native competitive plants	14,175.24	**85.71**	165.38	Slightly better effectiveness ratio than method B, while at the same time restoring native biodiversity. Costs per hectare are relatively high because of the costs for seeds.
D.	Grazing with horses	8,753.65	**24.52**	**356.95**	Least effective and least cost-efficient method per hectare, while grazing is not selective (can also decrease non-target populations), requires fencing around a targeted area, which may not be suitable for larger infested plots in protected areas.

The preliminary cost-efficiency assessment for *Impatiens glandulifera* indicates that milling and mulching (Method B) offers the most balanced and effective approach, combining a relatively high effectiveness rate (81.18% reduction in coverage) with moderate cost (€1,898.24/ha), resulting in a cost-efficiency ratio of 23.38. Although hot steam treatment (Method A) was the most cost-efficient in absolute terms (CER 21.12), it delivered only moderate effectiveness (51.65%), suggesting it may require multiple applications for comparable long-term results, increasing the overall costs of the intervention. Milling combined with sowing native species (Method C) achieved the highest reduction (85.71%), supporting biodiversity restoration goals, but incurred substantially higher costs (€14,175.24/ha), resulting in a less favourable CER of 165.38. Grazing with horses (Method D) was the least effective (24.52%) and least cost-efficient, with a high CER of 356.95, making it unsuitable for large-scale application.

These early findings suggest that mechanical methods, particularly milling with or without native sowing, offer the most promising options in terms of impact, though their scalability depends on site-specific factors and budget availability. Hot steam treatment may be particularly useful in sensitive or hard-to-reach areas. However, all conclusions are preliminary and should be revisited as additional monitoring data becomes available over subsequent treatment cycles.

NB: At this stage, the outcomes of the preliminary cost-efficiency assessment cannot be taken as robust enough to support policy recommendations on what types of eradication methods are most favourable and feasible. The accuracy and robustness of the analysis can be further improved as more monitoring data and information about costs for forthcoming application cycles become available as the project evolves in the next two years.

2.7 Control programmes and eradication methods applied in other countries

A variety of eradication and control methods for *Impatiens glandulifera* have been employed across Europe with varying degrees of effectiveness and cost efficiency. These methods can be categorized into manual, mechanical, chemical, biological, and integrated approaches.

- **Manual Removal:** This method, commonly referred to as "balsam bashing," involves pulling out plants by hand before they seed. It's highly selective and minimizes damage to native flora, making it ideal for low-density infestations or sensitive habitats. Costs for manual control range from €0.6 to €11.6 per m², depending on whether habitat restoration interventions are included. For example, in Ireland, controlling Himalayan balsam along 43 km of riverbank cost over €200,000 from 2011-2014. However, the cost-efficiency of this method can be improved when volunteer labour is available, as evidenced by the Wildfowl and Wetlands Trust in the UK, which valued volunteer efforts at €7,800 annually (Tanner, 2017).
- **Mechanical Removal:** Mechanical methods include mowing, strimming, or using more substantial agricultural machinery in accessible areas. A study in the UK found mechanical control to be roughly as cost-effective as chemical treatment but with fewer ecological side effects (Goodall and Wade, 2008). Mechanical cutting needs to sever the plant below the first node to prevent regrowth. Costs for mechanical removal are similar to manual methods, around €0.6 to €11.6 per m², especially when factoring in restoration (Tanner, 2017).
- **Chemical Treatment:** Herbicides like glyphosate and 2-4D amine are effective, especially for large, dense infestations. Glyphosate application typically costs around €0.6 per m², but the use of chemicals near waterways should be limited and treated with extreme caution due to environmental concerns. Chemical treatments can also damage non-target species, and multiple applications over several seasons are often required (Tanner, 2017).
- **Biological Control:** The rust fungus *Puccinia komarovii var. glanduliferae* has been trialled in the UK and Wales as a host-specific agent to suppress balsam populations. Initial rollout costs are estimated at €50,000 per country, with annual monitoring at €30,000. Biological control is a longer-term method, taking up to 7-10 years to show significant impact but is considered environmentally sustainable (Tanner et al., 2013; Pollard et al., 2021).
- **Grazing:** Livestock grazing, especially by cattle and sheep, can suppress Himalayan balsam. Grazing is considered moderately effective, especially where animals can access infested areas, although it's not an

eradication method. Grazing is low-cost if livestock is already present, and it effectively prevents plant regrowth by targeting plants below the first node (RAPID, 2018).

- **Integrated Methods:** Combining methods often yields the best results. For instance, hand-pulling paired with mowing, or biological control supplemented with mechanical methods, can maximize impact while minimizing ecological damage. The effectiveness of such strategies depends heavily on local conditions, infestation size, and resources available. For example, cross-border projects between Austria and the Czech Republic have successfully combined manual removal and mowing without herbicides, tailored to site-specific needs (EUROPARC Federation, 2024).

In summary, while manual and mechanical methods are labour-intensive, they are often effective for small or sensitive sites. Chemical treatments (e.g., spraying of herbicides) offer efficiency in large infestations but come with environmental trade-offs. Biological control is promising as a sustainable long-term approach but requires patience and initial investment. Integrated strategies are increasingly recommended for flexibility and adaptability across different landscapes (Tanner, 2017). Successful management also requires adaptive approaches, as demonstrated in Luxembourg, where control measures evolved from manual to mechanical and, eventually, to combined methods based on site conditions and population density (Ehl et al., 2023).

2.7.1 General control approach for Impatiens glandulifera

Based on international experience in management interventions for *Impatiens glandulifera*, a set of general principles and strategic recommendations have emerged for its control and potential eradication.

A. **Prioritization of Seed Prevention:** The central objective of Himalayan balsam management should be geared towards the **prevention of seed production**, which is critical to curtailing the species' annual regeneration and further spread. Given the plant's explosive seed dispersal mechanism (seeds can be projected several meters from the parent plant), early intervention during the growing season is essential. Management efforts should focus on removing plants **prior to the onset of flowering and seed set**, typically between late spring and early summer, depending on local climatic conditions. Control operations conducted after seed development are less effective and may inadvertently aid in the spread of propagules. Therefore, **timing is a critical factor** in determining the success of interventions.

B. **Landscape-Scale and Cross-Border Management:** Effective control of Himalayan balsam requires **interventions across entire hydrological catchments**, as the species primarily colonizes moist, riparian environments and readily disperses seeds via watercourses. Single-site interventions are unlikely to be effective in the long term due to continuous reinfestation from upstream seed sources. A **catchment-based approach**, encompassing coordinated efforts along entire river systems and their tributaries, ensures that upstream populations are managed before addressing downstream sites. In regions where water systems or infestation zones traverse political boundaries, **cross-border cooperation** is essential. Joint monitoring activities, together with synchronized management schedules, and shared resources between neighbouring jurisdictions can enhance the efficiency and scope of control efforts.

C. **Influence of Site Conditions and Stand Density on Method Selection:** The choice of management method for Himalayan balsam should be **tailored to local ecological conditions and infestation characteristics**. **Site accessibility, soil moisture, vegetation cover, and terrain slope** can significantly influence the feasibility of specific control measures (e.g., manual vs. mechanical approaches). The **density of balsam stands** may determine whether manual pulling is appropriate (for low to moderate infestations) or whether mechanical or chemical approaches are warranted (for dense or large-scale infestations). In sensitive habitats, including Natura2000 sites, non-chemical methods may be preferred due to restrictions on herbicide use and the presence of vulnerable native species.

D. Structured Eradication Strategies: Surveillance, Containment, Treatment, and Follow-Up: Where feasible, full eradication should be the objective, particularly in areas of recent colonization or where the infestation is still limited in scale. A structured and **strategically phased eradication programme** should include the following components:

a. **Surveillance:** Regular field surveys to detect new infestations, assess plant phenology, and map infestation extent.
b. **Containment:** Preventive measures to limit further spread, especially to uninvaded sites or sensitive ecological zones.
c. **Treatment:** Application of appropriate control measures (manual, mechanical, chemical, or integrated) at optimal times, adapted to the site and infestation conditions.
d. **Follow-Up Monitoring:** Post-treatment assessments to evaluate management efficacy, monitor regrowth or seedling emergence, and determine the need for repeated interventions. This phase is critical for long-term success and for adaptive refinement of management strategies.

E. Rapid Response to Newly Detected Populations: Early detection and rapid response (EDRR) are central to limiting the establishment and spread of Himalayan balsam. When small populations are identified in the field—particularly in new areas—swift action can significantly improve the likelihood of successful eradication. Depending on site characteristics and infestation size, a combination of **manual, mechanical, and chemical control methods** may be employed:

a. **Manual removal** (hand-pulling or cutting) is effective in small-scale infestations and in sensitive environments.
b. **Mechanical removal** (e.g., brush cutters, mowers) may be more efficient for larger stands but may require follow-up to address regrowth.
c. **Chemical control** using selective herbicides may be effective where manual or mechanical methods are impractical, though regulatory and environmental constraints must be considered.

In all cases, **timing and proper disposal of plant material** are essential to avoid further propagation. Ideally, all control actions should be conducted before the plants begin flowering or setting seed, and removed biomass should be composted in a controlled setting or incinerated if seed development is suspected.

2.8 Assessment of associated costs and benefits

Outside its native range, *Impatiens glandulifera* is regarded as invasive and poses significant ecological, economic, and social challenges. Its rapid spread along riverbanks, wetlands, and disturbed areas leads to dense monocultures, which among others suppress native biodiversity, disrupt soil stability, and increase erosion risks. In Latvia and across Europe, it degrades habitats and impacts ecosystem services such as water regulation, pollination, and recreational value. To quantify these impacts an adapted ranking framework is applied based on Blaalid et al. (2021) and Magnussen et al. (2020), which categorizes the severity of impacts on a scale from 0 to 4. The sum of the scale reflects increasing levels of ecological and socio-economic disruption (see Annex 1).

Table 4: Cost-benefit impact assessment Impatiens glandulifera

Benefit / Impact Category		Rating	Literature / Sources
Ecosystem Services	**Supporting:** ecological impact	**3** *High ecological impact. IAS significantly alters native species composition or ecosystem functioning.*	• *Impatiens glandulifera* manipulates soil microbial communities, degrading beneficial soil fungi and reducing foliar beneficial fungi in neighbouring plants. This alteration can lead to increased susceptibility of native plants to pests and diseases (Razak et al., 2023). • Its presence disrupts natural succession processes, particularly along riverbanks, affecting the overall ecosystem balance (Coakley and Petti, 2021; Razak et al., 2023). • Its impact on overall species richness and vegetation cover can be minimal in forest ecosystems (Cuda, 2017) • Below-ground communities may remain unaffected or even positively associated with the plant (Tanner, 2017)
	Supporting: ecological impact on endangered ecosystems	**3** *Endangered. Severe degradation or loss of key components; conservation urgent.*	• Himalayan balsam forms dense monocultures, which significantly reduce native plant diversity by outcompeting local species for resources (Coakley and Petti, 2021; Razak et al., 2023). • With the ability to out-compete late flowering native species in riparian zones, infestations of Himalayan balsam decrease the diversity of plants in these areas and can damage ecosystems.
	Regulating: water regulation, pollination, erosion	**3** *Major disruptions. Strong degradation of regulatory services impacting broader ecosystem or economy.*	• Himalayan balsam has extremely sweet nectar, which may attract pollinators away from native plants further altering ecological interactions (Invasive Species Council of BC., 2017). • The plant alters soil fungal and bacterial communities, often increasing fungal diversity but reducing bacterial activity and mycorrhizal fungi, which can affect nutrient cycling and soil stability (Gaggini, Rusterholz and Baur, 2017). • The shallow root system and annual nature of the plant exposes invaded areas to erosion during winter when the plants die off (Invasive Species Council of BC, 2017)
	Provisioning: food production	n/a	n/a
	Provisioning: non-food production	n/a	n/a
	Cultural: recreation, aesthetic beauty, natural heritage	**3** *Disturbance restricts access or use in certain areas; visible and spreading presence.*	• The dense growth of Himalayan balsam along waterways can reduce access as well as the aesthetic and recreational value of natural landscapes, impacting on tourism, local enjoyment of natural areas (Coakley and Petti, 2021), and recreational activities such as fishing (Tanner, 2017).
Other	**Human Health**	n/a	n/a
	Infrastructure	**2** *Moderate damage. IAS cause localized maintenance issues or interfere with infrastructure function.*	• Due to its preferred habitat in wet terrain, Himalayan balsam can clog drainage ditches, damaging infrastructure and leading to costly repairs.
	Total Score:	**14**	

The total impact score assigned to *Impatiens glandulifera* is 14, indicating a high overall level of ecological and socio-economic disruption. The species poses significant threats to supporting and regulating ecosystem services, particularly through the displacement of native vegetation, alteration of soil microbial communities, and increased erosion along riparian zones. It also negatively affects cultural services by reducing the aesthetic and recreational value of natural areas.

While no direct ecosystem services provisioning or public health impacts were identified, the cumulative score reflects a substantial justification for targeted management. The benefits of eradication, particularly in sensitive or protected habitats, are therefore likely to be considerable, warranting continued investment in cost-efficient control strategies and long-term monitoring. Overall, while there are minor socio-economic benefits, the ecological and economic impact of Impatiens glandulifera far outweigh them, justifying targeted control measures to mitigate its widespread impact.

2.9 Conclusion – Impatiens glandulifera

The management of *Impatiens glandulifera* has become a significant concern in various European countries, including Latvia, due to its aggressive spread, high reproductive potential, and negative ecological impacts. Originally introduced as an ornamental plant, it now poses a serious threat to native riparian ecosystems, where it outcompetes native vegetation, alters soil chemistry, and increases bank erosion. In Latvia, the species is widely established across diverse habitats and has been observed to form dense monocultures, suppressing biodiversity and destabilizing soil structures in ecologically sensitive areas.

Preliminary observations (based on one year of monitoring data from 2024) from the pilot eradication trials conducted by the LNCA suggest that several methods, in particular milling and mulching, and hot steam treatment, can significantly reduce plant cover, although the persistence of the seed bank requires repeated application and long-term monitoring. Conversely, methods such as grazing with horses were found to be less effective and less cost-efficient, especially at larger scales. The high CBA total impact score of 14 underscores the considerable ecological and socio-economic risks associated with continued spread.

Given its documented impacts, *Impatiens glandulifera* warrants priority attention in Latvia's invasive species management strategy. Future efforts should focus on integrating cost-effective control measures with targeted site restoration, adaptive monitoring protocols, and cross-sector collaboration to prevent reinfestation and support long-term ecological recovery.

3. Solidago canadensis [Canadian goldenrod]

3.1 Species characteristics

Solidago canadensis, commonly known as Canadian goldenrod, is a perennial herbaceous plant native to North America, particularly Canada and the United States. It is a highly invasive species that has spread across Europe and Asia.

The plant typically reaches heights of 70 to 150 centimetres, with erect, densely hairy stems that branch out into characteristic plume-like yellow flower clusters. Its flowers bloom from June to September and are notable for their role in supporting pollinators such as bees and butterflies (Poljuha et al., 2024). The plant reproduces both sexually through tiny, wind-dispersed seeds and vegetatively via creeping rhizomes, which enable it to form extensive, dense stands.

The allelopathic properties of Solidago canadensis allow it to outcompete native vegetation, making it a significant ecological and economic concern.

Photograph 3: Solidago canadensis flowering

Source: Consultant

It thrives in diverse habitats, including fields, prairies, woodlands, and roadsides, often colonizing disturbed areas due to its vigorous growth and adaptability to a wide range of soil and ecological conditions. Typically growing 2–5 feet tall, it produces clusters of yellow flowers from August to October, which attract pollinators.

3.2 Habitat and ecological characteristics

Solidago canadensis is a highly adaptable perennial plant that establishes most successfully in open, disturbed, and unmanaged environments. Its growth is facilitated by its ability to reproduce both by seed and through extensive rhizome systems, enabling it to quickly colonize and dominate various habitat types. The species favours moderate moisture levels, sunlight, and light to medium soil texture, but can also persist in less favourable conditions, making it one of the most aggressive invasive plants across temperate zones.

Due to its vigorous growth and adaptability to a wide range of soil and ecological conditions, Solidago canadensis thrives in a variety of habitats, including meadows, grasslands, roadsides, and disturbed sites, preferring moist soils but tolerating a range of conditions, except for waterlogged or highly shaded environments (Szymura, Szymura, and Wolski, 2016).

Solidago canadensis thrives in a wide range of habitats, particularly those that are open, sunny, and moderately moist. The species is highly adaptable and commonly invades disturbed or unmanaged areas where it outcompetes native vegetation due to its rapid growth, rhizomatous spread, and allelopathic effects. It can significantly alter the local biodiversity by forming dense stands that limit light and resources for native flora (Fenesi et al., 2015).

Specific ecosystems and habitat types where *Solidago canadensis* thrives best include:

- **Grasslands and meadows**: These are ideal environments for Solidago canadensis because they offer abundant sunlight and minimal canopy competition. The plant can form dense monocultures in these areas, suppressing native flora through both physical dominance and chemical interference (allelopathy). In abandoned pastures or under-grazed meadows, it rapidly takes over due to lack of disturbance from livestock or mowing (Cornell University, n.d.; Poljuha et al., 2024).
- **Prairies and open woodlands**: In both native (North American) and introduced ranges (Europe, Asia), Solidago canadensis can invade upland prairies and the edges of forests, especially where light penetration is sufficient. It thrives on open slopes and patchy canopy areas, where its intolerance to deep shade is mitigated by partial sunlight (USDA, n.d.; Popay and Parker, 2022).
- **Roadsides, railways, and wastelands**: These disturbed habitats often have poorly managed vegetation, exposed soil, and minimal competition from native species. Solidago canadensis often becomes dominant along transportation corridors due to constant disturbance and effective wind dispersal of its seeds (Popay and Parker, 2022).
- **Riverbanks, drainage channels, and wet meadows**: While not tolerant of prolonged waterlogging, Solidago canadensis thrives in moist soils such as those along riverbanks, seasonally wet meadows, and drainage ditches. These habitats provide the moisture the plant prefers without causing root rot or anaerobic stress (Poljuha et al., 2024; Cornell University, n.d.).
- **Abandoned agricultural fields and urban brownfields**: In post-agricultural or post-industrial landscapes, Solidago canadensis is often a first colonizer. Its ability to alter soil chemistry and inhibit the growth of other species allows it to dominate fallow lands, construction sites, and neglected urban plots (Poljuha et al., 2024).
- **Forest edges and clearings**: While it cannot compete in dense forest interiors due to shade intolerance, Solidago canadensis readily invades forest margins, clear-cuts, and gaps, especially in deciduous and mixed evergreen forests where light reaches the forest floor (Popay and Parker, 2022).

In general, the plant prefers moist to moderately dry soils with medium texture and moderate organic content, but it can also grow in a variety of soil types, including disturbed, dry, and even occasionally waterlogged soils, making it a successful generalist invader. It is not tolerant of dense shade or persistent waterlogging, and it is most successful in light-abundant environments with minimal canopy cover (Cornell University, n.d.; Popay and Parker, 2022; Poljuha et al., 2024).

3.3 Introduction and spread in Europe

Solidago canadensis, is a species native to North America that has become a widespread invasive plant in Europe. Its introduction to Europe dates to the mid-17th century, when it was brought over for ornamental purposes due to its bright yellow flowers and perceived aesthetic value (Królak, 2021). Initially cultivated in gardens, it eventually escaped into the wild, where its invasive characteristics allowed it to rapidly spread across various habitats.

The spread of Canadian goldenrod across Europe has been facilitated by its ability to reproduce both sexually via seeds and vegetatively through rhizomes. The plant produces large numbers of lightweight seeds that are easily dispersed by wind, allowing it to colonize new areas swiftly (Zhang et al., 2022). Additionally, its rhizome network enables it to form dense monocultures that outcompete native plant species. Its allelopathic properties further inhibit the germination and growth of neighbouring plants, giving it a significant advantage in disturbed habitats such as roadsides, meadows, and abandoned agricultural land (Poljuha et al., 2024).

Canadian goldenrod is now established in most European countries, including but not limited to the United Kingdom, Germany, Poland, Latvia, Lithuania, and the Czech Republic (Popay and Parker, 2022). Its adaptability to various soil types and environmental conditions has contributed to its success in establishing populations throughout Europe and parts of Asia.

Efforts to control its spread are ongoing in various EU countries, as it poses ecological risks by reducing native biodiversity, altering soil chemistry, and disrupting local ecosystems. Its invasive nature remains a priority concern for conservationists and land managers across Europe.

3.4 Baseline situation in Latvia

The baseline situation of Solidago canadensis in Latvia, as documented in the situation analysis of the invasive species control project, indicates that the species is already present and spreading across a variety of landscapes. The plant has established itself particularly in open or semi-open areas such as grasslands, roadside verges, and disturbed territories. Its presence is often marked by dense stands that dominate the herbaceous layer, particularly in areas with insufficient or irregular land management.

Initial surveys conducted in 2022 in locations like Ķemeri National Park, Kandava, Jēkabpils, and Daugavpils revealed that Solidago canadensis occurred in different densities, from isolated clumps to expansive, near-monocultural stands. In areas like Kandava, individual plants or small patches were scattered across most of the area, whereas in others like parts of Ruģeļi and Jēkabpils, the species covered up to 90% of some sample plots, with severely reduced plant diversity in the understorey.

These initial assessments also point out that the species was particularly dominant in sites where natural succession was left unchecked, often forming dense stands in previously unmanaged or abandoned sites, especially in former agricultural or infrastructural lands. The dominance of *Solidago canadensis* has led to poor species composition in many plots, mainly consisting of other ruderal or expansive species, and minimal coverage by native grasses or forbs.

The baseline survey of *Solidago canadensis* in Latvia demonstrates that it is a well-established invasive plant, thriving in disturbed, unmanaged, or semi-natural environments. Its presence is associated with diminished native biodiversity and structural homogenization of habitats, necessitating an adaptive and long-term approach to control and monitoring.

3.5 Eradication methods (pilot project)

Solidago canadensis is widespread throughout Latvia. The plant can be found in previously disturbed or ruderal areas (e.g., where soil was disturbed due to gardening or agriculture practices) which provide good growing conditions for this pioneering plant species. It is now present in a variety of habitats and locations, including in urban environments, and in and around protected areas and Natura2000 sites. The plant's aggressive growth, supported by rhizomatic spread and prolific seed production, poses significant threats to biodiversity and ecosystem functioning, especially in protected Natura2000 areas.

Consequently, a series of eradication trials began in Latvia during 2023 using mechanical mowing, mulching, planting of competitive native species, and in some cases, soil milling. Several testing locations with sample plots (generally 5x5 m in size) were set up by the LNCA, in Ķemeru National Park, Daugavpils, and Jēkabpils.

Eradication methods are implemented amongst others by the IAS team of the LNCA and by several external operators working on the basis of a service agreement.

Table 5: Eradication methods piloted for Solidago canadensis

	Method	Locations	Sample Plots	Description
A.	**Mowing** *(mowing 2x per year)*	Ķemeru National Park	SOL_KNP1, SOL_KNP2, SOL_KNP3, SOL_KNP4	Land under electric power line / infra
B.	**Mowing and sowing native competitive plants** *(mowing 2x per year; sowing Dactylis Glomerata)*	Ķemeru National Park	SOL_KNP5, SOL_KNP6	Land under electric power line / infra
C.	**Milling and mowing** *(mowing 1x per year)*	Daugavpils	SOL_RUG1, SOL_RUG4, SOL_RUG5, SOL_RUG6, SOL_RUG7, SOL_CIET1, SOL_CIET2, SOL_RUG12, SOL_RUG8, SOL_RUG9	Abandoned ruderal area (gardens, arable land)
D.	**Milling, mowing, and sowing native competitive plants** *(mowing 1x per year, sowing Dactylis Glomerata)*	Daugavpils	SOL_RUG2, SOL_RUG11	Abandoned ruderal area (gardens, arable land)
E.	**Milling, mowing, and sowing native competitive plants** *(mowing 1x per year, sowing White Clover and grasses)*	Daugavpils	SOL_RUG3, SOL_RUG10	Abandoned ruderal area (gardens, arable land)
F.	**Land levelling and mowing** *(mowing 2x per year)*	Jēkabpils	SOL_JPILS1, SOL_JPILS2	Land under electric power line / infra
G.	**Milling, mowing, and sowing native competitive plants** *(mowing 2x per year, sowing Dactylis Glomerata)*	Jēkabpils	SOL_JPILS3, SOL_JPILS4	Abandoned ruderal area (gardens)
H.	**Milling, mowing, and sowing native competitive plants** *(mowing 2x per year, sowing White Clover and grasses)*	Jēkabpils	SOL_JPILS5, SOL_JPILS6	Abandoned ruderal area (gardens)

3.5.1 Method A: Mowing (2x per year)

Mowing is a widely employed mechanical strategy to control *Solidago canadensis*. The typical approach involves mowing twice annually: first in mid-June, cutting the plants to approximately six inches above the ground, and mowing again in late August. This regimen aims to prevent the plants from flowering and setting seed, thereby reducing their spread. The sample plots in the Kemeri National Park in Latvia include areas that are relatively easy to access with mowing equipment and vehicles and are in open spaces underneath power line infrastructure.

Research indicates that consistent mowing can deplete the energy reserves stored in the rhizomes of the Solidago canadensis, leading to a decrease in clonal growth. For instance, a study found that mowing tall goldenrod annually during peak bloom over six years diminished rhizome resources and clonal expansion, though it did not completely eradicate the plants.

The timing and frequency of mowing are of crucial importance for its effectiveness. Mowing once in July may not significantly impact the plant's vigour or reproductive capacity. However, increasing the mowing frequency to two or three times per growing season, particularly before the plant reaches full bloom, has been shown to substantially reduce both above-ground biomass and rhizome mass. This intensified mowing schedule also lowers flowering rates, thereby curbing seed production and further spread.

Despite its benefits, mowing presents certain challenges. Solidago canadensis can regenerate from root fragments, necessitating repeated mowing sessions. Additionally, the method's efficacy can be limited by terrain that restricts mechanical access, and there's a risk of inadvertently promoting other invasive species if native vegetation is not concurrently supported. Therefore, integrating mowing with other management practices, such as overseeding with native competitive species, is often recommended to enhance restoration efforts.

In summary, while mowing twice per year is a labour-intensive method, it has proven effective in controlling dense populations of Solidago canadensis, especially when combined with regular monitoring and supplementary measures like reintroducing native plant species.

3.5.2 Method B: Mowing and sowing native competitive plants (2x per year; Dactylis Glomerata)

The treatment method for combating the invasive species *Solidago canadensis* using a combination of mowing (twice annually) and sowing native competitive seeds (*Dactylis glomerata*) involves a systematic approach to remove the above-ground biomass of the invasive plant while encouraging the establishment of native vegetation. Initially, the site is prepared by clearing excess vegetation, loosening the topsoil, and sowing Dactylis glomerata seeds at a rate of approximately 40 kg/ha. Mowing is performed twice per year: the first mowing occurs in mid-summer (June or July) before the goldenrod flowers, and the second mowing takes place in early autumn (September) to prevent seed production. In some areas, the mowed grass is removed, while in others, it is left in place. This process is complemented by monitoring vegetation changes in sample plots to evaluate the method's effectiveness.

The timing of the intervention is critical, as sowing of the native plant seeds it must align with the growth cycle of Solidago canadensis to effectively disrupt its reproduction. However, this approach presents several challenges, including the difficulty of establishing native seedlings like Dactylis Glomerata in unfavourable conditions such as drought, as well as the high resilience of Solidago canadensis, which can regenerate quickly even after repeated mowing. Additionally, the labour intensity required for mowing on uneven or steep terrain and the limited effectiveness of grass mulch in suppressing the Solidago canadensis' growth (unless applied in thick layers) further complicate the process.

Despite these challenges, preliminary results from the pilot areas show significant reductions in Solidago canadensis coverage and density, with decreases of more than 50% observed in some cases. Moreover, the method has led to an increase in native plant diversity, as competitive species such as Dactylis Glomerata create opportunities for other herbaceous plants to establish. The preliminary monitoring results suggest that this method has potential for long-term suppression of the Solidago canadensis, although sustained application and continued monitoring are necessary to ensure its success.

3.5.3 Method C: Milling and mowing (1x per year)

One method being tested in the pilot project involves a combination of milling and mowing (mowing 1x per year) treatment. This is a mechanical eradication approach that involves milling of the site with the Solidago canadensis and disturb the soil in the process, followed by regular mowing to prevent regrowth. The process begins with milling, where the topsoil is mechanically disrupted using reclamation milling machines. This step aims to destroy the root system of the invasive goldenrod, preventing its ability to resprout while also improving soil conditions for the reintroduction of native plant species. Following milling, annual mowing is conducted to further suppress any remaining goldenrod plants. The mowing takes place once per year, ideally in late summer or early autumn before the goldenrod disperses seeds. In some cases, additional soil preparations, such as levelling or mulching, are implemented, and competitive plant species like Dactylis Glomerata or White Clover are sown to outcompete any regrowing goldenrod.

The timing of this method is crucial for its success. Milling is best conducted in spring or early summer, before the goldenrod enters its reproductive stage, ensuring the root system is effectively damaged. Mowing is then performed once annually to maintain control over any resprouting plants. If the mowing schedule is not maintained consistently, the Solidago canadensis will regenerate from root fragments and regain dominance in the area.

Despite its potential, this method comes with several challenges. One of the primary concerns is regrowth, as Solidago canadensis is a resilient species that can rebound if mowing is not done diligently. The process is also labour-intensive, requiring specialized equipment and trained personnel to carry out milling and mowing operations effectively. Additionally, soil disturbance from milling can lead to issues such as erosion or colonization by other invasive plant species if not managed properly. Weather conditions also play a role, as excessive rainfall or prolonged drought can affect the success of both milling and mowing cycles.

Early results from pilot areas in Latvia under the LIFE-IP LatViaNature project indicate promising preliminary effects. Initially, there is a significant reduction in Solidago canadensis biomass, and as its population density and coverage, there is an observable increase in plant species diversity, as other herbaceous plants begin to recolonize the treated areas. In some cases, however, goldenrod has demonstrated resilience, regrowing through the milled soil if mowing is not sustained over multiple years. Additionally, the method appears to enhance soil quality, improving soil structure and fertility, particularly when combined with the introduction of native plant species.

3.5.4 Method D: Milling, mowing and sowing native competitive plants (1x per year; Dactylis Glomerata)

The method for controlling Solidago canadensis using a combination of milling, mowing (once per year), and sowing native competitive plants like Dactylis Glomerata, requires careful planning and a structured timed process. Initially, milling is conducted, where specialized equipment mechanically disturbs the topsoil. This step disrupts the goldenrod's root system, making it less likely to regenerate. Milling is particularly effective in areas with dense infestations and extensive root networks. Following this, mowing is carried out once per season, usually in late summer or early autumn, before it can produce seeds. This reduces the plant's ability to spread and opens up space for other vegetation. After the initial milling, Dactylis Glomerata is sown as a native competitive species to outcompete the Solidago canadensis. This fast-growing grass forms a dense cover that limits Solidago canadensis seedlings from re-establishing while stabilizing the soil and reducing disturbances.

The treatment timing is crucial for its success. Milling should be performed in spring (April-May), and Dactylis glomerata is sown immediately after to capitalize on the growing season. During summer (July-August), monitoring is conducted to assess Solidago canadensis regrowth. Finally, in late summer or early autumn (August-September), mowing is performed before the Solidago canadensis blooms to prevent seed dispersal. In areas with lower density, hand removal is also be conducted as part of the strategy.

Despite its effectiveness, this method faces several challenges. The Solidago canadensis’ robust root system can regenerate even after milling, necessitating repeated treatment cycles over several years. If Solidago canadensis regrows quickly, it can suppress Dactylis Glomerata before the grass can establish itself. Furthermore, the success of the method is heavily dependent on weather conditions. Prolonged drought conditions can reduce the establishment of native grasses, while excessive rainfall after milling may promote Solidago canadensis regrowth before the competitive plants can take hold. Another challenge arises from the soil disturbance caused by milling, which can create opportunities for other invasive species to colonize the area. Therefore, regular monitoring and supplementary seeding of native species may be needed to maintain control.

Preliminary results from the pilot sites indicate that the method has promising effects. Milling significantly reduces the immediate presence of Solidago canadensis by disrupting its root systems. In addition, the number of herbaceous plant species tends to increase as Solidago canadensis dominance declines. Areas where Dactylis glomerata successfully establishes show lower rates of Solidago canadensis regeneration. However, some sites experienced regrowth despite milling, indicating that deeper root structures might remain intact. Adjustments, such as additional mowing cycles or higher seeding rates for Dactylis Glomerata, may be necessary in such cases. Overall, this integrated approach shows potential for reducing the dominance of Solidago canadensis and increasing plant diversity in affected areas. However, long-term monitoring in the next three years to 2027 will be essential to fully evaluate its effectiveness and refine the method as needed based on site-specific conditions.

3.5.5 Method E: Milling, mowing and sowing native competitive plants (1x per year; White Clover)

Similar to the previous method D, this method combines milling, mowing, and sowing native competitive plants, in this case with White Clover. The process begins with milling, where the topsoil is broken up and loosened using machinery. This step reduces the root structures of the Solidago canadensis and creates favourable conditions for sowing competitive native plants. Milling also incorporates plant residues into the soil and helps disrupt dense invasive vegetation. Following this, mowing is carried out once per year, specifically timed to prevent the Solidago canadensis from reaching maturity and producing seeds. This typically takes place in late spring or early summer before the plant enters its flowering and seed-forming stage, which usually occurs between June and September. Lastly, native plants, in this case White Clover, are sown immediately after milling. White Clover is chosen for its ability to form dense ground cover, fix nitrogen, and compete effectively with the Solidago canadensis for resources. Sowing should occur in late spring, allowing the seeds sufficient time to establish before winter.

The timing of these activities is critical to their effectiveness. Milling and sowing should ideally be performed in early spring when conditions are optimal for plant establishment. Mowing, on the other hand, should occur mid to late summer, just before the Solidago canadensis begins to flower, to disrupt its reproductive cycle. However, the success of this method is not without challenges. Prolonged droughts can hinder the establishment of native plants like White Clover, which rely on adequate moisture for germination. Conversely, heavy rainfall can lead to soil compaction or erosion, which may compromise the results of milling and sowing. Another significant challenge is ensuring that the native plants establish quickly and densely enough to outcompete the Solidago canadensis. If competitive species fail to cover the ground robustly, the Solidago canadensis may regrow through residual roots or seeds already present in the soil. Additionally, the process can be resource-intensive, requiring specialized equipment and skilled operators for milling, while steep or uneven terrains necessitate manual or specialized equipment for mowing. Debris such as barbed wire or concrete remnants, commonly found in certain pilot areas (as most sample sites are on abandoned ruderal area), can further delay or complicate these operations.

Despite these challenges, preliminary results from pilot areas such as Ķemeri National Park and Jēkabpils indicate that this method shows promise. There has been a noticeable reduction in Solidago canadensis coverage, particularly in areas where mowing was combined with the sowing of competitive native plants. Furthermore, an increase in species diversity has been observed in plots where Solidago canadensis cover decreased, as native plants began occupying the freed niches. White Clover germination has been successful in some areas, even under dry conditions. However, in regions where the competitive plants failed to establish effectively, Solidago canadensis regrowth has been observed.

3.5.6 Method F: Land levelling and mowing (2x per year)

Another method tested in the pilot project includes a combination of land levelling and mowing. Compared to the milling method, levelling primarily serves as a preparatory method to improve the accessibility and manageability of the terrain for subsequent management techniques, such as mowing. It involves using machinery, such as excavators or bulldozers, to smooth out uneven terrain by filling in ditches, removing bumps, and eliminating obstacles like stumps or roots. The focus of levelling is on surface-level adjustments without significantly disturbing the deeper soil structure or root systems. Its impact on the soil is minimal, as it primarily ensures the land is suitable for other treatments and management practices.

In practical applications, levelling is often combined with other methods, like mowing, to enhance the effectiveness of control measures. The combination of levelling and mowing begins with initial site preparation, where the area is cleared of overgrowth such as trees and shrubs, including stumps and roots. If the terrain is uneven, the land is levelled to facilitate future mowing efforts. This step is crucial to ensure that the method can be effectively applied.

After levelling, mowing is conducted twice annually to prevent flowering and seed production. The first mowing typically occurs in early summer, around June or July, targeting the Solidago canadensis before it flowers. The second mowing takes place in early autumn, during August or September, to further inhibit regrowth and flowering. While the mowed grass is often left in place, in some cases it is used for mulching to suppress regrowth.

Timing plays a critical role, as mowing is aligned with the growth and reproductive cycle of the Solidago canadensis to maximize effectiveness. The twice-annual mowing schedule ensures that flowering and seed dispersal are consistently interrupted. However, the method faces several challenges. Uneven terrain or steep slopes can complicate mowing and often require specialized equipment. Drought conditions may also slow regrowth, potentially reducing the need for multiple mowing sessions but creating variability in results. Additionally, the persistence of Solidago canadensis remains a significant challenge, as the species is highly resilient and can regrow after mowing, especially if the roots are not fully removed. In urbanized or previously cultivated areas, debris such as wires and concrete can further delay mowing and land preparation.

3.5.7 Method G: Milling, mowing and sowing native competitive plants (2x per year; Dactylis Glomerata)

This method is similar to method D, but applies a schedule of mowing twice per year instead of mowing once, and sowing of Dactylis Glomerata as native competitive plant.

3.5.8 Method H: Milling, mowing and sowing native competitive plants (2x per year; White Clover)

This method is similar to method D, but applies a schedule of mowing twice per year instead of mowing once, and sowing of White Clover as native competitive plant.

3.6 Preliminary Cost-Efficiency Assessment

For *Solidago canadensis* eight different control methods, ranging from simple mowing to integrated approaches combining mechanical removal and sowing native competitive plant species, were applied under varying habitat conditions. Each method was evaluated based on its effectiveness in reducing IAS cover and the associated implementation costs, normalized per hectare.

The resulting cost-efficiency ratios (CERs) provide an initial comparative understanding of which methods may offer the best value for investment. While the findings reflect only the first year of treatment and monitoring, they offer valuable insights into method performance and lay the groundwork for future, more robust evaluations as additional data is collected over the duration of the project.

Table 6: Preliminary cost-efficiency assessment Solidago canadensis

#	Year = 2024 Method	Costs [EUR per Ha]	% Reduction [Effectiveness]	CE Ratio	Remarks
A.	**Mowing** *(mowing 2x per year)*	3,798.24	69.22	54.87	Mowing is a relatively simple and affordable method that achieved relatively good effectiveness. Its moderate CER makes it a practical and scalable option, particularly for accessible sites with medium-density infestations.
B.	**Mowing and sowing native competitive plants** *(mowing 2x per year; sowing Dactylis Glomerata)*	11,758.24	40.97	**286.98**	This method is significantly more expensive with limited effectiveness, resulting in the highest CER of all methods. Despite potential biodiversity benefits, it is not cost-efficient and may only be justifiable for targeted restoration objectives. Costs may be inflated due to the costs of seeds, which may be reduced when applied at a larger scale
C.	**Milling and mowing** *(mowing 1x per year)*	2,669.22	59.85	44.60	A low-cost and effective method, showing a moderate CER. This approach is suitable for dense stands of Solidago and offers strong potential for wider application.
D.	**Milling, mowing, and sowing native competitive plants** *(mowing 1x per year, sowing Dactylis Glomerata)*	3,390.69	95.78	35.40	Together with Method E, one of the most effective and cost-efficient methods. It combines high control success with biodiversity restoration potential, making it an excellent candidate for priority implementation in conservation areas.
E.	**Milling, mowing, and sowing native competitive plants** *(mowing 1x per year, sowing White Clover and grasses)*	3,142.77	**98.63**	**31.86**	Lowest CER and highest effectiveness overall. Together with Method D, this approach offers outstanding value for investment and is well-suited for restoration in heavily infested or ecologically sensitive areas.
F.	**Land levelling and mowing** *(mowing 2x per year)*	4,068.18	58.11	70.01	While moderately effective, the relatively high cost results in a weaker CER. This method may be better reserved for sites requiring terrain correction or infrastructure preparation.
G.	**Milling, mowing, and sowing native competitive plants** *(mowing 2x per year, sowing Dactylis Glomerata)*	3,914.01	**27.08**	144.52	Despite the intensive treatment, this method performed poorly overall in terms of effectiveness. Its high CER suggests low cost-efficiency, likely due to ecological or application-specific factors that limited suppression success.

#	Year = 2024 Method	Costs [EUR per Ha]	% Reduction [Effectiveness]	CE Ratio	Remarks
H.	**Milling, mowing, and sowing native competitive plants** *(mowing 2x per year, sowing White Clover and grasses)*	4,223.34	56.25	75.08	Achieved moderate effectiveness results, but with a relatively high CER. While it may support vegetation recovery, its cost-efficiency is low compared to similar single-treatment options (e.g. Method D and E).

The preliminary cost-efficiency assessment highlights several promising approaches in terms of cost-efficiency and ecological impact. Methods D (Milling, mowing, and sowing Dactylis glomerata, 1x per year) and E (Milling, mowing, and sowing White Clover and grasses, 1x per year) emerged as the most effective strategies, achieving the highest percentage reductions in species cover (Method D 95.78% and Method E 98.63% respectively), while maintaining relatively low costs per hectare. These methods also demonstrated the lowest cost-efficiency ratios, indicating strong value for investment. The integrated approaches of Method D and E clearly outperformed others in both suppression and restoration potential. In contrast, methods such as B and G, despite higher costs and treatment intensity, underperformed in terms of effectiveness and cost-efficiency.

Overall, this initial assessment supports prioritizing Methods D and E for broader application, particularly in ecologically sensitive or heavily infested areas. However, these observations must be considered preliminary. One vegetation season is insufficient to determine the long-term success or sustainability of Solidago canadensis suppression. Continued monitoring over multiple seasons is essential to evaluate the persistence of treatment effects, the potential for regrowth, and the establishment of competitive native vegetation. The ultimate success of any method will depend on consistent reapplication where needed, responsiveness to site-specific conditions, and a sustained commitment to integrated invasive species management. Future monitoring data will be critical to validate these early results and inform adaptive management strategies.

NB: At this stage, the outcomes of the preliminary cost-efficiency assessment cannot be taken as robust enough to support policy recommendations on what types of eradication methods are most favourable and feasible. The accuracy and robustness of the analysis can be further improved as more monitoring data and information about costs for forthcoming application cycles become available as the project evolves in the next two years.

3.7 Control programmes and eradication methods applied in other countries

In several other European countries, diverse methods have been employed to combat Solidago canadensis (Canadian goldenrod), with varying degrees of cost-efficiency and ecological success.

- **Mechanical control (mowing and soil disturbance):** Repeated mowing is one of the most commonly applied mechanical control methods. In Poland, for example, mowing Solidago twice annually (typically in May and August) over successive years has proven effective in significantly reducing its spread, especially when combined with soil cultivation. A study in southwest Poland estimated costs ranging from 123 to 266 million PLN (from €28 to €60 million) to recultivate roughly 130,000 hectares infested by Solidago canadensis, depending on the method used (Szymura, Szymura and Wolski, 2016). Sod-cutting, which removes the upper soil layer including the seed bank, and mechanical tillage also showed promising results. However, tillage can degrade the soil and is more expensive (approximately 2,047 PLN/ha) than mowing alone (approximately 1,015 PLN/ha) or sod-cutting (approximately 1,390 PLN/ha) (Szymura et al., 2016). In Austria, two annual mowing events over three years reduced goldenrod density by up to 95.6% in dry grasslands, demonstrating high effectiveness in specific ecological contexts (Hall et al., 2022).

- **Chemical control:** Chemical herbicides such as glyphosate and triclopyr are often used either as foliar sprays or applied to cut stems. A Czech study found that combining mowing with subsequent herbicide application was the most effective, reducing Solidago canadensis populations by up to 87% (Rajdus et al., 2020). However, herbicide-only treatments had limited success, and concerns persist regarding collateral environmental damage and the need for repeated applications.
- **Biological and ecological methods**: Biological approaches, though less common, are emerging. In the U.S., for example, cattle grazing has shown potential as a control measure when managed seasonally, though such approaches have not been widely reported in European contexts (Northern Ag Network, 2023). In Austria and Germany, converting invaded areas to triticale cultivation proved highly effective, with up to 97.2% reduction in Solidago canadensis density, although this method's success is dependent on favourable weather and soil conditions (Hall et al., 2022).
- **Combined and integrated management**: The most effective long-term strategies typically integrate multiple methods. For instance, the Polish study by Gala-Czekaj et al. (2021) found that combining mowing and rotary tilling led to the most substantial reduction in reproductive capacity of Solidago canadensis. Similarly, establishing competitive vegetation post-eradication (e.g., sowing grass-forb mixtures) was essential to prevent reinvasion (CABI, 2022; Szymura et al., 2016).

In summary, while mechanical and chemical controls are widespread and often effective, the success of each method increases significantly when integrated with ecological strategies such as replanting or selective biological control. Costs can be substantial (as observed for example in Poland), particularly for large-scale infestations, but long-term suppression and ecosystem recovery are more reliably achieved through sustained and adaptive multi-method approaches.

3.7.1 General control approach for Solidago canadensis

Based on experience from countries where *Solidago canadensis* has been extensively studied and managed, several key principles have been established for its control, reflecting both ecological considerations and practical field experience.

A. **Importance of Timely and Repeated Interventions:** Successful control of *Solidago canadensis* is heavily dependent on **early, well-timed, and repeated treatment interventions** that specifically target both the aboveground biomass and the belowground rhizome network:
   a. **Phenological Timing**: Control efforts should be aligned with the plant's phenological stages to maximize effectiveness. Interventions should ideally occur **prior to flowering** to prevent seed set and subsequent seed dispersal. Given that *Solidago canadensis* typically flowers in late summer to early autumn, mechanical or chemical treatment is best conducted in mid-summer, when the plant has developed sufficient foliage for herbicide (herbicide use is advised only on locations where this is admissible and ecologically justifiable) uptake but before seed development has occurred.
   b. **Vegetative Propagation Considerations**: In addition to seed production, *Solidago canadensis* spreads aggressively through rhizomes. Therefore, treatments must also **target the root system**, as superficial removal of stems and leaves is insufficient for long-term suppression. The rhizome network allows for rapid regrowth, and untreated root fragments can re-sprout, leading to reinvasion if follow-up treatments are not implemented.
   c. **Repeated Applications**: Due to the regenerative capacity of this species, **multiple treatment cycles per year** (often for several consecutive years) are generally necessary to exhaust the plant's energy reserves

and reduce population density. Consistent follow-up treatments help prevent re-establishment and increase the probability of local eradication over time.

B. Integrated Use of Manual, Mechanical, and Chemical Methods: A range of control techniques have been applied across different countries, each offering specific advantages depending on site conditions, infestation severity, and management objectives. The methods most often applied include:

a. **Manual Removal**: Hand-pulling or digging can be effective for small, early-stage infestations, particularly where the soil is soft and moist enough to facilitate the extraction of the entire root system. Manual control is generally not feasible for large-scale infestations due to labour intensity, but may be applied in ecologically sensitive areas where chemical use is restricted.
b. **Mechanical Control**: Mowing or cutting can reduce aboveground biomass and prevent flowering and seed dispersal. However, **mechanical treatments alone are often insufficient**, as they do not affect the underground rhizomes. Mowing may, in fact, stimulate vegetative regrowth if not followed by additional control measures. For best results, mowing should be followed by herbicide application to the regrowing shoots or repeated multiple times per growing season.
c. **Chemical Control**: The application of systemic herbicides (e.g., glyphosate-based formulations) has proven effective in reducing *S. canadensis* biomass and rhizome viability when applied at appropriate growth stages. Herbicides should be applied during active growth phases (typically late spring to summer), when translocation to root systems is maximized. Caution should be exercised near water bodies or in areas of high conservation value, in accordance with national and regional regulations regarding herbicide use.
d. **Combined Approaches**: In many cases, the most effective control strategy involves an **integrated management approach**, combining mechanical cutting with subsequent herbicide treatment or manual removal in follow-up stages. This integrated strategy increases overall efficacy while minimizing negative impacts on non-target vegetation.

C. Influence of Site Conditions on Method Selection: The **choice of control method** should be tailored to the specific environmental conditions of the infested site, including soil type, slope, accessibility, surrounding vegetation, and land use designations (e.g., agricultural land, protected natural areas, roadside verges). In **protected areas**, where the use of herbicides may be legally restricted, mechanical and manual methods should be prioritized, even if this increases the frequency of interventions required. On **agricultural or ruderal land**, where accessibility and scale permit, chemical treatments may be applied more broadly, though care must be taken to avoid non-target effects and resistance development.

D. Field Identification and Rapid Response: Once *Solidago canadensis* is identified in the field, **prompt initiation of eradication efforts** is critical. The species' ability to rapidly colonize disturbed habitats means that early-stage populations can quickly expand into extensive monocultures if not addressed. A rapid response protocol should consider the following actions:

a. Include immediate treatment using the most appropriate method for the infestation level and site characteristics.
b. Be followed by scheduled monitoring visits to assess regrowth and to implement further control actions as needed.
c. Integrate with regional or national IAS monitoring databases to ensure coordinated action across administrative boundaries.

3.8 Assessment of associated costs and benefits

As an invasive species in many parts of Europe and Asia, *Solidago canadensis* poses significant ecological risks. It outcompetes native plant species through aggressive growth and allelopathic effects, where it releases chemicals that inhibit the growth of surrounding vegetation (Zhu et al., 2022). This leads to reduced biodiversity and altered soil composition. Despite these negative impacts, Solidago canadensis also has recognized benefits, including medicinal uses for treating inflammation and urinary disorders, and potential applications in biofuel production and bioremediation (Poljuha et al., 2024).

To quantify the range of impacts we apply an adapted ranking framework based on Blaalid et al. (2021) and Magnussen et al. (2020), which categorizes the severity of impacts on a scale from 0 to 4. The sum of the scale reflects increasing levels of ecological and socio-economic disruption (see Annex 1).

Table 7: Cost-benefit impact assessment Solidago canadensis

Benefit / Impact Category		Rating	Literature / Sources
Ecosystem Services	**Supporting:** ecological impact	**3** *High ecological impact. IAS significantly alters native species composition or ecosystem functioning.*	• *Solidago canadensis* forms dense stands that outcompete native plant species, leading to the **decline in plant diversity and disrupting the local ecosystems** (Królak, 2021). • Releases allelopathic compounds that inhibit the germination and growth of neighbouring plants, further contributing to its dominance in invaded areas (Poljuha, et al., 2024). • Alters soil structure and nutrient composition **affecting the survival of native species** (Poljuha, et al., 2024). • Invasive *Solidago canadensis* can lead to a **decrease in the abundance of bees, particularly small-bodied species**, as dense stands of goldenrod can create an adverse environment (Fenesi et. Al, 2015). • Dry, standing stems of last year *Solidago canadensis*, offered a better habitat and forage area for spiders than the replaced native grass vegetation (Dudek et al., 2016), leading to significant increases in the number of spiders (by factor 7) and prey elements (by factor 11).
	Supporting: ecological impact on endangered ecosystems	**4** *Critical. Collapse imminent or ongoing; irreversible loss likely without intervention.*	• *Solidago canadensis* provides nectar and pollen for various pollinators. However, its dominance can lead to a decrease in the diversity of native flowering plants. This can **impact specialized pollinators that rely on specific native species** (Fenesi, et al., 2015). • The plant can outcompete native plants resulting in gross changes negatively affecting both flora and fauna to the point where **character species may disappear altogether** (Popay and Parker, 2022)
	Regulating: water regulation, pollination, erosion	**2** *Noticeable effects. Reduced effectiveness of natural systems (e.g., pollination decline, altered water flow).*	• *Solidago canadensis* provides nectar and pollen for various pollinators. However, its dominance can lead to a decrease in the diversity of native flowering plants. This can impact specialized pollinators that rely on specific native species (Fenesi, et al., 2015). • Provides late-season nectar for pollinators for honeybees (Poljuha, et al., 2024), which can be detrimental to the pollination of native flowering plants (Fenesi, et al., 2015). However, if honeybees rely solely on goldenrod honey for nutrition, their survival probability can be significantly lower compared to bees fed a mixed flower honey. • Dense infestations along waterways can impede flow and increase flood risk and erosion.
	Provisioning: food production	**1** *Small effects. Minor reduction in crop or livestock productivity.*	• The presence of *Solidago canadensis* can increase the costs associated with land management and weed control (Zhu, et al., 2022). • The plant can cause a reduction in crop yields due to competition for resources (Zhu, et al., 2022).

Benefit / Impact Category		Rating	Literature / Sources
	Provisioning: non-food production	**0** *No known impact on resources such as timber, fibre, or biofuel.*	Potential application of *Solidago canadensis* in the bioeconomy for various industries, pharmacy, agriculture, and cosmetics due to its bioactive compounds with antioxidant, antimicrobial, and anticancer properties. However, these benefits require further validation and prioritization to be fully realized (Poljuha, et al., 2024): • Biochar derived from its biomass is effective for water treatment and improving soil quality. • Biofuel production from its biomass is feasible, with significant energy potential. • Produces essential oils for use in natural insecticides and antifungal treatments. • It can be used as a natural dye source in the textile industry. • Its extracts are used for synthesizing gold and silver nanoparticles which could offer innovative applications in medical and industrial fields.
	Cultural: recreation, aesthetic beauty, natural heritage	**3** *Disturbance restricts access or use in certain areas; visible and spreading presence.*	• Alters landscapes by forming dense monocultures often perceived as visually unappealing. This can impact recreational and cultural value of the land (Poljuha, et al., 2024). • The presence of Solidago canadensis can impact cultural practices by changing the landscape and biodiversity of the land (Poljuha, et al., 2024).
Other	**Human Health**	**0** *No effects.* *IAS pose no health concern.*	• *Solidago canadensis* is not a major allergen source but is frequently mistaken as a cause of hay fever, which can lead to public concern (Poljuha et al., 2024). • The leaves and flowers of *Solidago canadensis* are attributed to have medicinal properties (folk herbal medicine). *Solidago canadensis* may help reduce inflammation, relieve muscle spasms, fight infections, and lower blood pressure; it has also been used to treat tuberculosis, diabetes, enlargement of the liver, gout, haemorrhoids, internal bleeding, asthma, and arthritis. • The plant contains bioactive compounds like flavonoids, terpenoids, and phenolic acids with antioxidant, antimicrobial, and anti-inflammatory properties (Poljuha, et al., 2024). • Potentially, *Solidago canadensis* can be used in treating ailments such as rheumatic and urinary disorders, and as an anti-asthmatic agent (Poljuha, et al., 2024).
Other	**Infrastructure**	n/a	n/a
	Total Score:	**13**	

Solidago canadensis poses a significant ecological threat in Latvia, particularly in open habitats such as meadows and disturbed landscapes. Solidago canadensis is among the most ecologically disruptive invasive species in Latvia, with a total impact score of 13, reflecting substantial negative effects on native biodiversity, ecosystem functioning, and land use quality. It forms dense monocultures that outcompete native species, alters soil nutrient dynamics through allelopathy, and degrades the ecological integrity of meadows, riparian zones, and other open habitats. The species has been linked to biodiversity loss, soil nutrient imbalances, and suppression of native flora through allelopathic effects.

Despite its ecological drawbacks, Solidago canadensis also holds potential value in other domains. It has traditional uses in herbal medicine and shows promise for bioeconomy applications, including the production of biofuels, natural insecticides, and pharmaceutical compounds (Poljuha et al., 2024). However, its invasive threat and ecological impact underscores the need for balanced management strategies. In its non-native range, particularly within biodiversity-sensitive regions like Latvia, management objectives should be primarily aligned with nature conservation priorities, while recognizing the need for a nuanced approach where low-risk utilization may be feasible under controlled conditions.

Overall, from an ecological management perspective, reducing the dominance of Solidago canadensis opens up ecological niches for native herbaceous species, enhances habitat quality for pollinators, and contributes to the restoration of semi-natural grasslands, many of which are protected under the EU Habitats Directive. Although direct economic benefits may not be immediately visible, improved land quality, reduced long-term management burdens, and enhanced biodiversity represent substantial long-term gains for conservation, recreation, and land use. Continued investment in cost-efficient, ecologically integrated control measures, paired with sustained monitoring and adaptive management, will be essential to securing these gains and mitigating the species' long-term impact.

3.9 Conclusion – Solidago canadensis

Solidago canadensis (Canadian goldenrod) is a fast-spreading perennial herbaceous plant native to North America, which has become invasive in various parts of Europe and Asia. In Latvia it continues to pose a serious ecological threat, particularly in grasslands, meadows, roadside verges, and disturbed habitats where it forms dense monocultures that suppress native vegetation, alter soil chemistry, reduce biodiversity, and alter ecosystem functions. Due to its ability to reproduce both generatively (through seeds) and vegetatively (via an extensive rhizome system), the species presents significant challenges to long-term control and eradication efforts, especially once it gets established.

Based on the preliminary Cost-Efficiency Analysis, the most effective and cost-efficient approaches were Method D (milling, mowing, and sowing Dactylis glomerata, 1x/year) and Method E (milling, mowing, and sowing White Clover and grasses, 1x/year), both demonstrating high suppression rates (95.78% and 98.63%, respectively) and the lowest cost-effectiveness ratios. These integrated methods not only reduce *Solidago canadensis* cover but also support the re-establishment of competitive, native vegetation, contributing to ecosystem recovery. In contrast, methods with high costs and lower suppression outcomes, such as Method B and Method G, showed limited cost-efficiency and are better suited for specific restoration contexts rather than broad application.

While mechanical methods like mowing and milling offer moderate success and may be more feasible in certain landscapes, they typically require repeated application and careful timing. It is also important to recognize the dual nature of Solidago canadensis, which, despite its invasiveness, has known uses in traditional medicine and emerging potential in the bioeconomy, including biofuel and insecticide production. However, in non-native regions such as Latvia, management must prioritize biodiversity conservation and habitat integrity above potential economic uses.

While complete eradication may be feasible in in isolated or newly infested areas with early detection and rapid response, long-term suppression is often the most realistic goal in sites where the species is well established. Continued surveillance, stakeholder coordination, and adaptive management will be essential to reduce the ecological and economic impacts of this invasive species across affected landscapes. Therefore, effective management of *Solidago canadensis* requires a **strategically planned, multi-year control programme** that combines precise timing, repeated treatments, and adaptive use of manual, mechanical, and chemical methods. Experiences from other countries stress the importance of early intervention, integrated approaches, and control methods tailored to site-specific conditions.

4. Amelanchier spicata [dwarf serviceberry]

4.1 Species characteristics

Amelanchier spicata, commonly known as dwarf serviceberry, thicket shadbush, or low June berry, is a deciduous shrub or small tree native to eastern North America and parts of Canada. It typically reaches heights of up to 3 meters and spreads vigorously via rhizomes and suckers, forming dense thickets.

The species produces pendulous clusters of small, edible berries that are highly attractive to birds, aiding in its seed dispersal and invasive potential. It thrives in a broad range of habitats—including dry pine and oak forests, grasslands, forest edges, dunes, and disturbed urban areas—due to its tolerance for a variety of soil types and environmental conditions, including salinity and cold temperatures down to -26°C (Kabuce and Priede, 2010; Native Plant Trust, n.d.).

While *Amelanchier spicata* is valued in its native range for ornamental use and ecological benefits such as supporting pollinators and wildlife, it has become invasive in parts of northern Europe, including in Latvia, Finland, and Sweden.

Photograph 4: Amelanchier spicata dense thicket

Source: Consultant

Outside its native range, it has significantly altered native ecosystems by forming impenetrable undergrowth, suppressing native ground flora, and transforming open pine forests into dense shrub thickets. This invasive behaviour has led to its classification as a significant biodiversity threat in some European countries (Great Britain Non-Native Species Secretariat, n.d.; Pratašienė and Marozas, 2018). Its rapid spread across Latvia in just five decades exemplifies the urgent need for targeted management strategies, particularly in affected Natura2000 sites and other protected landscapes.

4.2 Habitat and ecological characteristics

Amelanchier spicata is a highly adaptable species capable of thriving in a wide range of habitats, particularly favouring dry pine and pine-oak forests, scrubby grasslands, forest edges, coastal and inland dunes, open woodlands and clearings, sandy and rocky soils, roadsides and railway sidings.

It grows under diverse light conditions, from full sun to deep shade, and across varying terrain types such as summits, cliffs, open woodlands, forest clearings, and rocky or sandy soils. It can tolerate acidic, loamy, and peaty soils and is both moisture- and drought-tolerant, making it suitable for environments ranging from moist forests to dry grasslands. The species also exhibits salt tolerance and is winter-hardy down to –26 °C, which allows it to survive and spread in northern European climates (Native Plant Trust, n.d.).

In Europe, *Amelanchier spicata* has become invasive in several habitat types. It frequently colonizes dry pine and pine-oak forests, forest edges, scrubby grasslands, coastal and inland dunes, and open esker formations, especially those with sandy, nutrient-poor soils. In Finland, for instance, it often establishes on rocky slopes, open forests, and eskers, where it can form extensive clonal thickets via vegetative reproduction (Finnish Biodiversity Info Facility, n.d.).

The species is also prevalent in disturbed habitats such as roadsides, railway embankments, and urban forests, where its seeds are readily dispersed by birds. This allows *Amelanchier spicata* to exploit gaps and edges in vegetation, outcompeting native species and significantly altering plant community composition (Non-Native Species Secretariat, 2024).

One striking example of its invasive potential is found in Latvia's Ragakāpa Nature Park, where *Amelanchier spicata* has substantially changed the ecosystem structure. The spread of this shrub has transformed once-open coastal pine forests into dense, impenetrable thickets, leading to a decline in native dune species and reduced light availability for understorey flora (Latvia Nature, 2023).

4.3 Introduction and spread in Europe

Amelanchier spicata, native to northeastern North America and eastern Canada, was introduced to Europe for ornamental landscaping and erosion control due to its attractive flowers, edible berries, and adaptability to various environmental conditions (Pratašienė and Marozas, 2018; Ochmian, Kubus, and Dobrowolska, 2013). Its horticultural appeal led to its widespread planting in gardens, parks, and roadside vegetation during the 19th and 20th centuries (Schroeder, 1970).

Amelanchier spicata was introduced intentionally into Europe but has since spread across multiple regions, establishing itself as a problematic invasive species that requires targeted monitoring and control strategies. Once introduced, *Amelanchier spicata* exhibited strong naturalization and invasive capabilities. It spreads both vegetatively through rhizomes and sexually via bird-dispersed seeds, which has facilitated its rapid colonization of suitable habitats (Kabuce and Priede, 2010). A striking example is Latvia, where the species spread from a limited number of grid cells in the 1950s to occupying much of the country within five decades (Great Britain Non-Native Species Secretariat, n.d.).

The species has now established populations in many European countries, including Norway, Sweden, Finland, Denmark, Germany, France, Belgium, the Netherlands, the Czech Republic, Poland, the Baltic States (Latvia, Lithuania, Estonia), Belarus, Russia, and Bulgaria (Pratašienė and Marozas, 2018; Kabuce and Priede, 2010). It thrives particularly well in dry pine forests, forest edges, coastal and inland dunes, roadsides, and disturbed habitats with sandy or well-drained soils (Kuklina, 2011; Molganova and Ovesnov, 2023). In Finland, it is commonly found in esker habitats and forest margins where it forms dense thickets (Finnish Biodiversity Info Facility, n.d.).

Due to its adaptability, rapid reproductive strategies, and lack of natural predators, *Amelanchier spicata* has become invasive in several parts of northern and eastern Europe. In countries such as Finland, Latvia, Sweden, and Denmark, it is recognized as a significant threat to native biodiversity (Great Britain Non-Native Species Secretariat, n.d.; Molganova and Ovesnov, 2023). The European and Mediterranean Plant Protection Organization (EPPO) has listed it as a species of concern due to its ecological impact and risk of further spread (CABI, 2023).

The ecological effects of *Amelanchier spicata* include the alteration of forest understorey composition, suppression of native herbaceous plants, and displacement of native shrubs and tree seedlings (Pratašienė and Marozas, 2018). For example, in the Zakamsky pine forest in Russia, the species competes with native undergrowth like Sorbus aucuparia and Betula pendula, particularly in sandy soil environments (Molganova and Ovesnov, 2023).

4.4 Baseline situation in Latvia

Amelanchier spicata has established itself widely across northern Europe, including in Latvia, where it poses ecological challenges. In Latvia, its spread has notably impacted the coastal dune forests of Nature Park Ragakāpa in Buļļuciems. Originally dominated by sparse Scots pine forests, these habitats are now increasingly overgrown with dense thickets of *Amelanchier spicata*, resulting in altered soil composition and environmental conditions (Latvia Nature Conservation Agency, 2024). This transformation leads to the disappearance of native flora characteristic of coastal dunes and contributes to a more closed and opaque forest structure, undermining habitat quality.

The plant's aggressive expansion in Latvia is facilitated both by its prolific seed production—dispersed largely by birds—and its ability to vegetatively reproduce via stolons and rhizomes. Its tolerance for a broad range of conditions (light, terrain, and soil types) and its cold resistance further bolsters its invasiveness (Native Plant Trust, n.d.; Finnish Biodiversity Info Facility, n.d.). *Amelanchier spicata* invades areas typically lacking woody shrub cover, transitioning open forest landscapes into dense understoreys, suppressing ground vegetation, and diminishing biodiversity (Great Britain Non-Native Species Secretariat, n.d.).

The baseline monitoring conducted in 2022 as part of the LIFE-IP LatViaNature project in Ragakāpa confirmed the species' high density and dominance in selected test plots. Eradication activities, including mechanical uprooting and chemical stump treatments, only began in late 2023, so only limited monitoring data on treatment effectiveness is available (Latvia Nature Conservation Agency, 2024). The initial assessments, however, underline the urgent need for sustained and adaptive management interventions.

4.5 Eradication methods (pilot project)

Amelanchier spicata [dwarf serviceberry] has established its presence throughout Latvia, and is outcompeting native plants and trees, significantly altering habitats and landscapes including in key protect areas and Natura200 sites. To test a selection of eradication methods, the LNCA has set up 20 sample plots in Ragakāpa Nature Park, a coastal Natura2000 site established to preserve the sandy dunes covered with old growth pine forests and biodiversity typically found at the Baltic Sea coast:

Table 8: Eradication methods piloted for Amelanchier spicata

	Method	Locations	Sample Plots	Description
A.	Mechanical removal (pulling out with tractor)	Ragakāpa Nature Park	AME_RGK1, AME_RGK2, AME_RGK6, AME_RGK9, AME_RGK10, AME_RGK11, AME_RGK12, AME_RGK13	Wooded dunes landscape
B.	Manual removal (pulling out with hand tools)	Ragakāpa Nature Park	AME_RGK4, AME_RGK5, AME_RGK14, AME_RGK19, AME_RGK20	Wooded dunes landscape
C.	Manual trimming (trimming with hand tools)	Ragakāpa Nature Park	AME_RGK7, AME_RGK8	Wooded dunes landscape
D.	Chemical treatment	Ragakāpa Nature Park	AME_RGK15, AME_RGK16, AME_RGK17, AME_RGK18	Wooded dunes landscape

4.5.1 Method A: Mechanical removal

To eradicate an invasive species such as the *Amelanchier spicata*, ideally the plant including its root system should be removed from the target site. Mechanical removal is a widely employed method to control the Amelanchier Spicata. This approach involves physically extracting the plants from the soil, aiming to remove as much of the root system as possible to prevent regrowth. The process typically utilizes equipment such as small excavators and tractors fitted with gripping mechanisms to uproot the bushes, ensuring minimal disturbance to the surrounding soil. Post-removal, the extracted plant material is often chipped and disposed of appropriately to prevent re-establishment.

The timing to apply mechanical removal is crucial for its effectiveness. Conducting these activities in late autumn, from October to December (if weather conditions are favourable), is advantageous because the vegetation is less active, which minimizes ecological disruption and allows for more efficient targeting of the root systems. Immediate follow-up actions, such as stump treatments and clearing, are essential to address any potential regrowth.

However, mechanical removal presents several challenges. Dwarf Serviceberry possesses a complex root system, making extraction with basic tools inefficient; specialized equipment is often necessary. In dense stands, roots may be intertwined with those of nearby vegetation, complicating removal efforts and potentially causing unwanted damage to native vegetation. To this end, appropriate pre-cautionary measures must be taken to minimize damage to surrounding protected habitats, especially in areas with sensitive soils or ecosystems. Despite thorough removal efforts, stumps and residual roots may lead to regrowth, requiring off-site removal and processing of plant material, and necessitating consistent monitoring and follow-up treatments.

Preliminary observations indicate that mechanical removal can significantly reduce the above-ground presence of Dwarf Serviceberry. The use of appropriate equipment minimizes soil disruption, supporting quicker recovery of native vegetation. However, the potential for regrowth underscores the importance of ongoing management and monitoring to ensure long-term success.

In summary, while mechanical removal is effective in managing Dwarf Serviceberry infestations, it requires careful planning, specialized equipment, and diligent follow-up to address challenges such as complex root systems and potential regrowth. Integrating this method with other control strategies and maintaining consistent monitoring are essential for sustainable management of this invasive species.

4.5.2 Method B: Manual removal

In addition to mechanical removal methods, in areas that are not accessible with machines or where it is not allowed to use powered equipment, manual removal of Amelanchier Spicata can be considered. Manual removal is a labour-intensive but effective method to control this invasive species. This approach involves uprooting the entire plant, including its extensive root system, to prevent resprouting. For optimal results, this method requires the use of appropriate hand tools and proper timing during the growing season, particularly in spring or early summer when the plants are actively growing and before seed production begins. Removing plants at this stage helps prevent seed dispersal and ensures easier identification and extraction.

The removal process begins with preparation, where areas of infestation are identified and specimens of the *Amelanchier spicata* are marked. Key tools for the job include hand pruners for cutting smaller branches, loppers for thicker stems, and hand saws for larger branches. For tackling the root system, mattocks are ideal for loosening soil and cutting roots, while weed wrenches or extractigators are highly effective for uprooting the shrubs with substantial root systems. These tools leverage mechanical force to uproot the plant entirely, minimizing the physical strain on the operator.

Photograph 5: Use of extractigators hand tools to pull out Amelanchier spicata

Source: Consultant

To remove the Amelanchier Spicata, above-ground stems are first trimmed using pruners or loppers to reduce the plant's size and make it manageable. The soil around the roots is then loosened with a mattock. For larger plants, a weed wrench or extractigator is used to grip the base and apply leverage to remove the entire plant, including its roots. Once uprooted, all plant debris, including roots, should be removed from the site to prevent regrowth or seedling establishment. Proper disposal, such as chipping the material or handing it over to waste management services, ensures no remnants are left to regenerate.

However, there are challenges associated with this manual removal method. The extensive root network of the Amelanchier Spicata makes complete removal difficult, and any missed root fragments can result in resprouting, requiring repeated efforts. The labour-intensive nature of manual removal also poses physical challenges, particularly in areas with rocky or compacted soils, where loosening the roots becomes more demanding. Additionally, for large-scale infestations, the method may require significant manpower and time investment.

Despite these challenges, preliminary results suggest that manual removal is effective in reducing Amelanchier Spicata populations, especially since removal can be highly targeted and selective, leaving native vegetation as much as possible intact. It also minimizes soil disturbance compared to mechanical removal methods, preserving the native vegetation and soil structure. Regular monitoring of treated areas is crucial, as any new shoots or seedlings must be promptly removed to prevent re-establishment. Persistence and thoroughness are essential for long-term success, and this method is particularly suitable for smaller infestations or areas where chemical treatments are not desirable.

Although this is a labour-intensive eradication method, manual removal of Amelanchier Spicata using hand tools like pruners, loppers, saws, mattocks, and weed wrenches is a viable and environmentally friendly control method. With careful execution and ongoing monitoring, this approach can effectively curb the spread of *Amelanchier spicata* while preserving local biodiversity.

4.5.3 Method C: Manual trimming

Manual trimming is a control technique that involves the use of hand tools such as pruning shears, hand saws, or axes to remove the above-ground portions of the *Amelanchier Spicata*. It's particularly effective in areas where the terrain is challenging, and the use of mechanical equipment is impractical.

After identifying and marking the Amelanchier Spicata, the shrubs are then cut at the base, as close to the soil level as possible, to minimize the potential for regrowth. It's crucial to promptly remove the cut material from the site, as branches left in contact with the soil can potentially re-root and propagate new growth.

For manual trimming, timing plays a significant role in the effectiveness of the method. It's advisable to conduct trimming during the active growth season, typically from late spring to summer. This period allows for easier identification and management of the plant. Trimming should ideally occur before the plant begins fruiting to prevent seed dispersal, which usually happens later in the growing season. To effectively deplete the plant's energy reserves and prevent regrowth, it's recommended to repeat the trimming process annually or biannually.

However, manual trimming presents several challenges. The method is very labour-intensive, requiring substantial physical effort and time, especially in larger infested areas. Since this approach targets only the above-ground parts of the plant, the root system remains intact, leading to potential regrowth from root suckers. Consequently, multiple trimming sessions over several years are necessary to achieve long-term control. Additionally, in difficult or uneven terrain, accessing all the shrubs for effective trimming can be challenging. Proper disposal of the removed plant material is essential to prevent unintended propagation.

In terms of immediate effects, manual trimming results in a temporary reduction of the above-ground biomass of the Dwarf Serviceberry. However, without addressing the root system, regrowth is likely. Reducing the above-ground biomass of the Amelanchier Spicata can decrease shading and competition, allowing native plants in the immediate vicinity to begin recovering, which could be important factor to consider (especially for Ragakāpa Nature Park, which is a wooded dune landscape with pines, which is a more open forest ecosystem with a typically layer of nutrient poor soil, allowing more specialised plant species to thrive).

While manual trimming can provide immediate, albeit temporary, suppression of Amelanchier Spicata Serviceberry, a comprehensive management strategy that includes additional control methods incorporating root system removal is necessary to achieve long-term success, and to prevent root systems from re-resprouting.

4.5.4 Method D: Chemical treatment

An often-used practice to control Amelanchier Spicata involves the application of glyphosate-based herbicides, such as "Typhoon B," directly onto freshly cut stumps of the Amelanchier Spicata. This technique ensures that the herbicide penetrates the plant's vascular system, effectively inhibiting regrowth by reaching the root network. In the Ragakāpa Nature Park pilot area, this method was implemented following the uprooting or cutting of bushes to prevent further spread. The herbicide is meticulously applied to the stumps immediately after cutting to maximize absorption and efficacy.

Timing is crucial for the success of this method. The herbicide is most effective when applied during the plant's active growth periods—late spring to early summer or early autumn—when nutrients are actively transported to the roots. This approach ensures deeper penetration of the chemical into the root system, effectively suppressing regrowth.

After chemical application, the above-ground plant material is collected and removed from the area. In Latvia’s pilot tests, uprooted bushes and cut stumps were removed using either tractors or hand tools. The biomass was chipped, transported off-site, and disposed of in compliance with environmental regulations.

Photograph 6: Application of chemicals to cut off stems of Amelanchier spicata

Source: Latvia Nature Conservation Agency and consultant

Monitoring treated areas is integral to evaluating this method's effectiveness and assess any adverse impacts of the chemical on the ecosystem or waterflow. Implementing chemical control methods face specific challenges. The method is considered labour-intensive as applying herbicide manually with brushes, especially over extensive areas, is time-consuming and requires skilled personnel. Precautionary measures should be taken to avoid herbicide runoff into nearby water bodies, such as the Gulf of Riga or the Lielupe River, which border Ragakāpa Nature Park. Targeting only the invasive species is crucial to prevent damage to native flora in these protected habitats. If herbicide application is incomplete or poorly timed, the Amelanchier Spicata can regenerate, necessitating repeated treatments. Additionally, the method is susceptible to local weather conditions, such as rainfall shortly after application, which can reduce the efficacy of the chemical agent.

Initial observations in Latvia suggest that the chemical treatment method shows promise. Treated stumps of Amelanchier Spicata displayed minimal to no resprouting in pilot areas. Additionally, the reduction in this biomass of Amelanchier Spicata opened ecological niches for native vegetation to recover. For example, other herbaceous plants were observed colonizing the previously dominated areas, contributing to increased biodiversity. However, the full effectiveness of the method requires further monitoring, as long-term outcomes depend on consistent application and follow-up.

4.6 Preliminary Cost-efficiency Assessment

As an invasive shrub capable of forming dense thickets, *Amelanchier spicata* poses a growing threat to forest understoreys, dune systems, and semi-natural habitats, particularly in coastal and pine forest areas. The species spreads both vegetatively and by seed, making it difficult to eradicate once established. Several treatment methods were piloted to evaluate their effectiveness in reducing shrub density, along with the associated implementation costs. The preliminary cost-effectiveness analysis provides an initial comparison of these methods, helping identify which offer the most efficient use of resources.

Table 9: Preliminary cost-efficiency assessment Amelanchier spicata

#	Year = 2024 Method	Costs [EUR per Ha]	% Reduction [Effectiveness]	CE Ratio	Remarks
A	Mechanical removal	1,899.12	76.94	24.68	Method A is relatively effective and moderately priced method with a solid cost-efficiency ratio. The method is suitable for larger, accessible areas with dense stands where quick reduction is needed.
B.	Manual removal	2,422.27	81.32	29.79	Method B delivered slightly better results than mechanical removal but at a higher cost. The method is still cost-efficient and appropriate for smaller or ecologically sensitive sites where machinery use is limited.
C.	Manual trimming	2,559.35	**-126.56**	**-20.22**	Not only ineffective but **counterproductive**, with increased regrowth observed. This method should not be considered for control and may even exacerbate spread through resprouting.
D.	Chemical treatment	1,466.99	**96.79**	**15.16**	Chemical treatment is most effective and cost-efficient method tested. Ideal for targeted eradication, though its use may be limited in protected areas or where chemical application is restricted.

The preliminary cost-effectiveness assessment of control methods for Amelanchier spicata indicates that chemical treatment is currently the most effective and efficient option, achieving a 96.79% reduction in coverage with the lowest cost-effectiveness ratio (CER: 15.16). For the moment, based on one treatment cycle, this method potentially offers a strong return on investment and is particularly suitable for dense, well-established stands, provided it is applied in compliance with environmental regulations. Mechanical removal and manual removal also performed well, with effectiveness rates above 75% and moderate CERs, making them viable alternatives where chemical use is restricted, such as in protected areas or near water bodies.

In contrast, manual trimming not only failed to reduce the species but resulted in negative effectiveness (–126.56%), due to vigorous regrowth from cut stems. **This method should be excluded from future control plans unless paired with follow-up treatments to prevent resprouting**.

Amelanchier spicata presents persistent management challenges due to its strong vegetative reproduction and capacity to rapidly recolonize treated areas. These early observations highlight that while effective suppression is achievable, long-term success will depend on repeated treatments, post-removal monitoring, and adaptive management to prevent regrowth from root systems or seed banks.

NB: At this stage, the outcomes of the preliminary cost-efficiency assessment cannot be taken as robust enough to support policy recommendations on what types of eradication methods are most favourable and feasible. The accuracy and robustness of the analysis can be further improved as more monitoring data and information about costs for forthcoming application cycles become available as the project evolves in the next two years.

4.7 Control programmes and eradication methods applied in other countries

In several European countries, multiple methods have been used to combat *Amelanchier spicata*, with varying levels of effectiveness in terms of both ecological outcomes and cost-efficiency. These methods generally fall into four categories: manual removal, mechanical removal, chemical treatment, and preventive management.

- **Manual and mechanical removal**: Manual uprooting is one of the most direct methods used to control A. spicata. In some cases, tools like bush lifters or shovels are employed to extract the root systems, which are known to regenerate if left in the soil. However, this approach is labour-intensive and often impractical for large infestations, particularly due to the species' suckering ability and rhizome persistence (Kabuce and Priede, 2010). In Finland, for example, mechanical extraction using tractors has been implemented to remove large thickets efficiently. Still, even mechanical removal requires follow-up treatments to manage regrowth (Great Britain Non-Native Species Secretariat, n.d.).
- **Chemical control:** Chemical herbicides such as glyphosate or triclopyr are sometimes applied to cut stumps to prevent regrowth. This combined method—cutting followed by herbicide application—is viewed as more effective than either method alone, especially in areas where manual removal is not feasible. In Latvia, similar methods are being tested, reflecting growing regional consensus about the need for integrated approaches (Latvia Nature Conservation Agency, 2023; Kabuce and Priede, 2010).
- **Preventive and policy measures:** Finland has advocated for discontinuing the planting of A. spicata in public and mass landscaping to limit further spread. Additionally, removal is often prioritized in sensitive habitats like protected areas, dunes, or pine forests where the species poses the most serious ecological threat (Great Britain Non-Native Species Secretariat, n.d.).

While no direct economic losses have yet been reported, the difficulty and duration of eradication, i.e. requiring repeated treatments over several years, represent significant management burdens (Great Britain Non-Native Species Secretariat, n.d.; Kabuce and Priede, 2010). The costs of long-term management can be substantial, as complete eradication often requires repeat interventions over several years due to the plant's regenerative capabilities (Kabuce and Priede, 2010). While individual methods may temporarily reduce biomass, long-term suppression of the species usually demands a combination of physical and chemical tactics, coordinated with ecological monitoring (Molganova and Ovesnov, 2023; Pratašienė and Marozas, 2018).

The most effective strategies in Europe for managing *Amelanchier spicata* involve integrated control measures tailored to specific habitat conditions. Mechanical and chemical combinations show the most promise, especially when followed up regularly. Preventive strategies and public policy changes (e.g., regulation and banning trade) are also essential in reducing the spread. However, due to the resilience and spread potential of the species, permanent eradication is rarely feasible without sustained effort. Efforts in other European countries such as Finland and the UK further underscore ecological concerns, with recommendations for banning its cultivation and focusing removal in protected or high-conservation-value areas.

4.7.1 General control approach for Amelanchier spicata

International experience on the control and eradication of the *Amelanchier spicata* remains relatively limited in scope and documentation compared to more aggressively invasive species. However, based on experiences from countries where the species has been monitored or managed, several general principles can be outlined to guide its containment and potential removal.

A. **Phasing Out of Cultivation and Public Landscaping Use:** In regions where the *Amelanchier spicata* was historically introduced for horticultural or edible fruit production purposes—particularly in public green spaces or for landscape restoration projects—it is increasingly recognized that continued cultivation poses a risk of escape into adjacent natural ecosystems. Authorities and land managers in some countries have recommended the **phasing out of** *Amelanchier spicata* from horticultural use, particularly in public sector plantings, such as along roadsides, in urban parks, or in mass landscaping. As part of a broader strategy for biodiversity-friendly landscaping, the replacement of the *Amelanchier spicata* with **locally native shrubs** that provide similar aesthetic or ecological functions (e.g., fruit production for wildlife) is advised. This can reduce propagule pressure and limit the species' ability to establish feral populations.

B. **Prioritizing Control in Protected Natural Areas:** Given the potentially adverse ecological impacts of *Amelanchier spicata*, especially in forest understoreys and semi-natural habitats, control measures should prioritize **ecologically sensitive areas**. In conservation areas, particularly those designated under national biodiversity frameworks or the EU Natura 2000 network, the **eradication of *Amelanchier spicata* should be considered a management priority**. The shrub can form dense thickets that alter light availability, displace herbaceous species, and modify successional dynamics. **Early Detection** of initial occurrences at the margin of protected areas and Natura 2000 sites allows for localized eradication before extensive spread occurs.

C. **Integration with Forest Management Activities:** In managed forests, whether designated for commercial timber production, recreation, or mixed-use, opportunities exist to integrate *Amelanchier spicata* control into routine silvicultural activities:
   a. **Forest Operations as a Vector for Control:** During thinning, harvesting, or stand improvement activities, **targeted removal of *Amelanchier spicata*** can be incorporated into standard operating procedures.
   b. **Manual and Chemical Control Synergy:** Control is likely to be most effective when combining **manual removal (e.g., cutting, uprooting)** with **subsequent application of systemic herbicides** to prevent resprouting from roots or basal shoots. Manual cutting alone is rarely sufficient, as the species readily regenerates from remaining rootstock or stump tissue.
   c. **Seasonal Considerations:** Treatments should ideally be conducted during the active growing season (spring to early autumn) to maximize herbicide uptake and limit regrowth potential. Winter treatments may result in lower efficacy due to dormancy.

D. **Long-Term Monitoring and Follow-Up Treatments:** Like many woody invasive species, *Amelanchier spicata* requires **multi-year management interventions** to achieve effective population suppression or local eradication, and prevent re-invasion. Given its ability to spread vegetatively and via bird-dispersed seeds, long-term monitoring is essential, particularly in areas where the species has been previously established. Follow-up treatments should be based on systematic monitoring data, with protocols in place to reassess and adjust control strategies as needed, especially in mixed-species forests or high-biodiversity understoreys.

4.8 Assessment of associated costs and benefits

To evaluate the ecological, economic, and societal impacts of *Amelanchier spicata*, an adapted cost-benefit ranking framework is applied based on Blaalid et al. (2021) and Magnussen et al. (2020). This framework enables the structured assessment of the species' effects across a range of ecosystem services, human health, and infrastructure. Impacts are scored on a 0–4 scale, where 0 indicates no observed negative impact and 4 denotes a major, often irreversible, negative effect.

Table 10: Cost-benefit impact assessment Amelanchier spicata

Benefit / Impact Category		Rating	Literature / Sources
Ecosystem Services	**Supporting:** ecological impact	**4** *High ecological impact. IAS significantly alters native species composition or ecosystem functioning.*	• Amelanchier spicata is capable of establishing and invading habitats where similar woody shrub cover does not occur, changing it from open forest to dense understorey. It has the potential to suppress ground floras and reduce habitat available for both plant and non-plant species. *Classified as major impact, with medium confidence* (GB NNSS, 2024). • In the UK, Amelanchier spicata is listed in the top 30 threats to biodiversity because of its potential to arrive, establish and cause negative biodiversity impact (GB NNSS, 2024). • In sandy soils, such as esker forests, Amelanchier spicata can spread into large thickets, invading the habitats of native vegetation (Finnish Biodiversity Information Facility, nn). • Amelanchier spicata has a clear impact on the underlying vegetation: the number of species and moss cover clearly suffered more under shrubs of alien origin than beneath native bushes (Finnish Biodiversity Information Facility, nn). • Amelanchier spicata is posing an important threat to plant health, the environment and biodiversity in the EPPO region (European and Mediterranean Plant Protection Organization - EPPO). • Amelanchier spicata is found in areas rich in plant species diversity, which could suggest that while it competes with native species, it may also coexist with a range of plants (Pratašienė and Marozas, 2018). • In its **native range area** (USA and Canada), Amelanchier spicata attracts many species of birds, from insect-eaters in early spring when the flowers are in bloom, to fruit-eaters in early summer. It is the larval host of the striped hairstreak butterfly and serves as a host plant for more than hundred species of butterflies and moths (Native Plant Trust, nn).
	Supporting: ecological impact on endangered ecosystems	**3** *Severe degradation or loss of key components; conservation urgent.*	• Widley spread in protected areas such as the Zakamsky pine forest in Perm (Russia). Amelanchier spicata competes with native undergrowth species like Sorbus aucuparia and Betula pendula, especially in sandy soil conditions (Molganova, 2023). • Invasion of Amelanchier spicata in heathlands in Denmark will probably alter vegetation structure markedly. Its establishment in dune landscapes may affect dune dynamics (Great Brittain Non-Native Species Secretariat, 2024). • The dense growth of the Amelanchier spicata, for instance in Ragakāpa Nature Park, a coastal area defined by old growth pine forest on sandy dunes, has altered the ecosystem's soil conditions with more nutrients and organic content from the plant's leaves and root system.
	Regulating: water regulation, pollination, erosion	**0** *No impact on regulatory functions. Hydrology, pollination, and erosion control remain intact.*	• In its **native range (USA and Canada)**, due to its tendency to develop thickets, Amelanchier be used in soil stabilization and erosion control interventions (Native Plant Trust, nn).
	Provisioning: food production	**0** *No effects on agricultural production.*	• Fruits of Amelanchier are a rich source of polyphenol antioxidants and considered to be a health food (Trinklein, 2019). • The fruits from the Amelanchier spicata are a valuable source of polyphenols and can be consumed, for example in jam making (Ochmian et al., 2013).

	Benefit / Impact Category	Rating	Literature / Sources
			• Amelanchier spicata produces edible fruits in summer which can be used and processed in jams, cakes, etc. The berries are staple in the diet of several Native American tribes.
	Provisioning: non-food production	**0** *No known impact on resources such as timber, fibre, or biofuel.*	• Native Americans used the densely grained, hard wood of the service berry to make arrows, tool handles, fishing rods, and walking
	Cultural: recreation, aesthetic beauty, natural heritage	**3** *Disturbance restricts access or use in certain areas; visible and spreading presence.*	• The dense growth of the Amelanchier spicata, for instance in Ragakāpa Nature Park, has visually altered the landscape, characterised by old growth pine forest on sandy dunes. The dense undergrowth of the Amelanchier spicata has affected the recreational value of the park by lowering visibility to the original forest. • Amelanchier spicata is used as an ornamental plant in gardens and urban landscapes. Its popularity in landscaping contributes to the nursey and horticulture industry (Ochmian et al., 2013). • In its **native range area (USA and Canada)**, it is a favoured ornamental shrub, that can be planted in hedges. It is an attractive plant in the landscape due to is nice white blooming in early spring, edible fruits in summer and yellow-coloured leaves in autumn.
Other	**Human Health**	**0** *No effects. IAS pose no health concern.*	• Indigenous North Americans used different parts of the plant (including fruits, bark and twigs) for medicinal purposes.
	Infrastructure	n/a	n/a
	Total Score:	**10**	

Depending on locality, *Amelanchier spicata* is a moderately impactful invasive shrub species in Latvia, with an impact score of 10, reflecting its significant potential to alter native plant communities and forest structures. While its overall impact may be lower compared to some other invasive species, its impact on ecological functions and endangered ecosystems is substantial (scoring 4 and 3 respectively).

Its impact is particularly pronounced in high-value conservation areas, most notably the protected landscape of Ragakāpa, which is a unique site characterised by old-growth pine forests on coastal sandy dunes, and where it poses a serious threat to the integrity of the dune ecosystem. Its ability to spread both vegetatively and by seed enables it to form dense thickets that outcompete native herbaceous and understorey species, many of which are adapted to the low-nutrient, high-light conditions of sandy soils. The shrub's colonisation alters the open, species-rich character of the pine forest understorey, leading to a decline in native biodiversity and a shift toward a denser, more homogeneous vegetation structure. This threatens not only rare plant assemblages but also the broader ecological function of the dune forest system.

Although *Amelanchier spicata* may have some marginal value as an ornamental or fruit-bearing plant, these benefits are negligible in the context of its negative ecological impacts, and in particular in protected habitats. Given the ecological sensitivity of the Ragakāpa landscape, management of *Amelanchier spicata* should be treated as a priority action. Targeted, repeated treatments, coupled with long-term monitoring, will be essential to prevent further degradation of this rare and valuable dune-pine ecosystem. Effective suppression in such sites is critical not only for local biodiversity but also for preserving one of Latvia's most distinctive protected landscapes.

4.9 Conclusion – Amelanchier spicata

Amelanchier spicata, commonly known as the dwarf serviceberry, is a North American shrub species that has been introduced to various parts of Europe, where it has begun to exhibit invasive tendencies under certain conditions. Its ability to establish in a wide range of habitats, coupled with tolerance to disturbance and prolific vegetative reproduction, has led to concerns regarding its potential to outcompete native understorey flora, particularly in protected forest ecosystems. This is the case in Latvia (for example in Ragakāpa Nature Park, which is characterised by its old growth pine forests, and where the Amelanchier spicata has become highly invasive by taking over most of the forest's undergrowth, threatening the integrity of this protected landscape.

Based on the overall CBA impact score of 10, Amelanchier spicata is placed in the moderate range compared to more aggressive invaders. Its ability to form dense thickets and outcompete native understorey vegetation presents a significant risk to biodiversity in coastal dune forest ecosystems.

Based on the preliminary observations from piloting eradication methods, it is found that effective suppression is achievable. Among the tested methods, chemical treatment showed the highest effectiveness and the best cost-efficiency, followed by mechanical and manual removal, which also achieved strong results, particularly where herbicide use is restricted (e.g., chemical treatment should not be applied on a large scale in ecologically sensitive areas, nor in near watershed bodies). In contrast, manual trimming without root removal proved ineffective and may even stimulate regrowth, making it unsuitable for use.

Given the species' capacity for vegetative spread and persistence, early detection, site-specific treatment planning, and long-term monitoring are essential. In protected landscapes like Ragakāpa, where conservation of open, light-rich forest habitats is a priority, sustained management of Amelanchier spicata is critical to prevent long-term habitat degradation.

The management of *Amelanchier spicata* requires a proactive and integrated approach, combining prevention of further cultivation, prioritization of sensitive habitats for control, and effective integration into broader land and forest management frameworks. Although the species is not yet regarded among the most aggressive IAS in Europe, its ecological plasticity and expanding range warrant early intervention to prevent future widespread impacts. Complete eradication of populations may require several years of repeated treatment due to the persistence of root systems and shoot regrowth (Kabuce and Priede, 2010; Great Britain Non-Native Species Secretariat, n.d.).

Overall, while Amelanchier spicata is still manageable in many areas, delaying intervention risks allowing it to entrench further into vulnerable habitats. Strategic, repeated control efforts, in particular in conservation areas, will be key to preserving Latvia's native forest-dune ecosystems and preventing further biodiversity loss. As with other invasive shrub species, a **combination of mechanical removal and targeted herbicide application (only if ecologically justified)**, supported by **long-term monitoring**, appears to be the most effective strategy under current conditions. Collaborative efforts across forestry, conservation, and horticultural sectors will be essential to minimizing the spread and ecological footprint of the Amelanchier spicata in vulnerable ecosystems.

5. Acer negundo [boxelder]

5.1 Species characteristics

Acer negundo, commonly known as box elder, Manitoba maple, or ash-leaved maple, is a fast-growing, short-lived deciduous tree native to North America, particularly prevalent from southern Canada to Mexico. It typically grows along riverbanks, floodplains, and other moist lowland areas but exhibits remarkable ecological plasticity, enabling it to colonize dry, disturbed, or urban habitats.

The tree can reach heights of 8–15 meters and is recognizable by its irregular, often multi-stemmed form and pinnately compound leaves with 3–7 leaflets, which are atypical for maples. *Acer negundo* is dioecious, with male and female flowers on separate trees, and it produces prolific winged seeds (samaras) that are primarily dispersed by wind. In addition to sexual reproduction, it is capable of vigorous vegetative regeneration from root suckers and stump sprouts. These characteristics contribute to its rapid colonization and competitive dominance, especially in disturbed landscapes.

5.2 Habitat and ecological characteristics

Acer negundo is a highly adaptable and fast-growing tree species that establishes readily in a wide range of habitats. It is particularly prevalent in **riparian ecosystems**, where it takes advantage of moist soils and consistent water supply. These include riverbanks, stream margins, floodplains, and wetland edges. In such environments, its shallow and spreading root system allows it to anchor effectively and outcompete other vegetation, making it a dominant pioneer species in disturbed riparian zones (Hultine et al., 2007).

Beyond moist environments, Acer negundo also colonizes **urban and anthropogenically disturbed areas** such as parks, roadside verges, abandoned lots, and suburban gardens. These areas often provide the disturbed soil conditions and open canopy spaces that box elder requires for successful germination and establishment. In cities, it has been used intentionally in greening programs and shelterbelts, particularly in Eastern Europe and Russia, where it has become invasive (Dumas, 2019).

Acer negundo can also be found in **drought-prone and marginal lands**, especially once established. Although it prefers moisture-rich soils, *Acer negundo* demonstrates a resilience to dry and compacted soils, often growing on terraces, slopes, and degraded lands. Its ability to regenerate from suckers and damaged stems allows it to persist in erosion-prone or frequently disturbed habitats (California Native Plant Society, n.d.).

In **grassland-forest ecotones**, *Acer negundo* forms dense thickets along transitional zones, particularly where tree cover is sparse. These thickets can quickly expand and alter native vegetation dynamics by shading out herbaceous and shrub species, especially in environments lacking natural disturbances such as fire or flooding (Dumas, 2019).

Gender differences in habitat preference are also documented: female individuals are more often found in wetter lowland areas, where reproductive investment is supported by higher moisture availability, whereas males dominate drier upland or terrace sites, likely due to reduced resource demands (Hultine et al., 2007).

5.3 Introduction and spread in Europe

Acer negundo was introduced to Europe from North America, where it is native. Its initial introduction was primarily for ornamental purposes and for use in urban landscaping, shelterbelts, and soil stabilization due to its fast growth and adaptability to disturbed and urban environments (Dumas, 2019; Merceron et al., 2016). The species was widely planted in public green spaces and along roadsides, which facilitated its escape into the wild.

Once introduced, *Acer negundo* spread rapidly across various regions of Europe through both sexual and vegetative reproduction. The species produces abundant wind-dispersed seeds capable of traveling over 100 meters, and has a high germination rate in moist, disturbed soils (Straigytė et al., 2015). Additionally, it can regenerate vegetatively from stumps and roots, which enhances its persistence and spread, particularly in riparian and urban environments (Merceron et al., 2016).

Acer negundo is now established in numerous European countries. High invasion levels have been documented in Latvia and Lithuania, particularly in urban and riparian ecosystems in cities like Riga and Kaunas (Straigytė et al., 2015). It has also naturalized in countries such as France, Poland, Austria, and parts of Russia, often forming dense monocultures that outcompete native vegetation (Kettunen et al., 2009). Its success in colonizing diverse environments is attributed to its ecological plasticity and the absence of natural enemies in the introduced range.

The spread of Acer negundo in Europe illustrates a classic case of an ornamental introduction turning invasive, driven by both human activity and inherent reproductive traits of the species.

5.4 Baseline situation in Latvia

At the outset of the LatViaNature project, *Acer negundo* was already widely established as a problematic invasive species in several areas in Latvia, including the Krustkalni Nature Reserve and urban floodplain regions of Daugavpils. *Acer negundo* had formed dense thickets particularly around abandoned homesteads and road margins, where it benefitted from reduced land management, such as infrequent mowing (Latvia Nature Conservation Agency, 2022).

Initial field surveys conducted in 2022 documented its dominant presence in these locations. In the Krustkalni Nature Reserve, *Acer negundo* was especially abundant in ecotones between grasslands and forests, as well as along roadside habitats. In Daugavpils, the species established nearly monodominant canopies, with 100% cover recorded in several sample plots. Its dominance extended to the shrub layer in some sites, and in many cases, the herbaceous layer beneath was sparse and species-poor, demonstrating *Acer negundo's* suppression of native biodiversity (Latvia Nature Conservation Agency, 2022).

Biologically, Acer negundo is well-equipped for rapid and persistent colonization. It propagates both sexually—via wind-dispersed seeds—and asexually, through root suckers and vigorous stem resprouting, particularly after disturbance. These reproductive traits, coupled with high tolerance to a range of moisture conditions, make it highly adaptable and persistent across various habitats in Latvia (Latvia Nature Conservation Agency, 2024).

The ecological impacts of *Acer negundo* include reduced light availability for understorey species, inhibition of native plant regeneration, and potential alterations to hydrological cycles. For example, female individuals have been shown to contribute disproportionately to transpiration in floodplain environments, influencing moisture regimes (Hultine et al., 2007; Hultine et al., 2008). Despite its ecological dominance, assessments from Latvia and Lithuania have categorized its social, environmental, and economic impacts as moderate to low (Straigytė et al., 2015).

The baseline assessment positioned *Acer negundo* as a major ecological threat in several Latvian regions, warranting active intervention. Its proliferation, bolstered by reproductive flexibility and disturbance tolerance, posed a significant challenge to native biodiversity and habitat integrity.

5.5 Eradication methods (pilot project)

Acer negundo has become an invasive species in Latvia, particularly in riparian zones, wetland edges, and urban green spaces. It is known for its rapid growth, prolific seed production, and ability to form dense stands that displace native vegetation and alter habitat structure. Its shallow root system and tolerance to a range of soil and hydrological conditions allow it to colonize and dominate disturbed sites, including protected Natura 2000 areas. The LIFE-IP LatViaNature project set up pilots to test eradication methods in selected sites, including in Krustkalni Nature Reserve and the Daugavpils area. Methods tested include mechanical removal, manual treatments, and the application of chemicals such as juglone, in line with practices recommended in areas where chemical herbicides are restricted.

Table 11: Eradication methods piloted for Acer negundo

	Method	Locations	Sample Plots	Description
A.	Mechanical removal (Milling and mowing 1x per year)	Daugavpils	ACER_DAUG1, ACER_DAUG2, ACER_CIET5, ACER_CIET6	River floodplain, abandoned gardens
B.	Mechanical removal (Milling and mowing 2x per year)	Daugavpils, Krustkalni Nature Reserve	ACER_DAUG3, ACER_DAUG4, ACER_KDR1, ACER_KDR2	River floodplain, abandoned ruderal area, bushes
C.	Chemical treatment (Trees cutting and chemical application)	Daugavpils	ACER_CIET1, ACER_CIET2	Abandoned gardens
D.	Manual trimming (Cutting off shoots)	Daugavpils	ACER_CIET3, ACER_CIET4	Abandoned gardens
E.	Manual trunk ringing *(discontinued after storm, sample sites were cut afterwards – Method D)*	Daugavpils	ACER_CIET3, ACER_CIET4	Abandoned gardens

5.5.1 Method A: Mechanical removal (milling and mowing 1x per year)

The control of Acer negundo—an invasive alien tree species in Latvia—has become critical for ecological restoration within Natura 2000 sites. One of the principal non-chemical eradication strategies tested is mechanical removal via annual milling and mowing, a method designed to disrupt both the above-ground and subterranean regenerative capacity of Acer negundo.

In this treatment method, mechanical milling is employed to physically destroy the stumps and roots of Acer negundo. This process uses a reclamation milling machine capable of either point-by-point or continuous operation, depending on the density of infestation. In areas with high concentrations of the species the milling is conducted across the full surface to eliminate interconnected root systems and suckering potential. For more sparsely populated sites, localized (spot) milling targets individual stumps.

Photograph 7: Milling of Acer negundo infested area Krustkalni Nature Reserve

Source: Latvia Nature Conservation Agency

In Latvian pilot areas such as the Krustkalni Nature Reserve and the banks of the Daugava River near Daugavpils, milling was undertaken in the late summer to early autumn months (e.g., mid-October), following debris clearance and preparatory terrain levelling.

Following milling, annual mowing is carried out to suppress the regrowth of shoots and saplings from any remaining viable root fragments or seedling emergence.

This is typically conducted once during the growing season—usually in mid to late summer (July to September)—using a combination of trimmers and tractor-mounted mowers depending on terrain accessibility. The goal of mowing is to inhibit photosynthesis and prevent seed production, thereby reducing the long-term reproductive capacity of the species. In some cases, grass and sapling biomass is removed from the site, although in flatter, more accessible zones, mowing residue may be left in place.

This annual mechanical disturbance is expected to cause a progressive depletion of the species' energy reserves, ultimately leading to stand decline. However, several challenges have emerged. Site conditions can significantly complicate operations. Many infested areas are former allotments or garden sites containing buried waste such as barbed wire, concrete rubble, and metal fragments. These obstacles impede both mowing and milling machinery and increase operational costs and timelines. Moreover, post-milling soil compaction and terrain levelling may be required to restore site conditions and enable follow-up management. Such debris, common in previously inhabited or allotment areas, has repeatedly delayed operations and reduced the effectiveness of machinery, particularly in Daugavpils pilot plots.

Another significant constraint has been weather variability. Prolonged droughts in the summer of 2023, combined with high spring water tables, limited both plant growth and fieldwork scheduling. In several sites, planned multiple mowings were reduced to a single cycle because vegetation regrowth was minimal. These conditions underscore the importance of climate-adaptive management in mechanical control regimes.

Despite these difficulties, early observations indicate that areas treated with both milling and mowing showed substantially reduced regrowth of Acer negundo within the first season. In the Krustkalni site, for example, continuous stump and root milling in dense stands has effectively cleared previously dominant Acer negundo growth, setting the stage for recolonization by native vegetation. In flatter riparian plots subjected to annual mowing, preliminary vegetation monitoring suggested reduced canopy closure and increased ground-level light availability, though comprehensive floristic recovery remains to be assessed in subsequent seasons.

In conclusion, mechanical removal through annual milling and mowing represents a promising, scalable intervention for Acer negundo control in Latvia's protected areas. Its effectiveness depends on complete initial site clearance, proper sequencing of soil disturbance, and long-term commitment to follow-up mowing.

While the method avoids chemical herbicides, it is labour- and machinery-intensive, and its success is sensitive to both logistical and environmental constraints. Continued monitoring through 2027 under the LIFE-IP LatViaNature project will be essential to validate this approach and optimize its implementation across diverse ecological contexts.

5.5.2 Method B: Mechanical removal (milling and mowing 2x per year)

This method is similar to method A, but applies a schedule of mowing twice in the year instead of mowing once,

5.5.3 Method C: Chemical treatment (trees cutting and chemical application)

Combatting *Acer negundo* through chemical treatment combined with tree cutting (often referred to as the "cut and paint" method), is a widely used approach for managing this invasive species.

This treatment involves mechanically cutting *Acer negundo* trees at or near ground level using chainsaws. Immediately after cutting, herbicides—typically glyphosate (at a concentration of ~7.2 g/L) or triclopyr—are applied directly to the stump surface to prevent regrowth from the root system or dormant buds. This application should be done immediately after cutting to maximize herbicide uptake before the stump begins to seal its vascular tissues.

Chemical treatment is most effective when applied during the growing season, particularly late summer to early autumn, when trees are actively translocating resources to their roots. This ensures systemic herbicides are drawn deep into the root system. However, in Latvia, logistical or climatic factors (e.g. snowfall, soil moisture) may dictate a more flexible application window from May to October, with careful monitoring of local conditions.

Several challenges exist with chemical treatment, including:

- Delayed treatment after cutting reduces effectiveness due to rapid healing of stump tissues.
- Labour intensity for large stands or remote areas remains high despite reductions in follow-up regrowth.
- Safety risks arise from leaving poisoned trees standing, especially near public areas, as they become brittle and may fall unpredictably.
- In sensitive habitats (e.g., Latvian Natura 2000 areas), chemical use may be restricted or require permits, particularly near water bodies or in wetlands.
- Acer negundo can regenerate from root fragments or suckers if not comprehensively treated,

In Latvia, pilot control areas like Krustkalni Nature Reserve and Daugavpils Fortress have implemented similar techniques, often combining cutting and herbicide use with follow-up milling of stumps and roots. Monitoring plots have been established (e.g. 10×10 m) to assess treatment efficacy by measuring stump diameter and regrowth metrics. Long-term monitoring is needed to determine if seed banks or nearby untreated specimens cause reinvasion. Follow-up treatments for seedlings and suckers are recommended for at least 2–3 years post-treatment

Cutting followed by chemical treatment could be an effective core strategy for managing *Acer negundo* invasions in Latvia, especially in riparian and disturbed urban-natural interfaces, while observing strict ecological considerations when applying chemicals. When paired with local monitoring and adaptive management, this approach could contribute significantly to halting the spread and allowing native vegetation to recover.

5.5.4 Method D: Manual trimming (cutting off shoots)

Manual trimming (by cutting off shoots) is a low-tech, but a widely considered eco-friendly approach, which is particularly relevant where chemical use is restricted or undesirable, such as in Natura2000 protected areas and riparian zones. Manual trimming entails cutting back resprouting shoots from stumps, roots, or damaged trees. Typically, this is done using hand tools like shears, axes, or trimmers, focusing on regrowth after initial tree removal or damage. It is a reactive control method, primarily used after initial measures such as felling, girdling, or stump grinding have already been carried out.

In Latvia, this method is most relevant in areas like the Krustkalni Nature Reserve and Daugavpils region, where *Acer negundo* has been found forming dense thickets with minimal native understorey vegetation. Manual trimming is usually combined with initial clearing and root/stump treatment, or as a maintenance activity in years following primary eradication actions.

Manual trimming is best performed in spring or early summer, after the first flush of shoots appears. This ensures that energy reserves in the roots are depleted. In Latvia's temperate climate, trimming ideally begins in April-May and continues into September, avoiding extreme drought periods. Trimming should be repeated throughout the growing season (at least two to three times) to continually stress the plant and prevent photosynthesis-based recovery. As *Acer negundo* is known for vigorous vegetative regeneration from sleeping buds on roots and stumps, treatment is required over multiple years.

However, regular manual trimming is time- and labour-intensive, especially in areas with dense regrowth. Due to *Acer negundo's* strong ability to regenerate from roots, trimming must be maintained for several years to be effective. Furthermore, manual trimming can temporarily reduce above-ground biomass, but regrowth is common if trimming is not followed up with root treatment or repeated annually. In Latvia, accessibility of invaded plots may pose a challenge for treatment, as many invaded sites are riparian zones or former allotments with uneven terrain and debris, complicating access with tools and requiring careful manual labour. Furthermore, trimming on its own rarely kills the plant and is thus insufficient unless integrated with other measures like stump grinding or chemical treatments where permissible.

5.5.5 Method E: Trunk ringing

Among the methods explored for controlling *Acer negundo*, trunk ringing (or girdling) has gained attention as an ecologically appropriate, chemical-free approach suitable for use in sensitive environments. Trunk ringing involves the complete removal of bark, phloem, and cambium in a ring around the tree's circumference, typically 20–30 cm wide, at a height of 0.5 to 1.3 meters above ground level. This interrupts the translocation of photosynthates from the canopy to the root system, ultimately leading to root starvation and the gradual death of the tree (Merceron et al., 2016; Miller et al., 2006).

In Latvia, as part of the LIFE-IP LatViaNature project, trunk ringing is tested in several sites in Krustkalni Nature Reserve and Daugavpils. Tree trunks were girdled during the spring, and emerging basal shoots were manually removed in early autumn to suppress resprouting. Initial monitoring indicated partial success, particularly with smaller-diameter trees (Latvia Nature Conservation Agency, 2024).

The timing of trunk ringing is critical. Trunk ringing is most effective during the active growing season (spring to early summer), when cambial activity and sap flow are at their peak, thereby ensuring rapid disruption of physiological processes (Groninger et al., 1998). This period aligns with the observed effectiveness in Latvia, where ringing conducted in April resulted in visible dieback by October in thinner individuals (Latvia Nature Conservation Agency, 2024). However, to prevent regrowth, it is essential to monitor and remove epicormic shoots that emerge below the girdle. Repeated intervention over 2–3 years may be necessary, especially in vigorous stands or where large individuals are present (Merceron et al., 2016; USDA Forest Service, 2009).

While Latvia's environmental regulations prohibit the use of chemical herbicides in Natura2000 and wetland areas, this increases the relevance of mechanical and manual methods like trunk ringing (European Commission, 2013). Moreover, the gradual nature of girdling aligns with habitat restoration goals by avoiding sudden canopy loss, thus minimizing disturbance to soil and understorey flora. This makes the method especially suitable for application in ecologically sensitive zones such as the Krustkalni Nature Reserve, where biodiversity indicators such as *Thesium ebracteatum* and *Iris sibirica* are at risk from *Acer negundo* encroachment (Latvia Nature Conservation Agency, 2024).

Overall, trunk ringing presents a promising, ecologically compatible method for managing Acer negundo in Latvia. However, its success is contingent upon appropriate timing, repeated management of vegetative regrowth, and long-term monitoring. For best results, it should be integrated into a broader invasive species control strategy that includes seedling removal, habitat restoration, and public awareness campaigns.

The testing of the trunk ringing method in Latvia has been discontinued during 2024, after a storm hit the pilot sites, causing all ringed trees to break off. The remaining Acer negundo trees were cut afterwards (monitoring and treatment can be continued as Method D – manual trimming).

5.6 Preliminary Cost-efficiency Assessment

As a rapidly spreading invasive tree, *Acer negundo* threatens native vegetation, particularly in riparian zones and wetland habitats, where its presence alters light availability, soil dynamics, and ecosystem structure. The pilot trials tested include manual and mechanical method, and chemical application under real site conditions, with a focus on approaches suitable for protected and herbicide-restricted environments.

The cost-efficiency assessment compares the financial inputs required for each method against the observed effectiveness in suppressing or reducing *Acer negundo* regeneration. This analysis offers insight into which techniques may provide the most practical and scalable solutions for long-term control, particularly in ecologically sensitive areas.

Table 12: Preliminary cost-efficiency assessment Acer negundo

#	Year = 2024 Method	Costs [EUR per Ha]	% Reduction [Effectiveness]	CE Ratio	Remarks
A.	Mechanical removal (Milling and mowing 1x per year)	2,798.68	97.50	28.70	Slightly less cost-efficient than Method B, it offers a viable alternative in areas where annual follow-up may be more feasible or where vegetation pressure is lower. The effectiveness of methods A and B supports broader

#	Year = 2024 Method	Costs [EUR per Ha]	% Reduction [Effectiveness]	CE Ratio	Remarks
					applicability in long-term management planning, especially when paired with native vegetation recovery strategies.
B.	Mechanical removal (Milling and mowing 2x per year)	2,115.95	**100.00**	**21.16**	Method with the best cost-efficiency ratio (CER: 21.16), its success can be attributed to the combination of aggressive root disruption and follow-up mowing that prevents resprouting. It is particularly suitable for heavily infested areas and sites where chemical use is restricted.
C.	Chemical treatment (Trees cutting and chemical application)	n/a	100.00	n/a	Inconclusive, no info on costs or total area covered
D.	Manual trimming (Cutting off shoots)	n/a	n/a	n/a	Inconclusive, as only baseline data available, no info on costs or total area covered
E.	Manual trunk ringing	n/a	n/a	n/a	Inconclusive, as only baseline data available, discontinued in 2024 due to storm damage to test sites

The preliminary cost-efficiency assessment for Acer negundo indicates that mechanical removal, particularly milling and mowing conducted twice per year, is the most effective and economically viable method tested, achieving full suppression at the lowest cost-efficiency ratio. While single-application mechanical removal also performed well, the additional treatment significantly improved outcomes with minimal added cost. Chemical treatment showed comparable effectiveness but could not be evaluated for cost-efficiency due to missing financial data, and its applicability is limited by environmental regulations in protected areas. Manual methods remain inconclusive due to data gaps and implementation challenges.

These early results support the prioritization of mechanical control methods in future management strategies. While the data represent only one treatment cycle and limited temporal monitoring, the findings form a basis for refining management strategies and prioritising future efforts.

NB: At this stage, the outcomes of the preliminary cost-efficiency assessment cannot be taken as robust enough to support policy recommendations on what types of eradication methods are most favourable and feasible. The accuracy and robustness of the analysis can be further improved as more monitoring data and information about costs for forthcoming application cycles become available as the project evolves in the next two years.

5.7 Control programmes and eradication methods applied in other countries

A range of eradication and control methods have been implemented in several European countries, to manage the spread of Acer negundo. The most commonly applied methods include manual techniques such as girdling, mechanical removal, and chemical treatments.

In France, a comparative study tested four manual control methods, including girdling, low cutting, high cutting, and cutting followed by application of juglone (a natural allelopathic compound from walnut leaves). Girdling emerged as the most effective method, achieving a 65% mortality rate two years post-treatment. This method, which involves removing the bark, phloem, and cambium around the tree's circumference, was found to be eco-friendly and practical for localized removal. However, it requires repeated applications over two to three years to prevent stem healing and manage resprouts. Conversely, juglone did not show significant improvement in tree mortality compared to simple cutting, indicating limited added value from its application in this context

(Merceron et al., 2016). However, while this suggests that girdling is effective, it is not a standalone solution. It should be integrated with follow-up shoot management and possibly combined with ecological restoration efforts, such as the planting of native species to reduce niche availability (Dumas, 2019; Rivers of Carbon, n.d.).

Mechanical removal, such as stump grinding and cutting using heavy equipment, is labour-intensive and tends to be less effective in the long-term unless paired with follow-up treatments due to vigorous resprouting from stumps and roots. The cost and effort associated with removing large trees and their root systems can be significant and sometimes necessitate specialized equipment (Blue Mountains City Council, n.d.).

In Russia, chemical control using glyphosate (7.2 g/L) applied immediately to freshly cut stumps showed a notable efficacy, preventing resprouting in about 65% of cases. Alternative treatments, such as delayed herbicide application or the use of ammonium nitrate followed by glyphosate, were comparatively less effective. This confirms that timing and immediate application are critical for chemical treatments to succeed (Kolyada and Kolyada, 2017).

Cost-wise, eradication programmes vary significantly. For example, a one-time control programme in Spain (in 2014) where *Acer negundo* accounted for 90% of the targeted species cost an estimated €10,000 (Diagne et al., 2020). Similarly, a campaign in Bourgogne, France, cost around €13,000 (Diagne et al., 2020). A more comprehensive approach integrating mechanical removal with ecological restoration in Hungary and Slovakia reported costs between €1,500–€2,000 per hectare (Bajor and Penksza, 2015).

While girdling and immediate herbicide application to cut stumps are among the most effective and cost-efficient methods, they often require multi-year efforts and monitoring. Mechanical methods alone are less reliable unless part of an integrated strategy. Cost assessments show moderate expenditures for localized interventions, suggesting that while *Acer negundo* is invasive, control remains manageable with well-targeted approaches.

5.7.1 General control approach for Acer negundo

Based on management experiences in countries where *Acer negundo* invasions are problematic, a number of general management principles are proposed for its control and potential eradication.

A. **Preventative Measures Through Regulation of Planting Material:** One preventative strategy that has been proposed involves the **exclusive use of male specimens** in ornamental or landscape plantings, given that *Acer negundo* is a dioecious species—individual trees are either male or female. By restricting the planting of female trees, it is possible to **eliminate seed production** and thereby limit the species' potential for reproductive spread into adjacent natural or semi-natural ecosystems. However, while this approach may reduce the risk of dispersal via seeds, it does not address the species' ability to **regenerate vegetatively** or to establish from already existing seed banks in invaded areas.

   In some countries, recommendations have been made to phase out the planting of *Acer negundo* entirely, particularly in regions where it has shown strong invasive tendencies. A ban or restriction on the sale and distribution of reproductive material could support broader IAS prevention strategies.

B. Mechanical Control: Seedling Removal and Girdling: The most commonly employed control methods include **manual and mechanical interventions**, which aim to reduce seedling recruitment and gradually eliminate mature individuals from infested sites.

   a. **Manual Removal of Seedlings and Saplings:** Early-stage control can be effectively achieved through **manual uprooting of seedlings and young plants**, especially in moist soil conditions where root systems can be more easily extracted in their entirety. Repeated site visits during the growing season are often necessary to capture successive waves of germination, particularly in areas with persistent seed banks.

   b. **Girdling of Mature Trees:** For established adult specimens, **girdling** (removal of a complete ring of bark and cambium around the trunk) has proven to be an effective method for gradually killing the tree while minimizing disturbance to surrounding vegetation and soil. Girdling disrupts the tree's phloem transport system, starving the roots of carbohydrates and leading to mortality over a period of months. This method is particularly advantageous in protected or sensitive areas where the use of herbicides or heavy machinery may not be permitted. Girdled trees may remain standing for several years, so risk assessments related to falling hazards should be conducted in areas with public access.

   c. **Cut-Stump Treatment (Optional Addition):** In some cases, girdling is combined with **cut-stump treatment** using systemic herbicides (e.g., glyphosate or triclopyr), especially where rapid dieback is desired or where regrowth from basal shoots is observed following mechanical injury.

C. Need for Long-Term Management Approach: Although manual and mechanical approaches can reduce the local abundance of *Acer negundo*, complete eradication is challenging, particularly in areas with **dense infestations**, **persistent seed banks**, or **ongoing propagule pressure** from nearby unmanaged populations. Effective control requires **long-term monitoring and repeated interventions**, especially in the years following initial treatment, to detect and remove resprouts, root suckers, and new seedlings. To prevent reinvasion, it is recommended that **native vegetation be re-established** following removal efforts. Replanting with fast-growing, competitive native species can help occupy ecological niches and stabilize soils, reducing opportunities for re-establishment of *Acer negundo*. Control methods should be adapted to site conditions, including soil type, access limitations, habitat sensitivity, and landscape objectives (e.g., ecological restoration vs. urban park management).

5.8 Assessment of associated costs and benefits

To systematically assess the impacts of *Acer negundo* on ecosystem services, human health, and infrastructure, an adapted qualitative ranking framework is applied, based on Blaalid et al. (2021) and Magnussen et al. (2020). This framework enables standardized impact classification across key domains using a scale from 0 (no impact) to 4 (very high impact), supporting a structured comparison of ecological and socio-economic consequences.

The literature describes a variety of ecological, economic, social, and health-related impacts associated with *Acer negundo*. Ecologically, *Acer negundo* displaces native vegetation, inhibits forest regeneration, and alters hydrology in riparian zones. For example, the replacement of native riparian vegetation by Acer negundo may be ranked as a 3 (high impact) on biodiversity, while health impacts may be rated lower or more localized. The key types of impacts noted include the following:

Table 13: Cost-benefit impact assessment Acer negundo

	Benefit / Impact Category	Rating	Literature / Sources
Ecosystem Services	**Supporting:** ecological impact	**2** *Potential high ecological impact. IAS presence may disrupt ecosystem functioning or species interactions.*	• *Acer negundo* is considered as highly invasive in several countries in Europe, including in Latvia with a degree of invasion (.0788) in areas like Riga and Kaunas. It spreads rapidly into new riparian areas, potentially disrupting local ecosystems by outcompeting native species (Straigytė et al., 2015). • The species has a large ecological amplitude even in urban areas, which can contribute to urban biodiversity (Dumas, 2019). • ***In its native range*** (USA) riparian *Acer negundo* communities provide important habitat for many wildlife species and protect livestock from temperature extremes in summer and winter. Its seed are consumed by birds and small mammals and foliage supports caterpillars (California Native Society, n.d.).
	Supporting: ecological impact on endangered ecosystems	**2** *Vulnerable. Ecosystem shows significant decline in resilience or species composition.*	• *Acer negundo* forms monospecific stands, reducing both native species richness and abundance by decreasing light availability (Merceron et al., 2016).
	Provisioning: food production	**0** *No effects on agricultural production.*	• Acer negundo sap has a relatively high sugar content, which can be concentrated into a syrup or beverage. The syrup can be used as a sweetener in food (Plants for a Future, 2024)
	Provisioning: non-food production	**2** *Moderate effects. Notable reduction in yield, harvest delays, or increased costs.*	• *Acer negundo* can have negative impacts on ecosystems as it poses health risks (toxic) to horses due to hypoglycin (McKenzie, 2016; Dumas, 2019). • In France, Acer negundo invasion in some areas has led to replacement of economically important trees such as Salix alba (white willow) and Populus spp. (Merceron et al., 2016). • The species has a low commercial value (wood or timber), but has been used in making boxes, crates, and low-cost furniture and the wood pulp is used in paper production (California Native Society, n.d.).
	Regulating: water regulation, pollination, erosion	**2** *Noticeable effects. Reduced effectiveness of natural systems (e.g., pollination decline, altered water flow).*	• *Acer negundo* can have a substantial impact along waterways (Rivers of Carbon, n.d.). • In France, *Acer negundo* invasion has led to riverbank collapses and reduction of bird nesting (Merceron et al., 2016). • The dispersion of the species in different areas affects how water moves through the ecosystem, with female plants playing a bigger role in water flow in streamside areas (Hultine et al., 2007). • In its native range, due to its extensive root system, *Acer negundo* helps stabilize soil, which can help make it effective in preventing erosion along riverbanks and floodplains (California Native Society, n.d.). • In its native range (USA) *Acer negundo* has been used in restoration projects, and for revegetating flood control basins to provide quality wildlife habitat. Its ability to enhance survival and growth rates make it valuable for wetlands and streambank restoration and stabilization, which can help prevent soil erosion and maintain water quality (Baud, 2013).
	Cultural: recreation, aesthetic beauty, natural heritage	**2** *Aesthetic disturbance noticeable but recreational use remains largely unaffected.*	• *Acer negundo* can alter flora composition, affecting other trophic levels and limiting recreational activities in urban forests (Dumas, 2019; Sikorska et al., 2019). • The plant has aesthetic appeal: it's a distinctive foliage and seasonal colour changes and the visuals can add beauty to an area (Dumas, 2019).

Benefit / Impact Category		Rating	Literature / Sources
Other	**Human Health**	**1** *Mild discomfort or indirect health effects (e.g., allergens, minor skin irritation).*	• In some instances, *Acer negundo* has been planted in urban parks, it could enhance the aesthetic value of city landscapes, contributing to mental well-being in urban areas (Dumas, 2019). • The pollen of *Acer negundo* can cause allergies (Dumas, 2019).
	Infrastructure	n/a	n/a
	Total Score:	**11**	

With a total impact score of 11, *Acer negundo* is classified as a moderately impactful invasive species in Latvia. While it may not exhibit the same aggressive dominance as species like for example *Solidago canadensis*, its presence in ecologically sensitive areas, particularly along riverbanks, wetland edges, and floodplain forests, poses a tangible risk to native biodiversity and ecosystem structure. The species spreads rapidly via both seeds and vegetative regrowth, often forming dense, shade-producing stands that suppress native understorey flora and reduce habitat quality for dependent fauna.

Although the species may offer some benefits, such as soil stabilization and limited ornamental or ecological value in urban settings, these are outweighed by the ecological costs in natural and semi-natural habitats. In areas like the Krustkalni Nature Reserve and along riparian corridors, *Acer negundo* contributes to the gradual homogenization of forest structure and the decline of native plant communities, including willow and alder-dominated assemblages.

In summary, while *Acer negundo* does not currently present the most urgent IAS threat in Latvia, its ability to alter valuable wetland and riparian ecosystems justifies continued and proactive control. Prioritising its management in Natura 2000 and high-conservation-value areas will be key to preventing further ecological degradation and maintaining habitat quality.

5.9 Conclusion – Acer negundo

Acer negundo is a fast-growing, opportunistic tree species native to North America, which has been widely introduced across Europe and other parts of the world for ornamental, windbreak, and erosion control purposes. It has demonstrated clear invasive tendencies in Latvia. It establishes rapidly in riparian zones, wetland margins, disturbed forest edges, ruderal and urban habitats, where it can outcompete native species, disrupt successional dynamics, and alter soil conditions. Its dual reproductive strategy via abundant seed production and vigorous vegetative regeneration makes it particularly persistent once established and difficult to control through single interventions.

Early observations from the piloted eradication trials showed that mechanical removal (milling and mowing twice per year) was the most effective and cost-efficient method, achieving 100% suppression at a low cost per hectare. Manual methods such as trimming or trunk ringing yielded inconclusive results due to limited data or implementation challenges. These results underscore the need for well-planned, repeatable, and adaptive strategies that consider both local site conditions and long-term resource availability.

With an overall impact score of 11, Acer negundo ranks as a moderately impactful invasive species in Latvia. Though not the most aggressive on the targeted IAS list, its ability to spread and transform habitats, especially in Natura 2000 and high conservation value areas, justifies prioritised and proactive management. Effective control requires not only mechanical or manual intervention but also long-term follow-up and integration into broader land and habitat management frameworks. Preventative measures, such as avoiding further planting or using only male specimens, may reduce future spread, but will not reverse established invasions.

In conclusion, the management of *Acer negundo* in countries where it has become invasive, including in Latvia, necessitates a combination of **preventative, mechanical, and site-specific measures**, underpinned by **long-term monitoring** and **adaptive management**. Preventing seed production through the use of male trees in plantings can reduce future spread, but this measure alone is insufficient for population control in natural settings. Manual seedling removal and girdling of mature individuals represent the most effective current strategies, particularly in sensitive or protected landscapes. However, success depends on persistent follow-up and the integration of control efforts into broader land management frameworks. Ultimately, minimizing the ecological footprint of *Acer negundo* will require a coordinated, multi-scale approach that aligns local actions with regional invasive species management policies.

6. Rosa rugosa [beach rose]

6.1 Species characteristics

Rosa rugosa, commonly referred to as beach rose, Japanese rose, or rugosa rose, is a deciduous, woody shrub native to northeastern Asia, including Japan, Korea, China, and the Russian Far East. It typically grows 0.5–2 meters tall, forming dense thickets through both seed dispersal and extensive rhizomatous root systems.

The plant is notable for its leathery, rugose (wrinkled) leaves, profusion of thorns, and showy, fragrant flowers that bloom from late spring to autumn. Its large, orange-red hips are buoyant and can remain viable in salt and fresh water, aiding long-distance dispersal via ocean currents or animal ingestion (Latvia Nature Conservation Agency, 2023; Alaska Center for Conservation Science, n.d.; Kunttu and Kunttu, 2017).

Due to its aesthetic qualities and resilience, *Rosa rugosa* was introduced to Europe and North America for ornamental purposes and to stabilize dunes.

Photograph 8: Rosa rugosa flowering and seed

Source: Consultant

Its growth characteristics, combined with its tolerance for harsh conditions have made R. rugosa highly adaptable to coastal environments across its introduced range. It thrives in sandy, well-drained soils and withstands salinity, drought, and wind, allowing it to displace native dune flora such as *Ammophila arenaria* and *Eryngium maritimum*. It also alters soil chemistry by increasing nitrogen and organic carbon content, which shifts vegetation composition and suppresses native species regeneration (Stefanowicz et al., 2019; Woch et al., 2023). Its dense growth excludes native plant species, alters habitat structure, and reduces biodiversity, particularly in dune and sandy grassland ecosystems.

Regardless of the specific ecosystem, Rosa rugosa modifies the structure and function of habitats it invades. It exhibits “phalanx” growth—clonal expansion by rhizomes—that leads to the formation of dense, nearly impenetrable stands. These thickets can double in size every 4–5 years, with lateral growth of 0.2–0.7 m per year (Woch et al., 2023). The shrub also alters the microclimate, soil chemistry, and light regime, suppressing native flora and reducing biodiversity.

As an "ecosystem engineer," Rosa rugosa is capable of modifying entire habitats, reducing biodiversity and changing successional dynamics toward woody vegetation or forest-like conditions (Isermann, 2008; Toft, 2020). Rosa rugosa is recognized as one of the most aggressive invasive shrub species in many coastal environments. Its ability to form dense, impenetrable thickets through both seed dispersal and extensive vegetative reproduction via root suckers presents significant challenges for eradication and long-term control.

6.2 Habitat and ecological characteristics

Rosa rugosa is a highly adaptive and invasive shrub that colonizes a range of environments, most notably in coastal and disturbed habitats. It has successfully established across temperate and boreal regions in Europe and North America due to its tolerance to abiotic stresses and its aggressive vegetative spread.

Coastal dunes and beaches: The most characteristic habitats for *Rosa rugosa* include coastal sand dunes, where it thrives in nutrient-poor, well-drained, and often saline environments. These sites typically experience strong winds, salt spray, and periodic sand movement, conditions that many native species find challenging. However, it not only tolerates but often benefits from such disturbances. In Denmark, it has been documented to tolerate sand accumulation of up to 30 cm per year, making it particularly suited for colonizing and stabilizing active dune systems (Naturstyrelsen, 2016). Most notably, *Rosa rugosa* often dominates the foredune and grey dune zones, where it can displace native dune-building grasses like *Ammophila arenaria* (marram grass), leading to changes in dune dynamics and successional patterns (Woch et al., 2023). Additionally, the shrub's seeds are buoyant and salt-tolerant, allowing dispersal by tides along the shoreline, aiding in its long-distance spread along coastlines (Naturstyrelsen, 2016).

Coastal grasslands and heathlands: *Rosa rugosa* also readily invades coastal grasslands, heathlands, and maritime meadows, where it establishes in open, sun-exposed environments with minimal tree cover. In these habitats, the shrub forms dense, often monocultural thickets that outcompete herbaceous vegetation and disrupt the composition of plant communities (Hill et al., 2010). These grasslands are typically maintained by grazing or mowing, and disturbance or land abandonment often facilitates Rosa rugosa invasion.

In the Baltic region, for instance, Rosa rugosa encroaches into dry and mesic coastal meadows, replacing native low-growing forbs and grasses. It often colonizes areas with little canopy cover and slightly disturbed soils, further demonstrating its capacity to outcompete slower-growing, light-demanding native species (Woch et al., 2023).

Riparian zones and coastal woodlands: Although less commonly cited as a primary habitat, Rosa rugosa has also been observed in riparian zones—moist areas along rivers or streams—and coastal woodlands, particularly at the edges or in canopy gaps. These habitats offer moderate light and seasonal moisture variability. The shrub can establish in sandy or gravelly riverbanks, forest margins, or glades, where disturbance (natural or anthropogenic) creates openings for seedling establishment or rhizomatous spread (Kunttu and Kunttu, 2017).

Inland habitats (roadsides, forest edges, and agricultural land): While *Rosa rugosa* is primarily a coastal species, it has successfully colonized a variety of inland habitats due to human-mediated planting and accidental spread. It has been documented at elevations up to 200 m in Norway and as high as 435 m in Wales, indicating significant ecological plasticity (CABI, 2023). Inland, the species often escapes cultivation from ornamental plantings and spreads along roadsides, railways, urban parks, and edges of agricultural land.

These sites typically feature disturbed soils, full sun, and reduced competition, which facilitate the establishment of Rosa rugosa. Its adaptability to diverse soil types, including loamy, gravelly, and sandy substrates, and its tolerance to drought and low nutrient availability enable it to persist and spread aggressively in these environments (Stefanowicz et al., 2019).

Rosa rugosa is a highly adaptable species that thrives in a range of temperate ecosystems, from wind-swept beach dunes to forest edges and urban green spaces. Its success stems from its tolerance to extreme environmental conditions, robust reproductive strategies (both sexual and clonal), and ability to modify habitats to its advantage. While it offers some stabilizing benefits in sandy substrates, its invasive nature often leads to ecological degradation, especially in protected and biodiverse habitats.

6.3 Introduction and spread in Europe

Rosa rugosa is native to eastern Asia, including parts of China, Korea, Japan, and the Russian Far East. It was first introduced to Europe in 1796 in England, followed by Germany around 1845 and Denmark by 1875, primarily for ornamental purposes and to stabilize coastal sand dunes due to its resilience to poor soils and salt spray (Bruun, 2005; Kelager et al., 2013).

In Europe, *Rosa rugosa* was widely planted in gardens, parks, and along roadsides, as well as in coastal dune areas to prevent erosion. However, it soon escaped cultivation and became naturalized in the wild. The plant spreads aggressively both vegetatively through rhizomes and sexually via seeds, which are dispersed by birds, mammals, and ocean currents. Its buoyant rosehips allow seeds to be transported over long distances by water, while animals contribute to local seed dispersal after consuming the fruit (Latvia Nature Conservation Agency, 2024; CABI, n.d.).

Today, *Rosa rugosa* is recognized as one of the most invasive alien plant species in Europe. It has established dense stands in a wide range of European countries, especially along the coasts of the North and Baltic Seas. Notable countries with established populations include Denmark, Sweden, Norway, Finland (especially in the Archipelago Sea National Park), the Netherlands, the United Kingdom (notably the Sefton Coast), Germany, Poland, Lithuania, Latvia, and Estonia. More recently, it has also been recorded in southern countries such as Italy and Bulgaria (Kelager et al., 2013; Ribotta et al., 2021; Latvia Nature Conservation Agency, 2024).

The aggressive spread of *Rosa rugosa* leads to the displacement of native dune flora, reduces species richness, and alters habitat structure and nutrient dynamics. For example, in Baltic grey dunes, a habitat of European conservation importance, *Rosa rugosa* invasion leads to a marked decline in lichen and moss cover, reduced herbaceous diversity, and altered soil nutrient levels, threatening the ecological integrity of the site (Woch et al., 2023). Because of these impacts, the species is banned from sale and planting in several countries, including Denmark and Finland (Bruun, 2005; Dynamic Dunescapes, n.d.).

6.4 Baseline situation in Latvia

In Latvia, *Rosa rugosa* has established itself in sensitive coastal habitats, notably within the Natura 2000 protected site Ziemupe Nature Reserve, where it threatens coastal dune habitats such as grey dunes (EU habitat code 2130*) and foredunes (code 2120). Baseline assessments in 2022 identified individual plants and patches of *Rosa rugosa* ranging from 1 to 200 m², with notable occurrences in Ķīcu Orga, Griguļupe, Akmeņrags, and Rudupe. These stands were found in close proximity to rare and protected species such as *Dianthus arenarius* (sand carnation), *Eryngium maritimum* (sea holly), and *Lathyrus maritimus* (sea pea), highlighting the ecological urgency of control (Latvia Nature Conservation Agency, 2022).

Vegetation monitoring plots established in 2023 revealed *Rosa rugosa* cover between 6% and 30%, with bush heights typically ranging from 0.4 to 0.5 meters. Herbaceous plant diversity within affected plots was relatively low, with 8–11 species per plot, and bare substrate exposure ranged from 10% to 40%. In some areas, dominant dune species like *Ammophila arenaria* reached 50% cover, suggesting competitive displacement dynamics were already in progress (Latvia Nature Conservation Agency, 2024).

The species is recognized not only for its high rate of vegetative spread, of up to 20% area expansion per year, but also for its ability to form dense, impenetrable thickets. This disrupts native vegetation structure, limits light availability, and inhibits regeneration of indigenous flora, thereby functioning as an invasive ecosystem engineer (Latvia Nature Conservation Agency, 2024).

To address this, eradication actions under the LIFE-IP LatViaNature project have been planned across three forest blocks totalling approximately 10 hectares. These include manual removal, mechanical extraction, and targeted burning.

6.5 Eradication methods (pilot project)

As a highly invasive, rhizomatous shrub introduced for ornamental and erosion control purposes, *Rosa rugosa* has become a serious ecological threat in Latvia's coastal zones, particularly within Natura 2000 protected areas. Its ability to form dense, impenetrable thickets and displace native dune vegetation makes it one of the priority species for control under the LIFE-IP LatViaNature project.

The pilot interventions focused on testing various mechanical and manual eradication techniques tailored to coastal habitats, with particular attention to their feasibility and ecological impact. The tested methods aimed to reduce plant cover, prevent further spread, and restore native dune habitats. Testing for three different control methods was set up in Ziemupe Nature Reserve, following preparatory assessments conducted in earlier project stages, with results anticipated after a full growing season post-treatment.

Table 14: Eradication methods piloted for Rosa rugosa

	Method	Locations	Sample Plots	Description
A.	Flame treatment (burning the "epicentres" of Rosa rugosa with a gas burner)	Ziemupe Nature Reserve	No.1 (203-153-51)	Fixed dunes with herbaceous vegetation (EU habitat code 2130*)
B.	Mechanical excavation and soil sieving (mechanized digging out of Rosa rugosa with a mini tractor, for areas of 100-200 m2)	Ziemupe Nature Reserve	No.2 (203-150-51), No.3 (203-150-51)	Fixed dunes with herbaceous vegetation (EU habitat code 2130*)
C.	Manual excavation (digging out of Rosa rugosa with hand tools)	Ziemupe Nature Reserve	No.4 (203-141-1)	Fixed dunes with herbaceous vegetation (EU habitat code 2130*)

6.5.1 Method A: Flame treatment (burning)

The application of flame treatment, also referred to as thermal weeding or burning control, is an increasingly studied approach for managing Rosa rugosa, particularly in sensitive ecosystems where chemical herbicides are either restricted or undesirable. This method is planned for pilot testing in the Ziemupe Nature Reserve in Latvia, where Rosa rugosa threatens grey dune habitats (EU habitat code 2130*), a priority habitat under the EU Habitats Directive (Latvia Nature Conservation Agency, 2024).

Flame treatment involves the application of intense heat to the base of the plant using a gas burner. Prior to treatment, the root collar is exposed by removing 5–10 cm of soil and sand, after which the gas burner is used to char the stem until it is completely blackened. This aims to destroy the cambial tissues responsible for water and nutrient transport, thereby preventing regrowth. This approach aligns with best practices in thermal weeding interventions, where effectiveness is closely tied to the developmental stage of the target species. Younger and actively growing tissues are more susceptible to thermal injury (Ascard, 1995). The method requires careful timing of the application to maximize treatment efficacy.

Flame treatment offers several ecological and logistical benefits. Most notably, it provides a chemical-free alternative suitable for application in Natura 2000 sites and other areas where pesticide use is limited or banned. The method is also highly targeted, reducing the risk of collateral damage to nearby non-target species. Furthermore, the required equipment, including portable propane or butane burners, is relatively simple to operate and cost-effective for small- to medium-scale infestations (Hansson and Ascard, 2002).

Despite these benefits, flame treatment has notable limitations. Flaming is considered highly labour-intensive, as each plant must be individually treated, and its stem system partially excavated. Rosa rugosa is particularly challenging due to its vigorous rhizomatous growth habit, meaning that if the underground system is not fully eradicated, regrowth is highly probable. As a result, flame treatment often requires repeated applications over multiple growing seasons to be effective (Weidema, 2006). Additionally, flame use poses a wildfire risk, especially in dry or windy conditions, necessitating strict safety protocols and suitable weather windows for treatment (Rewicz, Pawlikowski, and Kaplan, 2020).

Preliminary experiences from applying the flame treatment suggest immediate dieback of above-ground biomass following treatment. Previous studies indicate that thermal treatments, while effective in the short term, tend to be more successful when combined with other mechanical or biological methods (Ascard, 1995; Hansson and Ascard, 2002). For example, coupling flame treatment with manual removal or excavation of root systems can improve outcomes and reduce the likelihood of reinvasion.

Flame treatment represents a valuable addition to the integrated management toolkit for Rosa rugosa, especially in conservation areas where chemical control is not an option. While it may not be a full solution to manage Rosa rugosa, its effectiveness can be further enhanced through repeated application and integration with complementary strategies.

6.5.2 Method B: Mechanical excavation and soil sieving

The mechanical excavation combined with soil sieving is a widely adopted method for managing *Rosa rugosa*, particularly in coastal dune ecosystems where its proliferation threatens native biodiversity. This approach focuses on the comprehensive removal of the plant’s aboveground and belowground components to prevent regrowth and restore native habitats (Latvia Nature Conservation Agency, 2024).

The process begins with the mechanical excavation of Rosa rugosa shrubs, typically using mini excavators or small tractors. Excavation reaches depths of up to one meter and extends laterally by approximately one meter to capture the extensive rhizome networks characteristic of this species. Following excavation, the soil undergoes mechanical sieving through meshes with openings around 20 millimetres. This sieving process effectively separates and removes rhizomes and root fragments from the soil. All extracted plant material, including aboveground parts and subterranean fragments, is collected and disposed of in accordance with environmental regulations, which either involves deep burial at depths exceeding 1.5 meters or transfer to licensed waste management facilities (Latvia Nature Conservation Agency, 2024; Dynamic Dunescapes, 2022).

The optimal timing for implementing this method is during late autumn to winter (November to February). Conducting operations during this period minimizes disturbances to nesting birds and other protected species, aligning with conservation best practices observed in northern European contexts (Dynamic Dunescapes, 2022).

Preliminary assessments of this method indicate high efficacy in removing Rosa rugosa populations, particularly when excavation and sieving are thorough. However, complete eradication is not always guaranteed, as residual rhizome fragments may persist in the soil, leading to potential regrowth. Consequently, ongoing monitoring and follow-up treatments are essential components of a successful management strategy.

It is important to note that while mechanical excavation and soil sieving are effective, they may also cause significant soil disturbance. Such disturbances can alter soil properties and microbial communities, potentially impacting the restoration of native vegetation. Therefore, integrating this method with ecological restoration efforts—such as replanting native species and monitoring soil health—is crucial for the long-term success of habitat restoration projects.

In conclusion, mechanical excavation combined with soil sieving represents a robust approach to managing Rosa rugosa invasions. However, its success depends on meticulous execution, appropriate timing, and integration with broader ecological restoration initiatives. Continued research and adaptive management will be vital to refine this method and ensure the resilience of restored ecosystems.

6.5.3 Method C: Manual excavation

Manual excavation is a widely recognized and ecologically sensitive method for controlling Rosa rugosa, particularly in coastal habitats where chemical treatments are often restricted due to environmental concerns. This approach involves the physical removal of the entire plant, including its extensive root and rhizome system, to prevent regrowth.

The manual excavation process entails digging out the Rosa rugosa shrubs using hand tools such as shovels and axes. In some cases, mechanical assistance with mini excavators equipped with custom buckets is employed to enhance efficiency, especially for larger infestations. The goal is to remove the plant to a depth of approximately one meter, including a lateral buffer zone of similar dimensions, to ensure the complete extraction of root suckers and rhizomes. All excavated plant material must be carefully collected and disposed of properly, either by deep burial (1.5–2 meters underground) or through certified waste management services, to prevent any chance of regrowth (Latvia Nature Conservation Agency, 2022).

The optimal timing for manual excavation is during late autumn to early spring, outside the bird nesting season, to minimize ecological disturbances. Moist soil conditions during these periods facilitate easier root extraction, enhancing the effectiveness of the method (Latvia Nature Conservation Agency, 2022).

While manual excavation has demonstrated effectiveness in reducing Rosa rugosa density, it is rarely sufficient as a standalone measure. The species' regenerative capacity necessitates ongoing monitoring and repeat treatments over a two to three-year period to ensure complete eradication.

International experiences further confirm these findings:

- In Denmark, the Netherlands, and the United Kingdom, manual excavation is considered the most effective method for removing Rosa rugosa, particularly in sensitive dune ecosystems. The process often involves sieving the soil to remove all rhizome fragments, followed by proper disposal of the biomass. These methods are labour-intensive and require sustained effort over multiple years, but they are favoured for their precision and minimal impact on non-target species (Boer, 2012).

- In the United States, similar practices are recommended. The Adirondack Park Invasive Plant Programme advises digging or pulling up the entire plant, including all roots and runners, using a digging tool. Extreme care must be taken to remove the entire root system, as any remaining fragments can lead to regrowth (The Nature Conservancy, 2019).
- In Finland, successful control has been achieved by removing all soil containing rhizomes with an excavator, followed by manual removal of any regenerating plants later in the season (Bruun, 2005). However, even with such intensive efforts, complete eradication remains challenging, and sustained management is essential to prevent re-infestation.

Although labour intensive, manual excavation is considered a viable and environmentally sensitive method for controlling Rosa rugosa infestations, especially in areas where chemical treatments are undesirable. However, its success depends on thorough implementation, appropriate timing, and a commitment to long-term monitoring and management. Manual removal is often recommended for smaller infestations or areas where mechanical methods are impractical due to terrain or ecological concerns.

6.6 Preliminary Cost-efficiency Assessment

At the time of developing this report, no monitoring data and cost information data is available yet for methods piloted to control *Rosa rugosa*. This information should become available when the treatment activities and monitoring is resumed in the coming years during project implementation.

Table 15: Preliminary cost-efficiency assessment Rosa rugosa

#	Year = 2024 Method	Costs [EUR per Ha]	% Reduction [Effectiveness]	CE Ratio	Remarks
A.	Flame treatment (burning)	n/a	n/a	n/a	Only baseline data available, no info on costs or total area covered
B.	Mechanical excavation and soil sieving	n/a	n/a	n/a	Only baseline data available, no info on costs or total area covered
C.	Manual excavation	n/a	n/a	n/a	Only baseline data available, no info on costs or total area covered

NB: At this stage, the outcomes of the preliminary cost-efficiency assessment cannot be taken as robust enough to support policy recommendations on what types of eradication methods are most favourable and feasible. The accuracy and robustness of the analysis can be further improved as more monitoring data and information about costs for forthcoming application cycles become available as the project evolves in the next two years.

6.7 Control programmes and eradication methods applied in other countries

Efforts to control and eradicate Rosa rugosa across other European have been widely implemented with varying success. The methods range from mechanical and chemical interventions to habitat restoration and experimental biological control.

In Denmark, control of Rosa rugosa has been most extensively implemented along the coastal dunes through a combination of mechanical, chemical, and ecological methods. The Danish Nature Agency's programme utilized mechanical digging with plant extirpators and cranes to remove entire root systems, followed by regular mowing and, in some cases, herbicide applications. Grazing was employed where feasible, though livestock often avoided dense stands of the plant. This integrated approach proved effective in reducing populations, especially when repeated over several seasons (Toft et al., 2020; Dynamic Dunescapes, 2024).

In the United Kingdom, notably on the Sefton Coast, a “dig and bury” method was employed with excavators to remove Rosa rugosa along with its root systems, which were then buried at a depth of two meters. This mechanical approach was supplemented with chemical treatments using glyphosate in follow-up applications to manage regrowth. The operation was relatively costly, with mechanical removal estimated at £107,000 and herbicide application costing an additional £42,000 (Dynamic Dunescapes, 2024). Despite the costs, this method proved highly effective in eliminating large stands when combined with diligent monitoring and reapplication where necessary.

In Italy (Bibione region), Rosa rugosa was fully eradicated through habitat restoration projects that, while not detailed extensively in applied methods, were reported to be completely successful. These efforts likely involved manual or mechanical removal paired with ecological restoration practices that enhanced the resilience of native dune vegetation, effectively preventing reinvasion (Ribotta et al., 2021).

In Sweden, control efforts relied on a combination of manual labour, mechanical extraction, and chemical treatments. These methods have shown variable success depending on the intensity of application and local site conditions. The annual costs associated with Rosa rugosa control in Sweden range significantly, from €10,000 to €150,000, indicating the financial burden involved in managing this species across different scales and landscapes (Gren et al., 2009; Diagne et al., 2020). While expensive, ongoing interventions have been necessary to prevent reinvasion and protect valuable dune habitats.

In a few countries, biological control has been explored as a potential long-term strategy. Research has focused on specific natural enemies such as aphids, leafhoppers, moths, and rust fungi, with emphasis on host specificity to avoid impacts on non-target species. While promising, these biological control methods are still largely in the research phase and have not yet been widely implemented (Bruun, 2006).

6.7.1 General control approach for Rosa rugosa

Rosa rugosa is a highly resilient species, well-adapted to a variety of environmental conditions, including saline coastal soils, poor nutrient availability, and frequent disturbances, which make it particularly difficult to eradicate. Its capacity for both generative (seed) and vegetative (root sucker) propagation, contribute to its invasiveness and complicate eradication efforts. Its biological features necessitate a multifaceted and sustained management approach that considers both aboveground and belowground plant structures.

In practice, eradication efforts targeting *R. rugosa* have often yielded mixed or unsuccessful outcomes, particularly in coastal dune systems where the species is most problematic. Several factors contribute to the difficulty of eradication:

- **Persistence of Root Systems**: Even small fragments of rhizome left in the soil after treatment can regenerate new shoots, resulting in reinfestation.
- **Incomplete Treatment Coverage**: Due to the plant’s ability to spread underground, infested areas are often underestimated, leading to partial removal and rapid recolonization.

- **Environmental Constraints**: In sensitive habitats—such as coastal dunes or protected conservation areas—the use of mechanical equipment or chemical herbicides may be restricted, limiting available management options.

Although some countries have attempted to manage or eradicate *Rosa rugosa*, there remains a general lack of comprehensive, evidence-based best practices for effective long-term control. The variety of control efforts applied across Europe, including mechanical removal, chemical treatments, and experimental biological control using insects and fungi, reflect the urgent need for integrated management strategies (Bruun, 2006; Dynamic Dunescapes, 2024; Ribotta et al., 2021).

Nevertheless, certain principles and strategies have emerged from field experience that can inform the development of more effective management approaches. Experiences suggest that integrated control approaches, involving a combination of mechanical, manual, and chemical strategies, offer the greatest potential for effective suppression.

A. **Containment and Targeted Suppression:** Although full eradication of *Rosa rugosa* is often unfeasible once the species is well established, containment and localized removal efforts can prevent further spread and reduce ecological impacts in high-value areas.
    a. **Preventing Spread**: Initial management efforts should prioritize preventing the species from colonizing new areas. This includes the removal of young, newly established plants and the targeted management of reproductive individuals prior to fruit and seed production.
    b. **Manual Removal**: For smaller infestations or areas where herbicide use is restricted, manual digging may be employed to remove both aboveground biomass and belowground root systems. This method is labour-intensive and often requires multiple follow-ups to address resprouting from missed rhizome fragments.
    c. **Mechanical Treatment**: In larger or less sensitive areas, mechanical removal (e.g., cutting, mulching, or excavation using heavy equipment) may be applied. However, such methods must be accompanied by **repeated interventions** to manage regrowth. Mechanical disturbance can sometimes stimulate vegetative propagation if not followed by appropriate follow-up treatments.
    d. **Chemical Control**: The application of systemic herbicides, such as glyphosate or triclopyr, directly to cut stumps or regrowth shoots has shown promise in controlling *Rosa rugosa*, particularly when applied repeatedly over multiple growing seasons. However, herbicide use near water bodies or in protected areas must comply with environmental regulations and be carefully managed to avoid non-target effects.

B. **Containment and Targeted Suppression:** Due to the plant's regenerative capacity and the persistence of its underground structures, long-term management is essential. Effective strategies should include:
    a. **Integrated Approaches**: Combining manual or mechanical removal with targeted chemical application is often more effective than any single method alone. An integrated strategy increases the likelihood of depleting energy reserves in rhizomes and reducing re-establishment rates.
    b. **Repeated Treatments**: Control efforts must be sustained over multiple years, with interventions timed to key phenological stages (e.g., early summer regrowth, late-season energy translocation to roots).
    c. **Monitoring and Adaptive Management**: Ongoing monitoring is required to detect regrowth and ensure timely re-treatment. Adaptive management, i.e., tailoring and adapting techniques based on treatment outcomes and site conditions, is critical to long-term success.

6.8 Assessment of associated costs and benefits

To systematically assess the multifaceted impacts of Rosa rugosa across ecosystem services, human health, and infrastructure, an adapted ranking framework is applied, based on Blaalid et al. (2021) and Magnussen et al. (2020). This structured method uses a standardized 0–4 scale, where 0 indicates no impact and 4 reflects a major, widespread impact. The framework enables a consistent evaluation of both the detrimental and beneficial effects of Rosa rugosa across multiple sectors. For example, in coastal habitats, the species may score a 4 due to its dense growth that displaces native dune vegetation and threatens protected habitats such as grey dunes (EU habitat code 2130*). Conversely, in certain urban areas, it may score a 0 (no negative impacts) for its ornamental and erosion control value, where it is used in landscaping and stabilizing sandy soils. In some contexts, despite its invasiveness, the species has economic and cultural value. It has long been used in East Asia for its medicinal properties, and its essential oils are used in perfumery.

Table 16: Cost-benefit impact assessment Rosa rugosa

Benefit / Impact Category		Rating	Literature / Sources
Ecosystem Services	**Supporting:** ecological impact	**4** *Severe ecological impact. Major, possibly irreversible damage to ecosystem integrity or biodiversity.*	• *Rosa rugosa* can cause a decline in native plant cover and richness, especially in yellow dune sites, and causes shifts in grey dunes, accelerating succession towards forest-like conditions (Woch, 2023). • It affects arthropod communities by changing vegetation structure, leading to a decrease in thermophilic predator species and a reduction in species richness and diversity among arachnids (Elleriis et al., 2015). • Its invasion impacts soil properties, increasing organic carbon, nitrogen, and phosphorus concentrations while reducing microbial biomass (Stefanowicz et al., 2019). • The plant can provide a habitat for wildlife (Zang et al., 2021), it can offer shelter for various birds (Alaska Center for Conservation Science).
	Supporting: ecological impact on endangered ecosystems	**4** *Critical. Collapse imminent or ongoing; irreversible loss likely without intervention.*	• Rosa rugosa is cited as one of the most invasive species of Europe. It spreads spontaneously in coastal areas of western, central and northern Europe, posing a threat to dune habitats, including those indicated in the EU Habitats Directive as particularly valuable (Woch, 2023). • *Rosa rugosa* forms dense thickets that outcompete native vegetation, leading to reduced plant diversity. In European coastal dunes, it significantly decreases species richness (Isermann, 2008; Woch, 2023). • The plant can threaten conservation interest of dune systems, for example as experienced in Sefton Coast in the UK (Smith and Deed, 2019; Boardman and Smith, 2016). • In Europe, the effects of Rosa rugosa on native flora and fauna are generally negative, by reducing the number of native species present at the invaded sites, displacing natural flora of beach and dune vegetation affecting both common and rare species (Pasiecznik, 2009).
	Provisioning: food production	n/a	n/a
	Provisioning: non-food production	**0** *No known impact on resources such as timber, fibre, or biofuel.*	• *Rosa rugosa* is rich in essential oils which is valuable for perfume production (Da et al., 2023) • The plant sometimes is referred to as “liquid gold” for its main fragrant components are monoterpenes. The genetic manipulation of the plant has been shown to enhance the production of these scent volatiles (Zang et al., 2021; Sheng et al., 2021)

	Benefit / Impact Category	Rating	Literature / Sources
	Regulating: water regulation, pollination, erosion	**0** *No impact on regulatory functions. Hydrology, pollination, and erosion control remain intact.*	• *Rosa rugosa* is known for its adaptability to various environmental conditions, it can be used for stabilizing sand dunes and preventing soil erosion (Zang et al., 2021). • The dense root systems of the plant help to bind the soil, which can protect coastal areas from erosion and provide a habitat for wildlife (Zang et al., 2021). • Rosa rugosa can quickly produce a dense cover over a large area (due to the ease of clonal reproduction), which effectively limits the mobility of dunes (Woch et al., 2023). • With its highly developed root system, Rosa rugosa has been used for soil protection and erosion control, e.g. in Bulgarian mountain fields and in Dutch and Lithuanian coastal dunes (Woch et al., 2023).
	Cultural: recreation, aesthetic beauty, natural heritage	**3** *Disturbance restricts access or use in certain areas; visible and spreading presence.*	• The spread of *Rosa Rugosa* has raised concern about the loss of cultural and natural heritage associated with native dune ecosystems (Uusitalo et al., 2024). • Dense growth of *Rosa rugosa* can have an impact on recreational and aesthetic values of coastal areas, it can limit access to beaches and dunes, which could impact tourism (Boardman and Smith, 2016).
Other	**Human Health**	**0** *No effects. IAS pose no health concern.*	• The pleasant scent of *Rosa rugosa* makes it a popular choice for gardens and public spaces, contributing to human well-being and quality of life (Zang et al., 2021). • The plant contains various compounds that may have medicinal properties, which could offer opportunities for research into natural remedies and health products (Zang et al., 2021). • Several medicinal properties have been attributed to the plant, including anti-inflammatory, antioxidant, and antimicrobial effects (Lu and Wang, 2018) • Extract from *Rosa rugosa* shows potential in preventing hair loss in a random control study of mice (Kim et al., 2024).
	Infrastructure	n/a	n/a
	Total Score:	11	

Based on initial literature research and early assessments in Latvia, *Rosa rugosa* has been allocated a total impact score of 11, reflecting its moderate to high ecological impact, particularly in Latvia's coastal dune ecosystems. The sub-scores concerning ecological impact (respectively 4 and 4) reflect the substantial negative effects the species has on coastal ecosystems, particularly in dune habitats where it aggressively forms dense, impenetrable thickets that outcompete native vegetation and significantly alter habitat structure and function. In Latvia, *Rosa rugosa* threatens protected Natura 2000 coastal sites, including grey and white dune systems, where it contributes to the loss of open dune vegetation. As a robust, rhizomatous shrub, it spreads aggressively and forms dense thickets that crowd out native vegetation, disrupt dune dynamics, and reduce habitat quality for species adapted to open, dry, and nutrient-poor conditions.

Although *Rosa rugosa* has been utilised selectively for its economic and cultural value, such as its use in landscaping, erosion control, and production of rosehips for food, medicine, and cosmetics. These advantages are largely confined to managed or urban contexts. In natural habitats, particularly along the coast, these benefits are outweighed by the species' ecological costs and the difficulty of its removal. The species is resilient to environmental stress, tolerant to harsh coastal conditions, spreads via both seed and rhizomes, and regenerates readily after disturbance, making eradication complex and resource-intensive, especially once it is established.

Therefore, while *Rosa rugosa* does not have the highest impact score among Latvia's invasive species, its **ecological threat in coastal habitats** is significant and warrants **focused, sustained management**. The moderate impact score reflects both its harmful ecological role and its limited, context-specific benefits.

6.9 Conclusion – Rosa rugosa

Overall, *Rosa rugosa* inhibits significant ecological risks, particularly in coastal dune systems of conservation importance. Despite its ornamental and commercial value in some contexts, in Latvia's natural coastal landscapes, the species demands prioritised, long-term control strategies to mitigate its impact and preserve native biodiversity. Early detection, consistent removal, and follow-up monitoring will be key to reducing its spread and ecological footprint.

Mechanical and manual removal methods could significantly reduce plant cover, but require sustained effort, repeat treatments, and careful site restoration to prevent regrowth from rhizomes (i.e., soil sieving is required to remove root systems). These efforts are often labour-intensive and expensive, especially in dynamic dune environments where mechanical access may be limited, and ecological sensitivity is high.

Rosa rugosa presents a major challenge for invasive species management due to the plant's resilience, reproductive strategies, and adaptability. Although eradication is difficult and rarely successful in large or well-established populations, containment and suppression strategies based on **early intervention, repeated and integrated treatment methods, and long-term monitoring** have demonstrated some success. Continued research into effective control measures, supported by knowledge exchange between countries, will be essential to refine best practices and limit the spread and impact of this invasive species in sensitive ecosystems, particularly coastal and dune environments.

7. Conclusions and recommendations

7.1 Overall findings and observations

The management of invasive alien species (IAS) remains a critical and complex challenge for biodiversity conservation in Latvia. Based on preliminary assessment of IAS and piloted eradication methods, it is evident that the five target species—*Impatiens glandulifera* (Himalayan balsam), *Solidago canadensis* (Canadian goldenrod), *Amelanchier spicata* (dwarf serviceberry), *Acer negundo* (box elder), and *Rosa rugosa* (beach rose)—pose varying degrees of ecological, economic, and social risk to Latvian ecosystems. The preliminary data derived from field experiments and cost assessments provide a strong foundation for shaping a strategic response to these threats.

All five IAS for which eradication methods are piloted, exhibit traits that enable them to dominate and transform ecosystems. They spread rapidly, reproduce prolifically, and often outcompete native flora through both direct competition and indirect ecological modification, such as altering soil chemistry or water flow. For instance, *Impatiens glandulifera* and *Solidago canadensis* have shown particularly aggressive patterns of spread in riparian and meadow ecosystems, forming dense monocultures that displace native species and increase soil erosion risks. Similarly, *Rosa rugosa* has become a dominant presence in coastal dune habitats, threatening rare and protected plant communities.

These species not only degrade habitats but also reduce ecosystem services. Their impact spans supporting (e.g., biodiversity, nutrient cycling), regulating (e.g., erosion control, water filtration), and cultural (e.g., recreation, aesthetic value) services. The displacement of native vegetation by species like *Amelanchier spicata* and *Acer negundo* in forest and urban settings further illustrates the multidimensional nature of the problem.

The Latvia Nature Conservation Agency's pilot programme to test eradication methods represents a commendable effort to identify effective and scalable solutions. Across 75 sample plots in various protected and non-protected sites, methods were piloted under controlled conditions and evaluated for both ecological effectiveness and financial feasibility. These methods included among others mechanical milling and mowing, hot steam treatments, manual excavation, horse grazing, sowing of native competitive plants, and chemical control measures.

While the preliminary CEA and CBA findings to date offer valuable insights, they must be interpreted with caution. A central limitation of the analysis is the restricted timeframe: only one year of post-treatment monitoring data was available at the time of reporting. Most of the control methods were applied in 2023, with monitoring in 2024. As invasive plant management often requires multi-year and iterative treatments, the short monitoring horizon cannot capture regrowth dynamics, seed bank persistence, or full habitat recovery.

Additionally, while the cost-efficiency analysis (CEA) provides a useful comparative tool, its results are sensitive to site-specific variables such as terrain, infestation density, and access. A method that is cost-effective in one site may be less so in another, especially when ecosystem sensitivity and restoration needs are factored in.

Despite the provisional nature of the findings, several strategic implications emerge:

1. There is a clear need to prioritize early intervention and the prevention of seed dispersal. Methods such as mowing or steam treatment applied before seed set can drastically reduce the long-term spread and management burden. Second, ecological restoration must be embedded into control efforts; merely removing the invasive species without re-establishing native vegetation risks recolonization or secondary invasions.
2. IAS management strategies must be tailored to local ecological and logistical conditions. A "one-size-fits-all" approach is unlikely to succeed across Latvia's diverse habitats. Integration of manual, mechanical, and biological control methods, supported by long-term monitoring and adaptive management, is essential for sustainable outcomes.
3. Capacity-building and public awareness are crucial. The spread of IAS is often accelerated by human activity—intentional or accidental. Engaging landowners, municipalities, and civil society through education and partnership will strengthen both compliance and stewardship.

The current (preliminary) assessment underscores that invasive species management in Latvia is both necessary and feasible, but must be grounded in science, strategic planning, and sustained effort. The current findings represent a strong starting point for evidence-based decision-making. As additional monitoring data become available over the coming years, particularly through 2027, the Latvia Nature Conservation Agency and its partners will be well-positioned to refine their approaches, improve cost-efficiency, and safeguard the integrity of Latvia's ecosystems.

In conclusion, while invasive plant species present formidable challenges, the lessons and results emerging from these initial interventions offer a roadmap for informed, adaptive, and effective management. With continued investment in research, field trials, and public engagement, Latvia can lead the way in demonstrating how to respond proactively to these multi-dimensional biodiversity threats.

As the current study provides a preliminary assessment of cost-efficiency of different control methods piloted in Latvia, using one cycle (one year) of available monitoring and expense data provided by the Latvia Nature Conservation Agency, the study will need to be updated on a yearly basis, when new cycles of monitoring and expense data become available. As the pilot project will continue in the coming two years and monitoring data becomes more enriched, at the end of the project, a more conclusive assessment can be conducted, using the **CEA and CBA tools developed** by the consultants in this current phase of the project.

7.2 Ranking of piloted methods based on Preliminary Cost-efficiency Analysis

Selection of which eradication and control methods would be best suitable to be considered for IAS management strategies should be based on overall **impact category** of the IAS (while **prioritising sub scores for supporting and regulating ecosystem services**), the **effectiveness rate** of different eradication methods, and the **cost-efficiency ratio** of available methods, as well as on **empirical and qualitative evidence**, considering a variety of contextual factors including species biology, site conditions, and ecological management priorities.

In general, control methods can be classified into four main categories:

- **Manual and Mechanical Control**: Physical removal, mowing, cutting, or trapping.
- **Chemical Control**: Use of herbicides or pesticides, subject to legal and environmental considerations.
- **Biological Control**: Introduction of natural predators, pathogens (for example introducing fungus), or competitive species, requiring rigorous risk assessment.
- **Integrated Management**: Combining multiple approaches to enhance effectiveness and sustainability.

In Latvia, field trials have been set-up to validate the effectiveness of different control methods, particularly in cases where existing research on IAS is deemed insufficient or regionally inapplicable. Based on the current initial cost-efficiency analysis (***while noting that the current analysis is limited to using 1 year of available monitoring and expense data***), the following picture emerges providing a preliminary ranking of tested methods:

Table 17: Preliminary cost-efficiency assessment after one treatment cycle (2024)

#	Impatiens glandulifera	Solidago canadensis	Amelanchier spicata	Acer negundo	Rosa rugosa
1.	A: Hot steam ER 51.65 and **CER 21.12**	E: Milling, mowing, and sowing native competitive plants (*White clover*) **ER 98.63** and **CER 31.86**	D: Chemical treatment **ER 96.79** and **CER 15.16**	B: Mechanical removal (Milling and mowing 2) **ER 100.00** and **CER 21.16**	A: Flame treatment n/a
2.	B: Milling and mulching ER 81.18 and CER 23.38	D: Milling, mowing, and sowing native competitive plants (*D. glomerata*) ER 95.78 and CER 35.40	A: Mechanical removal ER 76.94 and CER 24.68	A: Mechanical removal (Milling and mowing 1x) ER 97.50 and CER 28.70	B: Mechanical excavation n/a
3.	C: Milling and sowing native competitive plants **ER 85.71** and CER 165.38	C: Milling and mowing (1x) ER 59.85 and CER 44.60	B: Manual removal ER 81.32 and CER 29.79	C: Chemical treatment ER 100.00 and CER n/a	C: Manual excavation n/a
4.	D: Grazing with horses **ER 24.52** and **CER 356.95**	A: Mowing (2x) ER 69.22 and CER 54.87	C: Manual trimming **ER -126.56** and **CER -20.22**	E: Manual trunk ringing n/a	
5.		F: Land levelling and mowing (2x) ER 58.11 and CER 70.01		D: Manual trimming (Cutting off shoots) n/a	
6.		Milling, mowing, and sowing native competitive plants ER 56.25 and CER 75.08			
7.		B: Mowing and sowing native competitive plants (2x) ER 40.97 and **CER 286.98**			
8.		G: Milling, mowing, and sowing native competitive plants (2x) **ER 27.08** and CER 144.52			

The total cost for selected eradication methods is highly depending on factors like the scale of the infestation and spread of the invasive alien species, the accessibility of the treatment site, as well as the long-term management objectives (i.e., control the further spread, full eradication, border or site protection, etc.) and the frequency of treatments required. Proper budgeting for all methods and tracking their associated costs is critical to ensure both the short-term and long-term success of eradication efforts.

As the piloting of the control methods in Latvia has now completed the first cycle of treatments during 2024 (more years to follow), the final ranking of the different methods can be done based on the monitoring results from the last year of the project (foreseen for 2027).

What can be observed from the preliminary CEA scores, is that for Amelanchier spicata, the most in-effective and counterproductive control method is ***Method C: Manual trimming***. After the treatment, the plant showed rigorous resprouting, increasing its coverage even beyond its initial baseline coverage (hence the negative effectiveness rate ER and negative cost-efficiency ratio CER). Similarly, for Impatiens glandulifera, ***Method D: Grazing with horses***, also showed the least effectiveness rate and worst CER compared to the other methods.

For Solidago canadensis, ***Methods B and G*** showed both low effectiveness rates combined with relatively high CERs. For all these bottom ranked methods, it should be considered to abolish their further testing after the next treatment and monitoring cycle has been completed (or even to immediate effect) and no substantial improvements are observed, to save financial resources and time that can be invested in more promising interventions.

It should be noted that at this stage, the outcomes of the preliminary cost-efficiency assessment cannot be taken as robust enough (based on one growing season and treatment cycle) to support policy recommendations on what types of eradication methods are most favourable and feasible. The accuracy and robustness of the analysis can be further improved as more monitoring data and information about costs for forthcoming application cycles become available as the project evolves in the next two years.

7.3 CBA Prioritisation of IAS

Cost-Benefit Analysis (CBA) for invasive alien species (IAS) provide critical information for policymakers and nature conservation managers. It can inform strategic prioritization by identifying IAS that form the highest threat to the integrity of protected landscapes and ecosystems, and target interventions that maximize societal benefits per unit of control cost. This is particularly relevant in resource-limited contexts, where funding must be allocated to those IAS management efforts likely to deliver the highest ecological and socio-economic returns.

However, the large number of established or emerging IAS presents a significant challenge. Conducting a full-scale CBA for each species is often impractical due to the time, expertise, and data required to comprehensively assess all associated social costs and benefits. This would require extensive valuation surveys and ecosystem assessments for each IAS. Moreover, estimating the cost of controlling IAS is subject to considerable uncertainty. These uncertainties stem not only from variability in the costs of available control measures, but also from limited or site-specific knowledge regarding their effectiveness and the thresholds required for successful suppression or eradication. Compounding this is the frequently incomplete or spatially imprecise information on the current distribution and spread potential of many IAS, which further complicates both cost estimation and impact forecasting.

Given these constraints, semi-quantitative approaches—such as the use of structured impact scoring and avoided damage assessment, offer a pragmatic alternative. The tool (see Annex 1) developed as part of the current study, supports transparent, evidence-informed decision-making, even in the face of imperfect data and complex ecological dynamics. It has been applied for the five main Invasive Alien Plants Species for which control measures are being piloted under the management of the Latvia Nature Conservation Agency (*note that for the Rosa rugosa, no interventions have been piloted yet*).

Table 18: Ranking of IAS based on CBA negative impact scores

#	IAS	CBA Score	Remarks
1.	Impatiens glandulifera	14	Impatiens glandulifera received the highest CBA score, indicating the most significant ecological and socio-economic threat. It rapidly forms monocultures along watercourses, outcompetes native flora, and leads to soil erosion after dieback in winter. It disrupts pollination networks and incurs substantial control costs due to high reproduction rates and seed dispersal distances
2.	Solidago Canadensis	13	Solidago canadensis is a perennial plant that aggressively spreads via rhizomes and seed, forming dense stands that exclude native species and modify soil chemistry. Its

#	IAS	CBA Score	Remarks
			impacts include reduced biodiversity, disrupted pollinator dynamics, and increased costs of control.
4.	Acer negundo	11	Acer negundo alters riparian forest composition by out-shading native species and changing soil structure. It reproduces prolifically and has a high tolerance for environmental stress. It affects ecosystem services and landscape aesthetics, with some toxicity to livestock.
5.	Rosa rugosa	11	Although no monitoring data is yet available from pilot sites, literature indicates that Rosa rugosa poses a high threat to coastal habitats. It forms impenetrable thickets, displaces native dune vegetation, and reduces recreational access. It also affects arthropod diversity and soil nutrients
3.	Amelanchier spicata	10	Amelanchier spicata is a shrub species invading pine forests and dry sandy habitats, forming dense thickets. It suppresses native undergrowth and alters visual landscapes. While it has limited documented economic damage, its ecological impact in sensitive habitats is growing. Its significant ecological impact is visible in Ragakapa Nature Park, with profound changes to the landscape.

Based on this CBA assessment, it is concluded that Impatiens glandulifera represents the largest threat to the integrity of ecosystem services and human wellbeing (incl. human health and infrastructure) with a score of 14, followed by Solidago Canadensis with a score of 13.

The CBA framework and scoring for each IAS can be further complemented with information drawn from field observations and annual ecological monitoring conducted within the wider local ecosystems from each pilot area, to assess ecological damage and biodiversity degradation caused by each IAS over a longer period of time.

7.4 Dimensions of Effective and Cost-Efficient Management of Invasive Alien Species

A cost-efficiency assessment of a range of control methods is one specific element to consider in management decision-making. The management of Invasive Alien Species (IAS) and selecting the most appropriate control methods to combat IAS is a complex challenge that requires a tailored approach, considering ecological, economic, legal, and logistical factors. The effectiveness and cost-efficiency of IAS management strategies depend on multiple **contextual elements**, including 1) defined management objectives; 2) species-specific traits, 3) site conditions; 4) legal constraints; 5) available financial and technical resources, as well as the involvement of various stakeholders. These elements collectively define the feasibility, scope, and choice of management interventions.

To ensure success, IAS management must begin with a **clear definition of management objectives (short-term and long-term)**, taking into account both the opportunities and restrictions imposed by these contextual factors. This enables decision-makers to select the most appropriate strategies and allocate resources efficiently while minimizing unintended ecological and socio-economic impacts. By systematically assessing these factors, stakeholders can develop robust, context-specific IAS management plans that are both effective and sustainable, minimizing environmental and economic impacts while protecting native biodiversity.

7.4.1 Management goals and strategic approaches

Clearly defining management goals is essential for selecting the appropriate control measures. IAS management objectives typically fall into one of three categories:

- **Prevention**: Measures aimed at stopping the introduction or the further spread of IAS, such as biosecurity protocols and public awareness campaigns.
- **Containment**: Efforts to restrict IAS populations to a limited area, preventing further expansion while minimizing ecological damage.
- **Eradication**: The complete removal of an IAS from a defined area, often pursued in ecologically sensitive zones or conservation areas (e.g., Natura 2000 sites).

Each management objective would need to consider its implications for the short-term and long-term, as the choice would have implications in terms of the time and dedication required to achieve the objective, time horizon needed to achieve the objective including its post-intervention follow-up and continuous monitoring to ensure the results of the management are sustained (which could require a timespan of several decades), budget and capacity requirements, as well as supporting legislative frameworks.

7.4.2 Biological and ecological characteristics

IAS exhibit diverse biological and ecological traits that influence their invasiveness, persistence, and response to control measures. Understanding these characteristics is essential for selecting targeted and effective management strategies.

For invasive plant species, key biological factors that affect their management and control include:

- **Habitat Preferences**: Certain invasive species thrive well under specific ecological conditions (e.g., in wetlands, drylands, forest understoreys, disturbed habitats).
- **Growth Factors**: Some species exhibit high adaptability in terms of light, soil texture, or nutrient availability, allowing them to establish in a wide range of environments. Resistance to extreme conditions (salt, acidity, cold, drought) can further enhance their survival.
- **Growth Characteristics**: Differences between annual and perennial species, maximum plant size, flowering time, seed production rate, and dispersal mechanisms (e.g., wind, water, animals) influence the speed and scale of spread.
- **Reproductive Strategies**: IAS plants may reproduce generatively (via seeds) or vegetatively (through root suckers, stolons, or rhizomes), requiring different control strategies.
- **Seed Viability and Germination Power**: Longevity in soil seed banks and germination success influence eradication efforts, as dormant seeds may lead to re-establishment after control measures are implemented.
- **Defensive Mechanisms**: Some IAS plants produce allelopathic compounds or toxins that suppress native vegetation, making restoration efforts more challenging.

Invasive animal species exhibit a range of biological traits that determine their impact and management complexity, including inter-alia:

- **Habitat Preferences**: Dependence on specific environmental conditions, such as aquatic or terrestrial habitats, affects their potential distribution.
- **Growth and Survival Factors**: Dietary flexibility, shelter requirements, tolerance to extreme conditions (e.g., brackish water, seasonal temperature fluctuations) influence survival and establishment.
- **Reproductive Traits**: Key considerations include breeding season, gestation period, litter size, reproductive frequency, and mechanisms such as parthenogenesis (as seen in some invasive reptiles and insects).
- **Social and Behavioural Traits**: Some IAS exhibit cooperative behaviours (e.g., pack hunting, communal nesting) that enhance their resilience to control measures, whereas others may hibernate or migrate,

requiring seasonal management adaptations. For example, the common racoon dog usually lives in pairs (male and female), and in Finland a management control strategy is targeted at this trait (capturing, sterilizing, and releasing singles, to lure their male/female counterpart that can be captured and sterilized).

- **Movement and Dispersal Abilities**: The ability to traverse both terrestrial and aquatic environments, as well as human-assisted transport (e.g., via shipping routes or the pet trade), can facilitate rapid range expansion. For example, freshwater crawfish can travel short distances over land to colonize new waters, enabling its rapid spread.
- **Susceptibility to Diseases**: Some IAS act as vectors for pathogens, affecting native species and requiring integrated control strategies.

7.4.3 Site conditions

The physical, ecological, and socio-environmental characteristics of an invaded area play a critical role in determining both the feasibility and effectiveness of IAS management and feasibility of the control method.

For **invasive alien plant species**, relevant site conditions to consider include:

- **Habitat Type**: Forests, grasslands, wetlands, riparian zones, dunes, urban areas, and transportation corridors present different invasion dynamics and management constraints.
- **Soil and Water Conditions**: Factors such as moisture levels, pH levels, salinity, and nutrient availability affect the growth potential of IAS and may influence the success of eradication efforts.
- **Disturbance Regime**: Areas subjected to frequent disturbances (e.g., road verges, agricultural fields) may be more prone to invasion due to reduced competition from native species.

For **invasive alien animal species**, additional considerations include:

- **Predator Pressure**: The presence or absence of natural predators influences population control.
- **Food and Shelter Availability**: Abundant food resources and nesting sites can facilitate population establishment and expansion.
- **Water Salinity and Hydrology**: For aquatic IAS, factors such as freshwater vs. saltwater environments, water temperature, and flow dynamics can determine habitat suitability.

Beyond the above-listed ecological considerations, site conditions impose logistical constraints on management operations. Remote, rugged, or protected areas may restrict access to control equipment, limiting the feasibility of certain interventions. Eradicating IAS from highly in-accessible terrains such as wetlands or swamps may prove to be near impossible or require innovative techniques and technologies which may be very costly. Controlling IAS in steep slopes or rugged terrain might require time-intensive manual labour instead of mechanized control solutions as it may be difficult to operate vehicles and heavy equipment.

7.4.4 Legal and regulatory frameworks

IAS management is often subject to national and international legislation that governs the control, trade, and distribution of invasive species. Key legal considerations include:

- **Prohibitions on Possession, Trade, or Release**: Many jurisdictions restrict the importation, breeding, sale, and transport of invasive species to prevent further spread.
- **Mandatory Control or Eradication Measures**: Some species are subject to legal requirements for removal, with penalties for non-compliance (in Latvia, this is the case for the control of Hogweed, for which specific laws have been established to ensure its management).

- **Restrictions on Management Methods**: The use of chemical herbicides or pesticides may be restricted near water bodies or in protected areas. In the European Union, for example, certain chemical treatments are banned in specific countries or under seasonal regulations.
- **Reporting and Monitoring Obligations**: Some regulations require landowners or authorities to report sightings and monitor IAS populations to facilitate early intervention (in Latvia, this is the case for the control of Hogweed, requiring active action from landowners and authorities to remove Hogweed from their lands).

Compliance with legal frameworks is essential, requiring a thorough review before implementing any management strategy. While invasive species management in Latvia is a relative new area of work and previously has focused on Hogweed mainly, a **legislative review including gap analysis** would need to be conducted to assess **alignment with existing EU legislation and directives, comparison with legal frameworks established in other countries** that are combating invasive species (e.g., countries with strict border control mechanisms, import and trade restrictions for animals and plants, etc.), as well as draw from experiences in other countries which have established **clear production and use regulations for their internal markets** (e.g., to avoid trade and further spread of live species, organic material and seeds in for instance pet or garden stores, etc.).

7.4.5 Budgetary considerations

Financial constraints play a decisive role in IAS management, especially considering the extended time horizons involved in controlling IAS, influencing the selection of control methods. Factors affecting cost-efficiency include:

- **Scale and Density of Infestation**: Large-scale invasions require more intensive and costly interventions.
- **Labor and Equipment Costs**: Manual removal may be viable for small infestations, whereas mechanical, chemical, or biological control may be necessary for larger areas.
- **Long-Term Maintenance Needs**: Even after initial eradication efforts, ongoing monitoring and follow-up control may be required to prevent re-establishment.

Typically, a substantially large initial effort with corresponding high costs is required for the first one or two years to start the eradication of IAS, followed by a lower level of annual costs to maintain the area under control and conduct monitoring for a varying number of years.

7.5 Monitoring of pilot sites and sample plots

To enhance the effectiveness and credibility of Invasive Alien Species (IAS) eradication methods, it is essential to strengthen both the documentation of pilot sites and the monitoring of surrounding ecological conditions.

A more rigorous and standardized approach to site description will improve the consistency of data across sites and allow for more accurate attribution of ecological changes to eradication measures. Each pilot site should be characterized using a standardized template that captures precise geographic coordinates, elevation, area size, and habitat classification. Descriptions should also include land-use history, current management practices, and any known ecological disturbances or pressures. Mapping of microhabitats and environmental gradients, such as moisture levels, shading, or soil composition, should also be integrated to inform treatment strategies and future ecological interpretation.

Baseline data collection is critical and should include comprehensive inventories of both IAS and native species presence in pilot sites. For IAS, presence, abundance, and spatial distribution must be recorded in detail. For native species, emphasis should be placed on abundance estimates, with particular attention to those of conservation interest. Environmental parameters such as local climate, temperature, rainfall, and seasonal patterns should also be documented. If possible, remote sensing tools or automated weather stations should be employed to ensure continuity and accuracy of environmental data.

Ecological monitoring should not be limited to the core treatment area. Establishing buffer monitoring plots in the immediate vicinity of each site (e.g., 50–100 metres from the eradication zone) is recommended to assess potential reinvasion by IAS, track native species recolonization, and evaluate broader ecosystem responses. A multi-taxa monitoring framework should be adopted to capture a comprehensive picture of ecological recovery. This should include not only vegetation assessments but also monitoring of key faunal groups such as insects, birds, amphibians, and soil microbial communities. The use of biodiversity indices and functional indicators, such as pollinator abundance or evidence of natural regeneration, can help measure ecosystem functionality post-eradication.

Where possible, the utilisation of technological tools, including high-resolution satellite imagery, drone surveys, and vegetation indices such as Normalized Difference Vegetation Index (NDVI), should be leveraged to supplement field data and provide spatially explicit information on vegetation structure and habitat change over time. Monitoring should be planned with a long-term perspective, with data collected at regular intervals following intervention (e.g., 6 months, 1 year, and annually thereafter), to capture both short-term and delayed ecological responses. The use of technology would be especially recommended for monitoring Protected Areas and Natura 2000 sites, which are often less accessible due to terrain characteristics (e.g., wetlands, swamps, mountainous terrain, dense forests, etc.).

Finally, the current data management and reporting can be further strengthened through the establishment of a centralized monitoring database. This should facilitate the storage, comparison, and analysis of data across pilot sites, supporting evidence-based decision-making and adaptive management. Geotagged photographic records and GIS mapping should be routinely incorporated into monitoring protocols. Key information could be complemented through engagement with local stakeholders and the inclusion of citizen science approaches to support long-term monitoring efforts and enhance local stewardship of IAS management activities.

7.6 General Guiding Principles for Effective IAS Management

Managing IAS effectively requires a proactive, science-based approach that incorporates early detection, prevention, and long-term control strategies. While numerous management techniques exist, their effectiveness depends on species biology, site conditions, and socio-economic factors. A combination of **cross-border and international cooperation, regulatory frameworks, strategic planning, and community engagement** is essential for minimizing the ecological and economic impacts of IAS.

By implementing well-informed, adaptive management strategies and ensuring that control efforts are based on **rigorous scientific evidence**, conservation practitioners can significantly reduce the negative impacts of invasive species while safeguarding biodiversity and ecosystem resilience.

To mitigate the impact of IAS, a combination of proactive measures is essential, including:

- **Robust Policies and Regulations**: Strict biosecurity laws and enforcement mechanisms are crucial to prevent the introduction and spread of IAS.
- **Early Detection and Rapid Response**: Surveillance programs and immediate action plans can help contain new invasions before they become widespread.

- **Public Awareness and Education**: Engaging stakeholders, including landowners and managers, policymakers, and the general public, is critical for fostering responsible behaviours and ensuring compliance with regulations.

A substantial body of literature exists on the management and control of Invasive Alien Species (IAS), derived from extensive research and long-term field experience. Based on the insights from the literature review conducted, the following key principles can be outlined to guide effective IAS management strategies.

7.6.1 Prevention and early intervention

Preventing the introduction and spread of a new IAS is significantly more cost-effective than attempting to manage or eradicate an established population. Once an invasive species has firmly established itself in a new area, control measures often require extensive financial and logistical resources, making eradication difficult or, in some cases, impossible.

Given that IAS do not adhere to political boundaries, **cross-border international collaboration** is often necessary to ensure effective containment. Neighbouring countries should develop coordinated strategies, share surveillance data, and establish joint response plans to prevent transboundary spread. Focusing management interventions on selected IAS that are targeted jointly with neighbouring countries may increase both the local and regional effectiveness of containing and eradicating the IAS.

7.6.2 Long-term and adaptive management approaches

Successful IAS management typically requires a multi-year management approach, as eradication or population suppression often necessitates repeated interventions implying an extended time horizon of management and monitoring interventions. Continuous monitoring and adaptive management are essential to detect re-emergence and assess the effectiveness of control measures. Management plans should be designed with flexibility to allow adaptive responses based on observed outcomes.

7.6.3 Timing and seasonality of control efforts

Optimal timing of eradication interventions for invasive plant species: The effectiveness of control measures often depends on the season in which they are applied. For example, targeting invasive plant species before seed set prevents further propagation, while removing female individuals of animal IAS during their reproductive phase can significantly reduce future populations.

Targeting reproductive stages in invasive animal species: Seasonal timing is equally crucial in managing invasive animal species. Many IAS exhibit predictable breeding cycles, and interventions timed to disrupt these cycles can significantly enhance control effectiveness.

7.6.4 Control methods for invasive alien plant species

1. **Manual Removal for Small Infestations:** In cases where IAS infestations are limited in scale, manual removal (e.g., hand-pulling, cutting) can be an effective and cost-efficient strategy, particularly when native vegetation can quickly re-establish.
2. **Risk of Vegetative Regrowth:** Some IAS species, particularly those with robust rhizome or stoloniferous growth, may exhibit vigorous regrowth following cutting. In such cases, mechanical control alone may be insufficient, necessitating follow-up treatments.

3. **Mechanical Control Considerations:** Repeated cutting or mowing may be required to exhaust the plant's energy reserves. Additionally, for species that propagate vegetatively, complete removal of root material is necessary to prevent regrowth. While this approach is labour-intensive, it can be more effective and economically viable for smaller infested areas than large-scale mechanical operations.
4. **Use of Volunteers:** Community-based efforts, such as involving trained volunteers, can significantly reduce management costs while increasing public awareness. However, logistical aspects, including training, transport, and the provision of personal protective equipment (e.g., gloves, boots), must be considered to ensure safety and efficiency.
5. **Chemical Control for Large-Scale Infestations:** Herbicides can be effective in managing large-scale infestations of invasive plants. However, their use near water bodies or sensitive habitats must be carefully regulated to avoid unintended harm to native species and ecosystems. Additionally, national and regional regulations may impose restrictions on chemical use in certain areas.
6. **Biological Control Considerations:** The introduction of biological control agents (e.g., fungi, bacteria, insects) can help suppress IAS populations over time. However, biological control methods generally do not lead to complete eradication and may take years to yield noticeable results. Moreover, the introduction of biocontrol agents carries ecological risks, as these organisms may affect non-target species, necessitating rigorous risk assessment before deployment.
7. **Grazing as a Management Tool:** The use of livestock grazing to suppress invasive plant populations can be effective in localized, enclosed areas. However, its utility in broader landscapes is often limited. Grazing may reduce IAS biomass and prevent seed production, but it is unlikely to achieve full eradication.

7.6.5 Control methods for invasive alien animal species

1. **Seasonal Considerations:** As with plant species, the timing of interventions targeting invasive animal species is critical. Certain life cycle stages, such as moulting, breeding, or migration periods, present opportunities for effective population control.
2. **Behavioural Insights for Control Strategies:** Understanding the social behaviour of invasive animal species can enhance management effectiveness. Species that exhibit strong territoriality, social hierarchies, or seasonal congregation behaviours can be targeted with specific control measures.
3. **Chemical Control of Aquatic IAS:** The application of chemical treatments to control aquatic invasive species is often limited to non-flowing water bodies and is strictly regulated in many countries. Chemical treatments in aquatic environments require careful evaluation to minimize collateral damage to native aquatic flora and fauna.
4. **Potential Risks of Incentivized Hunting and Fishing:** Encouraging private hunters or fishers to control IAS populations through financial incentives (e.g., bounties) may have unintended consequences. There is a risk that individuals may engage in activities that sustain, rather than eliminate, IAS populations due to continued economic incentives. Long-term control efforts should be carefully designed to avoid counterproductive outcomes.
5. **Use of Natural Predators:** In some cases, introducing or encouraging native predator species may help regulate IAS populations. However, this approach must be applied with caution, as predator-prey dynamics can be complex, and unintended ecological consequences may arise.

7.6.6 Integrated and context-specific approaches

It should be considered that no single IAS management method is universally effective. The selection of control measures should be based on ecological assessments, species-specific characteristics, and site conditions.

Combining different approaches—such as manual removal, mechanical control, chemical treatments, and biological control—often yields the most effective and sustainable results. Integrated management principles can be applied to IAS control, ensuring that multiple strategies work synergistically. Most importantly, effective IAS management extends beyond short-term eradication efforts. It requires ongoing monitoring, adaptive management, and consideration of ecological restoration strategies to prevent reinvasion and promote the recovery of native ecosystems.

Annex 1: A Tool for CBA of Invasive Alien Species

A1.1 Developing a pragmatic tool for IAS CBA

Quantifying the impacts of Invasive Alien Species (IAS) in strict monetary terms is often infeasible due to the complexity, context-dependency, and lack of market values for many affected ecosystem services—particularly non-market services such as biodiversity, cultural heritage, and regulating functions like water purification or pollination. Additionally, the spatial and temporal variability of IAS impacts, as well as the difficulty in attributing changes to specific species or interventions, pose significant challenges to conduct comprehensive economic valuations, which would provide the required inputs to Cost-Benefit Analysis (CBA).

To address the challenge of economic valuation of ecosystem services in the context of managing the impact of Invasive Alien Species, it is proposed to apply a mixed approach based on available literature research and expert opinions. We develop a **semi-quantitative ordinal ranking system** that provides a pragmatic alternative that captures the relative magnitude of avoided damage across diverse benefit categories. This approach allows for consistent, transparent, and scalable assessments of IAS control measures and management outcomes, even when data are incomplete or non-monetizable, thereby supporting informed decision-making in both ecological and socio-economic domains.

For the purpose of the current study, a rating framework has been developed, based on recent research from Blaalid et al. (2021) and Magnussen et al. (2020), which is further complemented by the consultant team.

The IAS CBA Tool provides a structured and semi-quantitative framework for evaluating the **avoided damages resulting from the management of Invasive Alien Species (IAS)**. It enables practitioners, researchers, and decision-makers to assess the **benefits of IAS interventions** across a broad range of **ecosystem services** and **socioeconomic sectors**, including ecological, economic, cultural, and human well-being dimensions.

The tool is designed to complement the current field research and testing of IAS eradication measures. Moreover, its purpose is to:

- **Support evidence-based decision-making** by enabling transparent comparisons of IAS management benefits across sectors.
- **Facilitate cross-disciplinary communication** between ecologists, economists, policymakers, and land managers.
- **Enable prioritization of resources** by identifying areas where IAS management yields the greatest return in terms of avoided damage.
- Serve as an input for **cost-benefit analysis, multi-criteria assessments, restoration planning**, and **performance evaluations** of conservation programs.

Importantly, the framework accommodates both **retrospective assessment** (based on observed outcomes) and **prospective scenario planning** (based on projected impacts), allowing for flexible application across **invasive species risk assessment, management planning, and policy evaluation**.

By "rating" the impact of IAS on ecosystem services and other "human" impact categories (human health, human infrastructure), and by communicating the benefits of IAS management, this tool enhances strategic planning and supports the justification of investments in **prevention, early detection, rapid response, and long-term control measures**.

A1.2 Benefit / Impact Categories for Ecosystem Services and Human Wellbeing

The framework is organized by major **benefit / impact categories**, aligned with the Common International Classification of Ecosystem Services (CICES), including:

Benefit / Impact Category		Description
Ecosystem Services	**Supporting:** ecological impact (non-use value)	This category refers to the foundational ecological processes and biodiversity elements that do not directly yield goods or services but are essential for functioning and sustaining ecosystems. It captures nutrient cycling, soil formation, habitat provision, primary production, impacts on species diversity, ecological interactions, evolutionary potential, and natural system resilience (Millennium Ecosystem Assessment, 2005; Pejchar and Mooney, 2009). These values are typically non-use in nature—people may value the existence of intact ecosystems or rare species even if they never directly interact with them. Invasive species can disrupt food webs, outcompete native species, predation, hybridization, or degrade habitat structure—leading to cascading effects that undermine long-term ecosystem integrity (Vilà et al., 2011).
	Supporting: ecological impact on endangered ecosystems (non-market / non-use value)	This subcategory emphasizes the status and stability of ecosystems classified as vulnerable, endangered, or critically endangered (e.g., wetlands, island habitats, native grasslands). The focus is on conservation value and ecosystem uniqueness, often in the absence of direct market transactions (TEEB, 2010). IAS pose acute risks in these systems, where even minor disruptions can tip fragile ecosystems into irreversible decline (Nentwig et al., 2018). Protecting these areas from IAS invasions contributes to biodiversity conservation and global ecological heritage.
	Regulating: water regulation, pollination, erosion (non-market / non-use value)	Regulating services maintain environmental conditions conducive to life and productivity. In this context, the focus is on hydrological regulation and water catchment (e.g., runoff moderation, groundwater recharge), pollination by native fauna, and flood protection and erosion control through stable vegetation cover. IAS can severely impair these functions by displacing native pollinators, altering water cycles, increasing sedimentation, or destabilizing soils (Millennium Ecosystem Assessment, 2005; Vilà et al., 2011). Though not typically bought or sold, ecosystem regulating services are critical to both ecosystems and economies, and their preservation represents a major avoided cost. By mitigating the impacts from IAS, effective IAS control helps sustain ecosystem functionality and reduces risk to human and ecological systems.
	Provisioning: food production (market / use value)	This category encompasses the direct production of consumable goods derived from ecosystems, including crops, livestock, fisheries, and forage resources. It represents tangible, market-valued outputs critical for food security, rural livelihoods, and economic activity. Examples include food, crops, livestock, fisheries. IAS may reduce yield, outcompete economically important plant species, contaminate water supply or edible products, poison livestock, or render agricultural lands unsuitable (Pejchar and Mooney, 2009; Kumschick et al., 2015). Avoiding such impacts through effective IAS management supports national food systems and market stability.
	Provisioning: non-food production (market / use value)	This includes the generation of raw materials and bioresources not used for food, such as timber, fiber, medicinal plants, biofuels, and ornamental goods. These services have direct market value and support industrial supply chains. IAS may interfere by reducing growth rates, changing forest composition, degrading rangelands, or increasing management costs (Roy et al., 2022). Preventing these disruptions is essential for preserving the economic viability of ecosystem-based industries.
	Cultural: recreation, aesthetic beauty, natural heritage (non-market / use value)	Cultural services encompass the physical, emotional, and symbolic interactions between people and nature. This includes recreation (hiking, boating), landscape appreciation, spiritual values, and connections to cultural identity and natural heritage. IAS can visually degrade landscapes, displace culturally important species, restrict access, or diminish the sense of place (TEEB, 2010; Pejchar and Mooney, 2009). In culturally significant or protected landscapes, even small changes can have outsized social and psychological impacts. IAS management helps preserve this intangible but deeply valued connection to nature. Management that avoids these disruptions helps preserve community well-being, tourism revenue, and the societal value of natural environments.

Benefit / Impact Category		Description
Other	**Human Health** (market / non-market)	IAS can directly or indirectly impact human health through toxic effects, allergens, physical harm, or by acting as vectors for zoonotic diseases (Roy et al., 2022; Pejchar and Mooney, 2009). Examples include invasive plants that cause dermatitis or respiratory issues, or invasive mosquito species that spread diseases. In addition, psychological distress can result from landscape degradation or biodiversity loss. These impacts may generate both direct healthcare costs and broader societal burdens. Some IAS pose serious health risks, including toxicity, increased disease exposure, or reduced access to clean water and air. Management actions that prevent or remove these risks can have significant public health benefits, particularly in vulnerable communities. IAS management can thus yield critical health co-benefits, reducing both market and non-market risks to human populations.
	Infrastructure (market / use value)	This category addresses physical damage or disruption to human-built structures and systems, including roads, buildings, water management and protection infrastructure, irrigation networks, power lines, and transport routes. IAS can cause damage through overgrowth (e.g., blocking signage or rail lines), root intrusion, burrowing, biomass accumulation, or increased fire risk. These effects often translate into real economic losses through repair, maintenance, and productivity disruptions (Nentwig et al., 2018; Kumschick et al., 2015). Avoiding such impacts can significantly reduce long-term infrastructure costs and support uninterrupted service delivery.

Each category is assessed on a **5-point ordinal scale (0 to 4)**, reflecting the **severity of potential or actual damage** that would have occurred as a result of the invasive species, **<u>in the absence of IAS management</u>**, thereby emphasizing the **magnitude of benefits derived from prevention, control, or eradication efforts**. Rating descriptions are tailored to reflect real-world outcomes and impacts observed or expected in specific IAS contexts.

Rating Scale Explanation:

- **0 – None:** No measurable or anticipated **damage** in the absence of IAS management.
- **1 – Low:** Minor or localized impacts with limited ecological or economic relevance.
- **2 – Moderate:** Clearly detectable damage with moderate spatial or systemic significance.
- **3 – High:** Severe damage affecting core ecosystem functions or critical services.
- **4 – Very High:** Catastrophic or irreversible damage to ecosystems, economies, or public health.

Each rating level is further contextualized through **qualitative descriptors** (*see table framework in the next page overleaf*) that capture the specific types of disruption or degradation relevant to the category in question. For example, provisioning services consider reductions in crop yield or livestock mortality, while cultural services account for loss of recreational access or heritage value.

A1.3 Framework for Assessing Avoided Impacts of IAS on Ecosystem Services and Human Well-being

Framework for Assessing Avoided Impacts of IAS on Ecosystem Services and Human Well-Being							
	Benefit / Impact Category	**Rating - 0**	**Rating - 1**	**Rating - 2**	**Rating - 3**	**Rating - 4**	**Literature / Source**
Ecosystem Services	**Supporting:** ecological impact (non-use value)	**No known ecological impact.** Ecosystem processes and biodiversity unaffected.	**Low ecological impact.** Minor disruption to native species or functions.	**Potential high ecological impact.** IAS presence may disrupt ecosystem functioning or species interactions.	**High ecological impact.** IAS significantly alters native species composition or ecosystem functioning.	**Severe ecological impact.** Major, possibly irreversible damage to ecosystem integrity or biodiversity.	
	Supporting: ecological impact on endangered ecosystems (non-market / non-use value)	**Ecosystem intact.** No threat to conservation status.	**Near threatened.** Early warning signs of degradation.	**Vulnerable.** Ecosystem shows significant decline in resilience or species composition.	**Endangered.** Severe degradation or loss of key components; conservation urgent.	**Critical.** Collapse imminent or ongoing; irreversible loss likely without intervention.	
	Regulating: water regulation, pollination, erosion (non-market / non-use value)	**No impact on regulatory functions.** Hydrology, pollination, and erosion control remain intact.	**Slight disruptions.** Limited or localized interference with natural regulation (e.g., minor erosion).	**Noticeable effects.** Reduced effectiveness of natural systems (e.g., pollination decline, altered water flow).	**Major disruptions.** Strong degradation of regulatory services impacting broader ecosystem or economy.	**Critical loss.** Regulatory services collapse, leading to systemic risk (e.g., flood risk, crop failure).	
	Provisioning: food production (market / use value)	**No effects on agricultural production.**	**Small effects.** Minor reduction in crop or livestock productivity.	**Moderate effects.** Large reduction in area/productivity or grazing capacity.	**High effects.** Major losses due to toxicity or large-scale reduction in usable land.	**Very high effects.** Near-total loss of production capacity or high livestock mortality.	
	Provisioning: non-food production (market / use value)	**No known impact** on resources such as timber, fiber, or biofuel.	**Minor effects.** Slight reduction in non-food yield or quality.	**Moderate effects.** Notable reduction in yield, harvest delays, or increased costs.	**High effects.** Severe impact on production, access, or quality of goods.	**Very high effects.** Collapse of resource availability or market viability due to IAS.	

Framework for Assessing Avoided Impacts of IAS on Ecosystem Services and Human Well-Being							
	Benefit / Impact Category	Rating - 0	Rating - 1	Rating - 2	Rating - 3	Rating - 4	Literature / Source
	Cultural: recreation, aesthetic beauty, natural heritage (non-market / use value)	**No effect on visual or recreational values.**	**Minor aesthetic change.** IAS are small, low visibility, no activity restriction.	**Aesthetic disturbance noticeable** but recreational use remains largely unaffected.	**Disturbance restricts access or use** in certain areas; visible and spreading presence.	**Severe degradation.** Major aesthetic loss, widespread restriction of recreational activities or cultural heritage.	
Other	**Human Health** (market / non-market)	**No effects.** IAS pose no health concern.	**Mild discomfort or indirect health effects** (e.g., allergens, minor skin irritation).	**Harmful.** IAS are poisonous/toxic, requiring precautionary health measures.	**Severe health risks.** Life-threatening to vulnerable populations or requiring medical treatment.	**Deadly to humans.** Exposure can result in fatalities or major public health emergencies.	
	Infrastructure (market / use value)	**No damage to infrastructure.**	**Indirect effects.** Slight visibility issues or minor nuisance near roads/buildings.	**Moderate damage.** IAS cause localized maintenance issues or interfere with infrastructure function.	**Major damage.** IAS impact road safety, utility functioning, or building integrity.	**Severe structural damage.** Widespread, costly harm to buildings, roads, or critical infrastructure.	

Source: Adapted from Magnussen et al. (2019) and further complemented by the consultant.

Annex 2: Documentation and Bibliography

A2.1 Project documentation and reports

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