MARIE PATINET • ÉTIENNE BRANQUART • ARNAUD MONTY

INVASIVE ALIEN AQUATIC AND RIPARIAN PLANT SPECIES

BEST MANAGEMENT PRACTICE GUIDE

RIPARIAS

Reaching Integrated and Prompt Action in Response to Invasive Alien Species

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Table of contents

INTRODUCTION

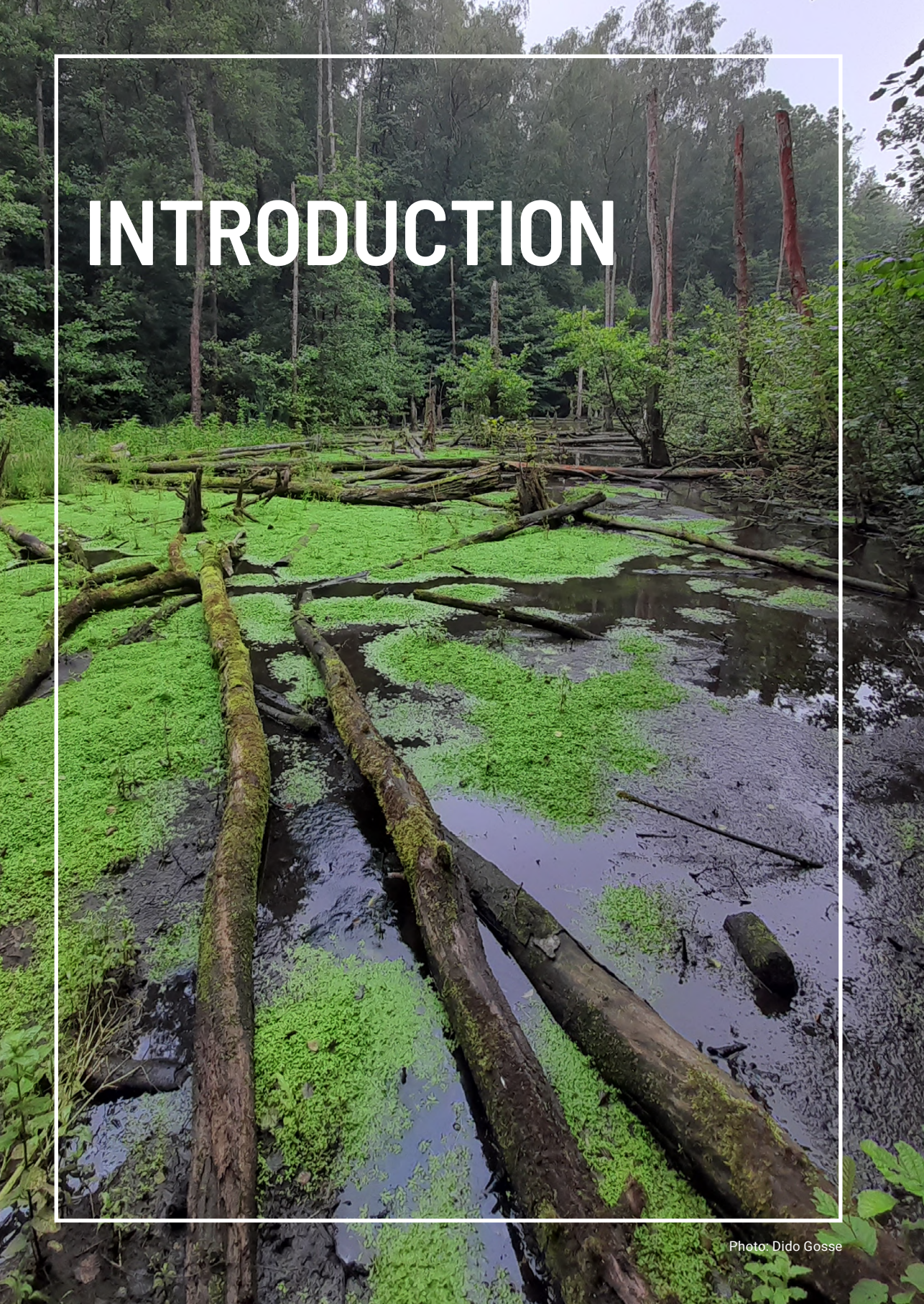


Photo: Dido Gosse

Invasive Alien Species (IAS) are species that are accidentally or intentionally introduced outside their natural range and have the ability to rapidly spread in the environment, causing significant damages. In Europe, while biological invasions represent a growing threat to ecosystems and biodiversity, adverse impacts on human well-being and the economy have also become major sources of concern.

The management of invasive alien plant species is a complex and challenging task. Indeed, most invasive plant species share some successful biological characteristics that make them particularly complicated to control and eradicate. Some of the most important aspects include their high reproductive, competitive and dispersal capacities, which notably allow for rapid range expansion. Invasive alien plant species can naturally spread via animals, wind and water as well as through human endeavours like gardening, green waste disposal or recreational activities. While often lacking natural enemies in the invaded ecosystem, invasive plants also usually display a high tolerance to diverse environmental conditions as well as a high resistance to disturbances. These characteritics contribute to their resilience in the face of management actions aimed at controlling or eradicating their populations. Further technical constraints regarding management itself can increase the complexity of their management.

This guide was developed as a tool for practitioners, and more specifically for field managers involved in invasive plant species management. It is the result of a thorough literature review and exchanges with experts. Several methods for controlling or eradicating invasive aquatic or riparian plant species*, at local scale, are presented. The methods selected for this guide are described as "best management practices" (BMP). Those practices have shown an acceptable level of effectiveness while being ethically and legally acceptable. The use of herbicides or any chemical treatment, for instance, is not considered as such. Given the diversity of biological and ecological characteristics among the different plant species included in this guide, the BMP are, therefore, species-specific. Those practices were experimented by field researchers and experts involved in IAS management worldwide. The information contained in this guide is based on the general knowledge of IAS management available at the time of writing. It is important to note that due to the rapid evolution of scientific knowledge, cross-referencing this publication with up-to-date documents is recommended.Although defined as best practices, the success of those techniques cannot be fully guaranteed.

* Species targeted by the LIFE RIPARIAS project and the LIFE RIPARIAS alert list (see sections below).

For each species, the ordder of presentation of BMP is based on their nature. Practices involving the removal of the plant from the ecosystem are presented first, followed by the modifications of environmental conditions. The introduction of organisms for *in situ* plant regulation is finally presented, if applicable. In each of these 3 categories, BMP are listed according to the severity of impact on the ecosystem, ranging from the least intrusive to the most impacting.

Case studies have been included in this guide in order to provide users with concrete examples of management actions that took place in the field in Belgium. These instances illustrate both success stories and failed management actions. They should therefore not be used as models for future measures but rather serve as accurate representations of real-life situations from which lessons must be learned.

In-text references have purposely been excluded to improve readability. Key resources are, however, listed after each BMP for further information. A glossary is available at the end of the guide.

The LIFE RIPARIAS project

Responses to address the issue of biological invasion have often been insufficient, and actions taken so far have had varying and sometimes limited results. The diversity of actors involved in IAS management along with the fragmented nature of available IAS data sources impede the implementation of concerted and coherent management.

Moreover, the number of IAS and associated costs are constantly increasing. It has therefore become essential to take efficient and coordinated decisions to determine which species and sites should be considered as a priority for management actions.

To address these challenges, Belgian authorities and their partners have joined forces through the LIFE RIPARIAS project, which aims at optimising the management of IAS in aquatic and riparian environments across regional borders. To do so, a scientific evidence-based workflow which supports decision-making processes on IAS management has been developed.

The project targets riparian and aquatic plant species that are listed as IAS of Union concern under the (EU) Regulation No 1143/2014. Other species, included in an alert list, are also targeted for rapid eradication after early detection in the natural environment.

The LIFE RIPARIAS project is developing and testing its innovative approach in the Dyle, Senne and Marcq river basins in the Scheldt river basin district. This pilot area covers 263,103,000 ha across the three regions of Belgium (the Walloon Region, the Flemish Region and the Brussels-Capital Region). This project is co-funded by the European Union as part of the LIFE Programme.

Species of EU concern

IAS listed as "species of Union concern" are species representing a major threat to biodiversity and ecosystems. Since 2015, a European Regulation on invasive alien species (No 1143/2014) compels Member States to take measures to address the issue of biological invasion. This Regulation was established with the aim to curb the phenomenon on a continental scale.

The Regulation aims to prevent the introduction and establishment of listed species, while minimising and mitigating the adverse effects associated with their spread. The Union list entered into force in July 2016 and was updated several times. It now counts a total of 88 species. More than 50% of them thrives in freshwater and riparian habitats. Listed species are subject to regulation which include restrictions on introducing, keeping, breeding, growing, transporting, selling, exchanging, using and releasing into the environment.

Species of the LIFE RIPARIAS alert list

Alert lists can be defined as lists of alien species that are not yet present in a certain area, or with a very limited distribution, and that pose a threat to biodiversity.

Active surveillance and monitoring are recommended for a prompt response in the event of introductions and spread in the wild.

An alert list of freshwater aquatic and riparian plant species was established for the LIFE RIPARIAS territory. This list was developed using information such as species availability on the Belgian market, the risk of establishment, spread and impact on biodiversity (assessment made via the Harmonia+ risk scoring system).

The alert list includes 9 plant species native to various regions of the world.

CHAPTER I - Prevention measures

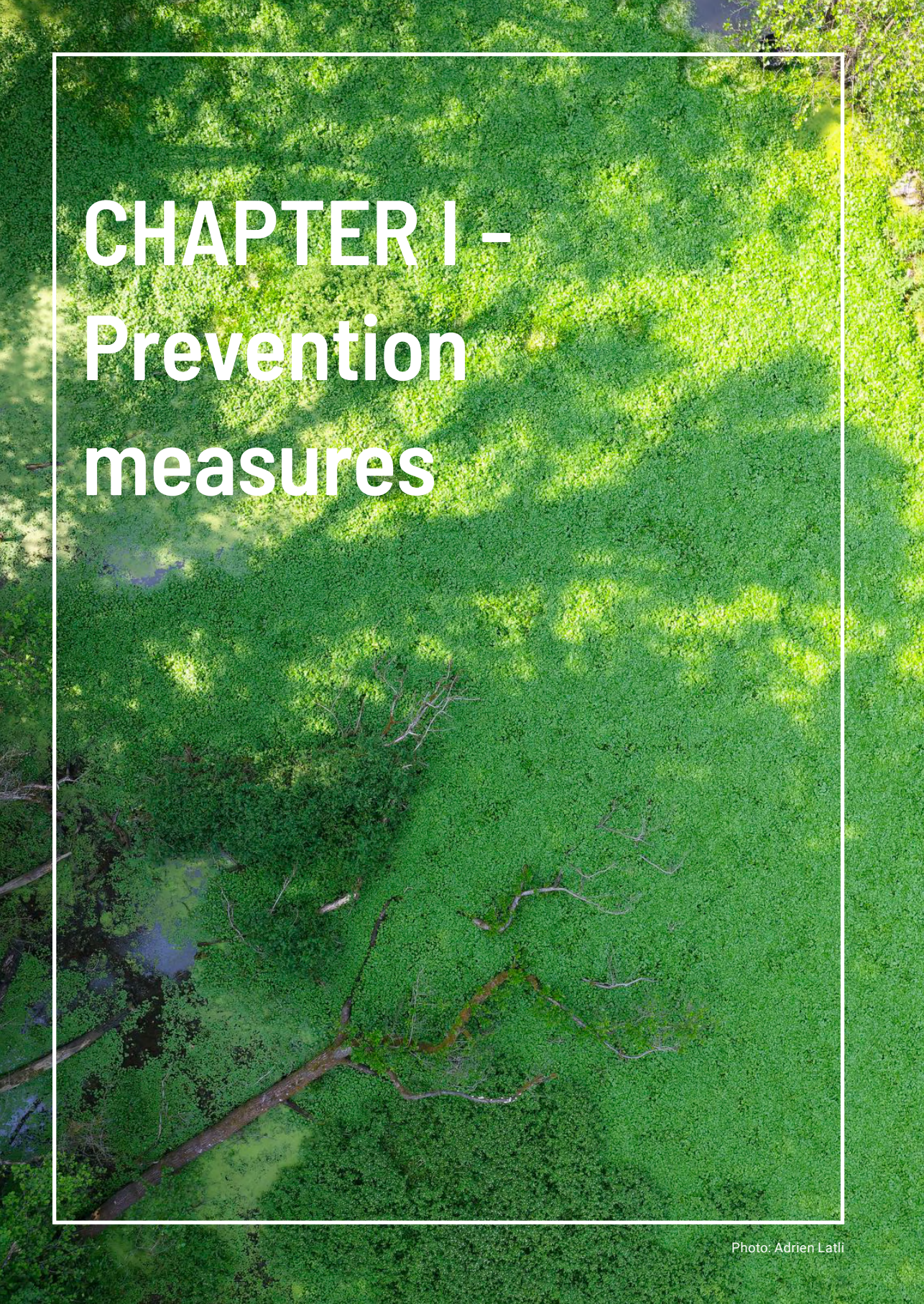


Photo: Adrien Latli

Prevention is the most effective and economical approach to limit the spread of IAS, especially those that are highly challenging to control once established. This prevention involves various good practices:

Banning the use of IAS and promoting indigenous species

Many IAS have ornamental values that are sought after by some gardeners and landscapers. Aquatic plants, on the other hand, have been used for their oxygenating properties in ponds or aquariums. As a result, most IAS have intentionally been introduced in gardens, parks, ponds or directly into the wild by dumping plant material in the natural environment. Nowadays, many non-native plants are still being sold, often without any information provided to buyers about the risks. Some of these are well known IAS, which are already causing problems on the territory. Others are still rarely observed in the wild, but their invasive nature has already been pointed out by the scientific community; some of which were included in the LIFE RIPARIAS alert list.

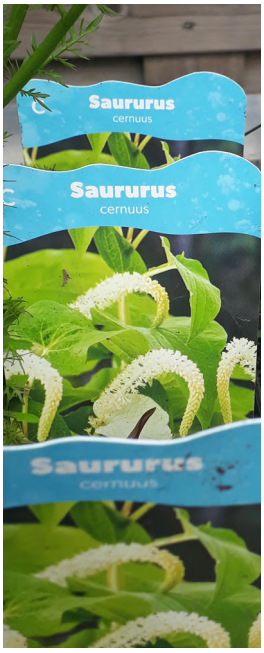


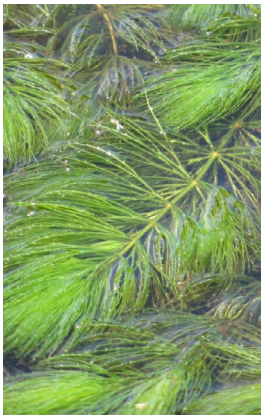
Fig 1. Many exotic plant species such as *Saururus cernuus* are already known for their invasive tendencies but are still being legally sold and available through the plant trade.
Photo: Arnaud Monty

Fortunately, some species are subject to a ban on trade, transport and therefore, introduction into the territory. These are the IAS "of Union concern", under the (EU) Regulation No 1143/2014. If the sale or transport of these species is observed, the competent authorities* must be alerted.

As it is not always possible to anticipate the invasiveness of an exotic species, it is also recommended to ban, on a voluntary basis, the use of non-native species. The use of native species in ponds and gardens should, therefore, be promoted.

There are possible alternatives for some invasive alien aquatic and riparian plant species that are frequently introduced in garden and ponds. For instance, popular non-native oxygenating plants such as *Myriophyllum* spp. and *Elodea* spp. can be replaced by native plant species also known for their oxygenating properties (Fig 2).

* In Belgium, the competent authorities depend on the regions. The Département de la Nature et des Forêts (DNF) is the authority to refer to for the Walloon Region; Brussels Environment (BE) for the Brussels-Capital Region and Agentschap Natuur & Bos (ANB) for the Flemish Region

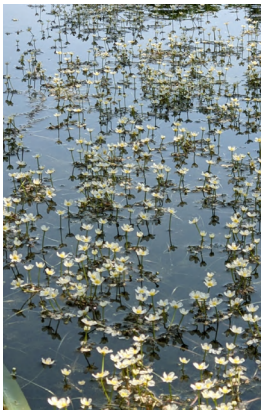


A

B

C

Fig 2. Examples of indigenous plant species known for their oxygenating properties
A. Hornwort (*Ceratophyllum demersum*)
B. Shining pondweed (*Potamogeton lucens*)
C. Eurasian watermilfoil (*Myriophyllum spicatum*)



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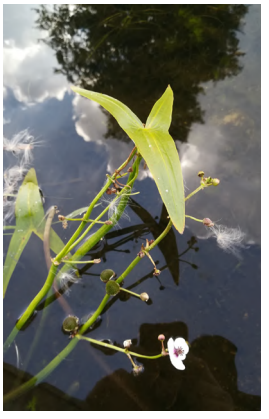
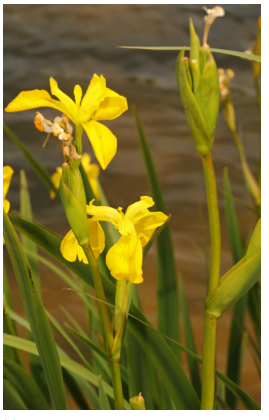


E

F

Fig 3. Examples of indigenous ornamental plant species for garden ponds
D. Common water-crowfoot (*Ranunculus aquatilis*)
E. Arrowhead (*Sagittaria sagittifolia*)
F. Marsh marigold (*Caltha palustris*)

G



H

I

Fig 4. Examples of indigenous riparian plant species with aesthetic value
G. Queen-of-the-meadow (*Filipendula ulmaria*)
H. Yellow iris (*Iris pseudacorus*)
I. Purple loosestrife (*Lythrum salicaria*)

Amphibious non-native species such as the floating pennywort (*Hydrocotyle ranunculoides*) and primrose species (*Ludwigia grandiflora* and *L. peploides*) were notably introduced as popular ornamental plants for garden ponds. Common water-crowfoot (*Ranunculus aquatilis*), Arrowhead (*Sagittaria sagittifolia*) and Marsh marigold (*Caltha palustris*) are all examples of possible indigenous alternatives to favour (Fig 3). Ornamental semi-aquatic plants like the Himalayan balsam (*Impatiens glandulifera*) can be replaced by other riparian plants with aesthetic values as presented in (Fig 4).

Preventing the spread of IAS through illegal disposal

While the use of native species should be encouraged, many non-native species still proliferate in gardens and ponds. Over the seasons, plant biomass can be removed during gardening activities. It is absolutely crucial that green waste generated is not disposed of in the environment due to the risk of creating new invasion hotspots. The same applies to aquarium plants: if they are to be eliminated, they must not be released in any aquatic environments. Composting away from water systems can be considered for aquatic species.

Preventing the spread of IAS from invaded areas

In some invaded areas, it may be decided not to intervene to reduce some IAS populations. Reasons* may include a lack of resources, difficulty of access, low biological interest of the site or limited risk of dispersal. Even if there are no planned management actions (at least in the short term), containment measures must be considered and implemented, in particular for IAS of the Union concern list. For example, it may be appropriate to prohibit activities known to spread IAS such as boating and fishing in these core areas. Fencing and information boards can be used to discourage plant picking in unmanaged invaded sites.

On the other hand, when management measures are being considered, it is also important to avoid further spread of the managed IAS caused by the measures in place. Indeed, implementing management actions in an invaded area constitutes a non-negligible risk of unintentionally spreading IAS via seeds or plant fragments. It is absolutely essential to minimise this risk, otherwise control efforts may result in further spread of the species.

It is strongly recommended to use an expert to supervise the managed area. This expert will inform the different stakeholders about the specificities of the species to be controlled (e.g., does the species spread by seeds? Can small stem fragments form a new invasion?), but also about the conservation issues of the site (are protected or threatened species present? Will they be impacted by the measures? etc.).

The risk of dispersal will vary with the species and the control method chosen, but often containment measures will be required around the treated area. This is typically the case in aquatic environments, where physical barriers will need to be installed at the start of the work to prevent the spread of plant fragments. In a pond, typically, a fine-mesh wire will be installed at the outlets. It should be cleaned regularly and must remain in place for several days after the work is completed. In the case of large treated areas, large bodies of water or rivers, it is also advisable to surround the area (or at least the downstream part of the area) with physical barriers such as curtains of floating nets or bubble curtains. The choice of material will be based on the effectiveness in retaining plant fragments, the technical possibilities and the costs. Regular visits of the managed area are important to remove any remaining visible fragments.

* For IAS of Union concern, Member States can obtain possible derogations from the obligation to implement eradication measures if one of the 3 following conditions are met:

°eradication is demonstrated to be technically unfeasible because the eradication methods available cannot be applied in the environment where the invasive alien species is established;

°a cost-benefit analysis demonstrates on the basis of the available data with reasonable certainty that the costs will, in the long term, be exceptionally high and disproportionate to the benefits of eradication;

°eradication methods are not available or are available but have very serious adverse impact on human health, the environment or other species.

Fig 5. Examples of physical barriers installed before the start of management actions. Photo : Emmanuel Delbart

Whenever material is moved from the managed area, the 'check, clean, dry' principle should be applied to prevent the spread of IAS to uninvaded areas. Equipment, machinery, footwear and clothing should be inspected for mud, plant fragments and seeds (or any other organisms that must be prevented from spreading), cleaned with clean water and dried.

Fig 6. Precautionary measures are being applied after a field visit to prevent the spread of *Crassula helmsii.* Photo: Marie Patinet

Many control methods involve the removal of large quantities of plant material from the environment. This biomass will require special attention to ensure that it is destroyed and does not become the source of a new infestation. If it is left on site, care should be taken to ensure that it does not take root again. For aquatic species, it must be ensured that no fragments can develop, especially during heavy rainfall. If the biomass is transported to disposal facilities (composting, incineration, etc.), adequate sheeting over the vehicles should prevent any loss of fragments or seeds during transport. In all cases, knowledge of the ecology of the species being managed is essential in deciding what will happen to the biomass removed. Most species reported in this guide can be transported to disposal facilities. It is however not recommended during seed set.

Fig 7. Example of inadequate biomass disposal. The plant material of Hydrocotyle ranunculoides, manually removed, was placed in an area that was too wet, allowing the plant to recover the following year. Photo : Emmanuel Delbart.

Finally, it is important to keep in mind that management actions can be highly damaging and significantly impact ecosystems for many years. Weakened ecosystems, already providing fewer services, become therefore more vulnerable to new invasions. Therefore, great care should be taken to minimise disturbance to the soil and vegetation during those actions. Wherever possible, ecological restoration of the environment should be considered. Again, expert advice will be required to assess the need to re-establish adequate native species in the disturbed area.

Raising awareness of good practices amongst stakeholders

Although the phenomenon of biological invasions has been known for decades, there is still a lack of understanding of the problem among many field managers. It is therefore necessary to continue to raise their awareness and train them on good practices. Indeed, everyone can act, at their own level, against the expansion of IAS.

Citizens are encouraged to provide information on IAS populations they observe in the field. It is through good surveillance of the territory that managers can intervene early in the management of a population. The earlier the intervention, the greater the chances of success: this is the principle of early warning and rapid response. User-friendly websites and smartphone applications are available to report species occurrence. Ideally, the geographical location, population size and a photograph should be provided for validation purposes, and the data generated should be open, i.e., accessible to all.

Private owners of invaded lands can also approach competent authorities to help them undertake adequate management actions. Authorising access to their property as part of IAS management programs makes it possible to intervene effectively at the river basin-scale and prevent potential re-invasion to occur.

iNaturalist and Observations.be are examples of applications used by citizens to record information on invasive alien species observed in the field.

Photo: Etienne Branquart

CHAPTER II - Control and eradication: General principles

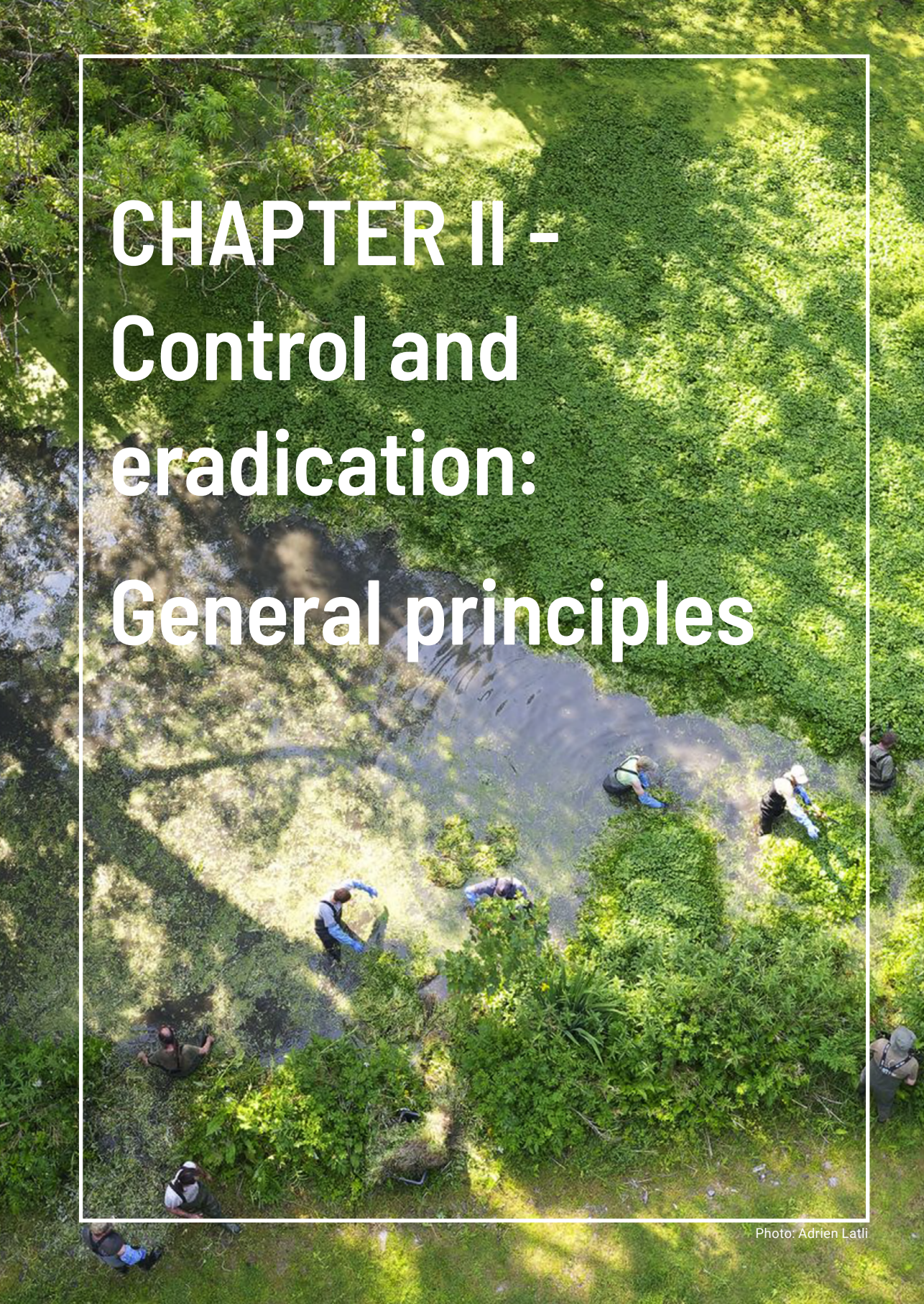


Photo: Adrien Latli

Although prevention is an important aspect of IAS management, it is not sufficient to limit the impact of IAS: control and eradication measures are also necessary. In the following sections, different methods are presented to hinder the spread of the species targeted by the LIFE RIPARIAS project. These methods are to be considered at the scale of an invaded area. A distinction is made between local eradication (total and permanent elimination of the species from the area) and local control (significant population reduction, in the medium term, of the invaded site).

Local eradication is, of course, preferable over local control, but is not always achievable. Control is usually considered in heavily invaded areas. It leads to the reduction of IAS local abundance, the reduction of damage they cause and enables the (re)development of a diverse indigenous flora. If control actions are properly carried out over several years, eradication may become a new achievable goal.

Before implementing management measures in a given area, whether aimed at eradication or control, it is recommended to follow some general principles

Integrating efforts in a global strategy

The fight against IAS requires significant financial and human investments. It is therefore likely that not all species will be managed, in all invaded areas at the scale of the river basin, province, region or country. Priorities for action should therefore be determined, depending on the general strategy adopted for each species at national, interregional and/or regional level, the localisation of an area and the chances of success.

The implementation of management actions in a specific site must be consistent with the priorities for action at the regional, interregional and/or national level. Otherwise, the resources invested may not have the desired effect. For example, managing an aquatic invasive plant population in a given site without tackling the upstream populations is likely to fail due to the re-invasion risk from flood-borne propagules. Additionally, the use of resources would not be optimised if priority was given to the management of prevalent IAS:

In general, priority should be given to species:

- Which are emerging and for which eradication on a regional, interregional or national scale is still achievable
- Which are subject to legal management obligations
- For which realistic local eradication methods exist

And, for a specific species, priority must be given to sites:

- Which have a particular ecological interest and/or protection status
- Where populations are likely to disperse massively
- Which are not expected to be re-invaded rapidly
- Where local eradication, or at least a good level of control, is technically feasible based on site specificities (type of banks, size, access, etc.)
- Which have good ecological restoration potential

Management strategies

Invasion situations, on a national, interregional or regional scale, vary greatly between the different invasive plant species. Therefore, management objectives will diverge depending on the targeted species. National management strategies include the following possibilities:

- **Complete eradication** from the territory: all populations are known and eradicated, so that the species is no longer present in the territory. This strategy may seem ideal, but can only be considered at the start of an invasion process. It requires a good knowledge of the invaded sites.

- **Containment in "core areas"**: one or several areas are too heavily invaded to aim for a total eradication of the territory. However, eradication is still reachable outside these areas. Management measures can be taken in heavily invaded areas to control populations and limit the dispersal of individuals.

- **Maintenance of "pest free areas"**: the species is widespread on the territory, but some areas are subject to special management efforts, with the goal to eradicate the species or prevent its establishment. These areas can, for instance, include sites with high conservation value.

- **Mitigation of impacts**: the species is widespread and abundant on the territory, but efforts are maintained over the long term to reduce populations densities and, thus reduce associated adverse impacts.

Moreover, strategies at interregional level will be developed in the framework of the LIFE RIPARIAS project between 2023 and 2031. The project will set priorities for the management of several invasive alien species found in the river basins of the Dyle, Senne and Marcq, in collaboration with stakeholders.

Knowing the plant and the invasion situation

Before any intervention, it is necessary to clearly demarcate and assess the invaded area. A thorough field survey should be carried out to provide accurate mapping of the invaded areas. Elements that may complicate management actions, such as difficulties of access, difficult control of the water level, the instability of the banks, severe siltation of water bodies etc., should be listed. The inventory is also an opportunity to ensure that there are no other IAS that could potentially spread.

Furthermore, it is essential to have a good knowledge of the biology of the plant to be managed. Its reproduction and dispersal means must particularly be well understood. Some plants are capable of vegetative reproduction (from stem fragments or underground organs), others reproduce by seed, or even combine both modes of reproduction. *Ludwigia* spp., for example, have a strong capacity to reproduce and disperse through vegetative reproduction. Great care must therefore be taken not to spread stem fragments. In some areas, those species can also display significant seed production, which can be observed in the field during fruit development. In such a situation, the seed bank is an important element to consider for their management as new seedlings could germinate even after the elimination of the whole population.

Planning, supervising and documenting the different management steps

An IAS management project cannot be improvised. The first step is to ensure the overall feasibility of the project, by identifying possible sources of funding, the required budgets and the people available. If the necessary resources are not available to ensure the management in the long-term (e.g. follow-up methods, surveillance), the chances of success decrease drastically. It might therefore be advised not to start any management measures, if the probability of having the necessary resources is low.

Prior to the implementation of management actions, it is recommended to plan the interventions over time and to clearly identify responsible people for the different aspects. A project manager, in charge of supervising the work and reaching the goals, should be the main contact for the various stakeholders. If the project manager does not have all the necessary knowledge about the targeted species, the site or the ecological issues, they may be supported and guided by a scientific expert. Similarly, they may also need the support of technical experts for the use of machines. Clearly identifying a responsible staff member for cleaning the equipment when entering and leaving the site is essential to avoid accidental spread of an IAS. Any potential subcontractors, groups of volunteers, or other stakeholders must also be identified beforehand.

Depending on the situation, many stakeholders (civil servants, private companies, associations, scientists, volunteers, etc.) may be involved in management measures. It is extremely important that anyone working in the managed area is aware of the issues and challenges and respects the biosecurity rules. It must also be ensured that all individuals involved fulfill the role they have been assigned to and respect the technical requirements. All this is only possible if the site is supervised by the project manager on a daily basis. It will also be necessary to ensure the safety of both operators and the public as well as to restrict public access to the managed area whenever possible and relevant. It may be advised to inform local residents of the ongoing work.

Finally, it is important to properly document the actions being carried out, to inform and obtain the necessary authorisations from the competent authorities and any required permits. Ensuring information records is the responsibility of the project manager.

Adapting management actions to site specificities

The methods presented in this guide are based on scientific literature, technical publications and feedback from practitioners. Nevertheless, invasion situations can vary greatly, and each area has its own specificities and constraints. It was not possible to deal with all these particular cases in this publication. It may therefore be necessary to show adaptability, even creativity, in the practical execution of the work, while keeping in mind the biology of the targeted species. The choice of machinery (e.g., excavator, floating machines), materials (e.g., types of tarpaulin or geotextile) or equipment (e.g., containment nets, boat, diving equipment) should be made considering material availability, cost and acceptability by all stakeholders.

Finally, the methods presented in this guide can be used on their own, but it may be appropriate to combine them for the whole managed area or only in different parts of the site to be managed.

Monitoring the managed area and its surroundings during several years after management actions

Once the management objective is achieved, the treated area should be monitored annually to ensure that no regrowth or re-invasion occurs from neighbouring areas or through unintentional and intentional disposal of plant material. This is particularly important in the case of local eradication. If a new hotspot is detected, all plants observed must be removed.

Furthermore, even if containment measures have been put in place, it is recommended to explore areas surrounding the treated site where the species could establish, to ensure that no new infestation occurs. Once again, if a new hotspot is detected, all plants observed must be removed.

CHAPTER III – Control and eradication

Best management practices

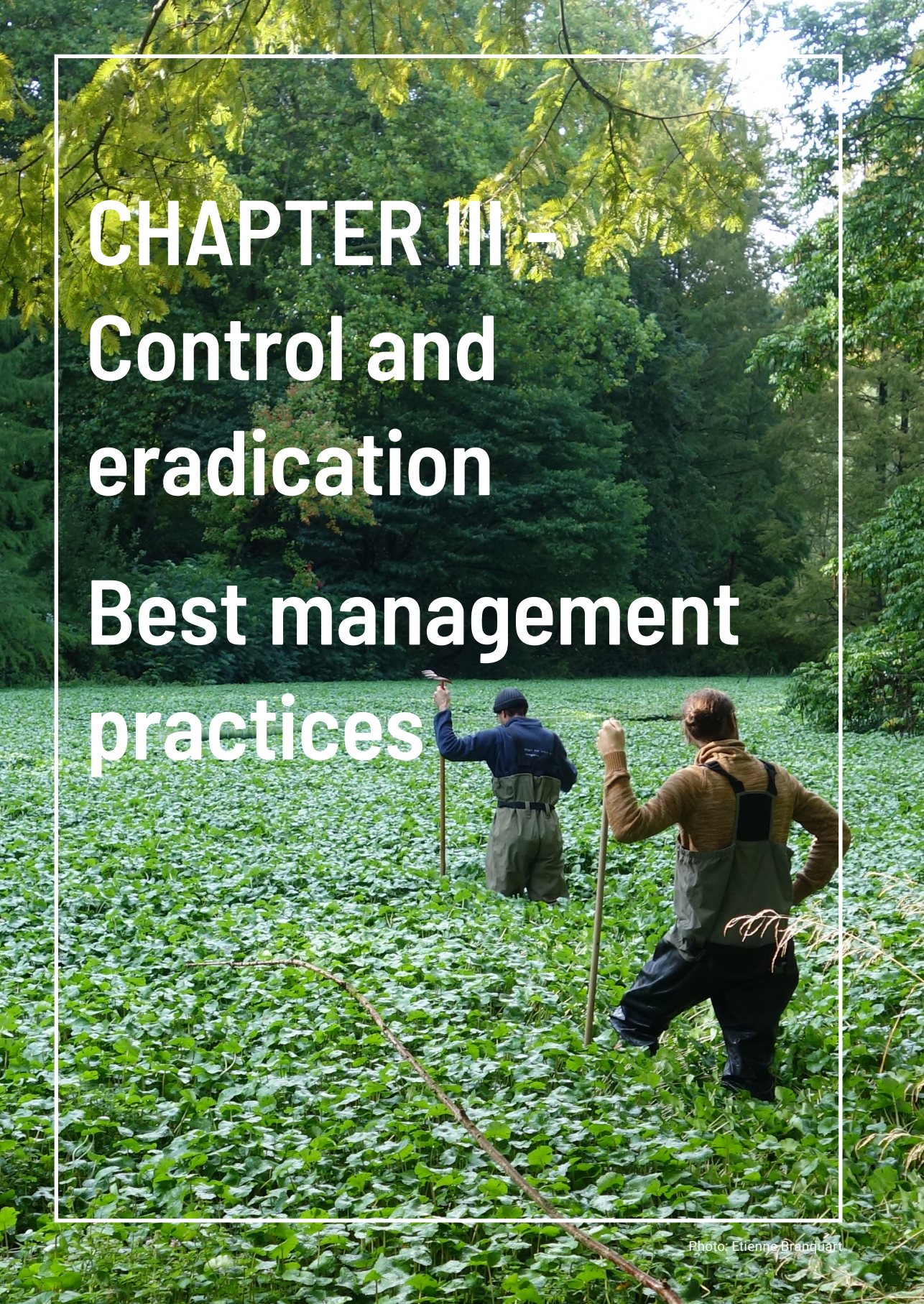


Photo: Etienne Branquart

AQUATIC SPECIES OF EU CONCERN

Cabomba caroliniana

Species description

Fanwort (*Cabomba caroliniana*) is a submerged aquatic plant native to South and North America. The species was introduced to Europe, including Belgium, via the aquarium industry as a popular ornamental and oxygenating plant for aquarium. The first record of fanwort's presence in the environment in Belgium dates from early 2000s. Disposal of aquarium waste in water systems is probably at the origin of its escape in the wild. Today, fanwort represents a problematic aquatic invasive species in many countries worldwide and is now listed as IAS of Union concern under the (EU) Regulation No 1143/2014. This species can easily be confused with other plant species including native macrophytes like water-crowfoot. Its distribution on the Belgian territory is probably underestimated

Fig 8. *Cabomba caroliniana.* Photo: Kieft Ben

Photo: Eric C. Maxwell

Cabomba caroliniana

Fanwort thrives in fresh, stagnant or slow-moving water systems often rich in nutrients such as streams, ditches, ponds, lakes and canals. As a highly competitive invasive species, the plant has diverse environmental, social and economic impacts. Due to its long branching stems, the species can form dense populations and colonise the whole water column. This has significant detrimental impacts on the ecosystem and biodiversity through native plant exclusion, water quality modification, light penetration restriction, etc. Social and economic effects include restriction of recreation (fishing, boating), swimming hazards, water treatment costs and management strategy related costs.

Biological characteristics, reproduction and spread

This invasive weed makes shallow roots in the substrate which limits its distribution to stagnant or slow-moving waters. Fanwort sinks back to the bottom during winter and is therefore undetectable at that period. It then grows rapidly to the surface the next season as the weather gets warmer (around April). In Western Europe, flowers and floating leaves are occasionally produced.

Reproduction in Belgium appears to be exclusively vegetative. Stems are fragile and easily break up when disturbed. Plant fragments can form new plants, and therefore new populations, away from the initial invaded area. Fanwort dispersal notably occurs though water movement or via fragments attached to boats, water equipment and animals. The plant can survive in a free-floating state for 6 to 8 weeks. Stem fragments are, however, highly sensitive to dryness and remain viable for only 24 hours under dry conditions but for weeks under moist soil conditions. Those high dispersal abilities highlight the importance of the implementation of effective management measures.

General considerations about management

A range of management options have successfully been used to control or eradicate this species. Local eradication of fanwort is considered achievable for limited or dense infestations in small water bodies. Eradication of the species remains however more challenging in moving water systems notably due to the complexity to implement effective methods such as light deprivation. As fanwort requires full sun for growth, promoting environmental shading through revegetation with native species can help prevent the (re)establishment of this invasive plant. The fragility of the stems is also a major constraint limiting the efficiency of some operations such as mechanical removal due to incomplete uprooting of plant material. The eradication feasibility of fanwort populations must, therefore, always be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

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Due to the species' ability to reproduce vegetatively by fragmentation, precautionary measures must be put in place prior to management to prevent fragment spread within the managed area or to other water systems. Managed areas are, therefore, isolated by physical barriers. The harvested plant material must be safely disposed of away from the water and brought to refuse sites. Material that has been in contact with the plant (e.g. waders, clothing) should be checked, cleaned and dried before going to another site. It is also recommended to restrict public access to the managed area to isolate the infestations as much as possible and limit the risk of spread.

Managed and downstream sites must remain under enhanced surveillance for a 5-year period after the implementation of the last treatment.

Fig 9. A ditch entirely invaded by fanwort in Belgium. Photo : Provincie Oost-Vlaanderen dienst

Fig 10. Fanwort population restricting light penetration. Photo : Eric Keith

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Manual removal

- ✔ Local eradication can be achieved if carefully implemented in the long-term
- ✔ Manual removal is highly selective and will have minimal disturbance and impact on ecosystems and other organisms
- ✖ The method is only suitable for small and early-detected infestations or for small water systems
- ✖ The method is time consuming and labour intensive, particularly in large sites
- ✖ There is a risk to spread fragments to uninvaded areas
- ✖ Scuba diving requires qualified operators

Method description

The principle is to remove the whole plant from the ecosystem without breaking the fragile stems or leaving root fragments in the sediments. Plants are cautiously pulled out by the roots either by operators walking in the water or by scuba divers (e.g. deep or turbid water). Operators must move very carefully through the water to avoid creating plant fragments. It is also strongly recommended to place a net at the downstream part of the managed area. Manual removal can be conducted all year round but might be more suitable in spring, when the plant is visible but still prostrate. It is strongly recommended to repeat the operation shortly after the initial removal, once sediments have settled, to ensure that no plants have been overlooked. This management strategy is conducted and repeated several times every year until no regrowth is found (minimum 3 years). It is also suitable to have people on the bank catching the fragments that would be released.

Material

Management: Waders, diving equipment

Transport and stocking: Buckets or mesh bags, trucks and containers

Precautionary measures: Hand net, floating booms, contain

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Mechanical removal: floating machines

- ✔ Good control can be expected
- ✔ Mechanical removal is suitable for many situations, even well-established populations in deep or shallow waters
- ✖ Eradication is probably unlikely or hardly achievable
- ✖ This method can negatively affect fish communities and ecosystems through oxygen depletion
- ✖ This technique can negatively impact plant communities due to accidental removal of non-target plant species
- ✖ It is an expensive method, especially during the first few years of implementation

Method description

The principle is to mechanically remove the whole plant from the ecosystem. Plants are uprooted by floating machines such as weed conver boats. The harvested plant material can be stocked on board or unloaded on the bank. One concrete example of machines used is the harkboot, a boat equipped with a large rake on one side and another rake with inserted mesh on the other. The large rake scrapes up to bottom of the water body to a depth of 10 to 15 cm while the rake with inserted mesh is used to collect the uprooted plant material and discharge it on the bank. The type of rake tines must be chosen accordingly with the type of substrate and the targeted species. For the management of fanwort, coarse tines will be preferred in clay beds while small tines will be favoured for peat and sand beds. Mechanical control is preferably implemented a few times per year (up to 4 times) between May and October, when the plant is visible. As different boat dimensions are available, this method can be applied for large or small infestations in deep or shallow waters (at least 0.6 m deep). If the method is implemented in running waters, it is recommended to work accordingly with the direction of the current to prevent re-infestation of cleaned-up areas to occur. Similarly, if mechanical removal is implemented in stagnant waters, the direction of the wind or the presence of hydraulic infrastructures, which may influence current, must be taken into account. As the weather and wind direction can change throughout the day, the working method must be adjusted accordingly.

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The harkboot must be stopped, and management postponed when hypoxia is observed by the operators. Mechanical removal is immediately followed by manual removal of plants that were inaccessible to the machines (e.g. plants rooted near the bank or obstacles). Remaining drifting plant fragments are also removed. Repeated mechanical removal is often necessary (at least once a year) over a few years (4 years) to notice a drastic reduction of the population. Regular site surveys must be implemented. Once good level of control is achieved and the infestations limited, manual aftercare is implemented to remove regrowth.

Material

Management: The adequate weed conver boat

Transport and stocking: Buckets and trucks

Precautionary measures: Hand net, retention nets. A floating net with lead-line must also be placed at the downstream part of the managed area and remain in place for at least 5 days following the operation.

Fig 11. Mechanical removal using floating machines is ususally implemented in large water systems. Photo : Aquarius Systems

Substrate removal: mechanical dredging

- ✔ This is one of the fastest methods to achieve good long-term control
- ✔ This method is suitable for large infestations
- ✖ Local eradication is possible but unlikely
- ✖ This method can only be implemented in sites where the whole area is accessible to the machines
- ✖ Dredging can create vast numbers of plant fragments with the risk to spread the species to uninvaded areas
- ✖ This method can have high negative impacts on aquatic living organisms

Method description

The principle is to remove the bottom sediments contaminated with all parts of the invasive plant such as roots, stems, etc. Excavators equipped with a cleaning bucket thumb are used for excavation at a depth of 20 to 60 cm. This method is always preceded by a water drawdown or a complete drainage (whenever possible) during which care should be taken not to spread plant fragments. The placement of mesh filters at the outlet is therefore necessary. Biofilters must be placed if pumping is required to prevent fragment spread, notably via the sewage system. It is also strongly recommended to place a net at the downstream part of the managed area. Mechanical dredging is preferably conducted in spring, during the growing season. This management method is immediately followed by manual removal to eliminate any remaining plant material. Manual removal is, then, implemented as a follow up measure for minimum 2 years to remove any regrowth.

Material

Management: Excavators equipped with cleaning bucket thumb

Transport and stocking: Buckets or mesh bags, trucks and containers

Precautionary measures: Hand net, floating booms, containment nets, biofilter, sand or mesh filters

References

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Light deprivation: floating cover

- ✔ Local eradication or really good control can be achieved within a few months
- ✖ The method is suitable for small water bodies or limited invaded areas
- ✖ This method is limited to stagnant waters
- ✖ The method is not selective and will have high impact on other living organisms, particularly if the whole water body is covered
- ✖ Shading alters the physicochemical properties of the water bod

Method description

The principle is to exclude the light or significantly reduce the amount of light reaching the plant to cause its death. A floating opaque sheeting (at least 99% light-blocking) is either placed over the whole pond or over a section of the water body. As fanwort displays a high tolerance to shade, it is important that no light reaches the plants from any adjacent area, gaps or at the edges of the sheeting. Operators must therefore ensure that sheets overlap correctly. The use of large continuous pieces of sheeting is recommended whenever possible. If floating covers are placed over a section of the water body or used to manage edge infestations, side-curtains are fixed to the edges of the blanket to ensure that no light reaches the plants by the sides. The blanket is then attached and secured to the bank. Floating blankets must be placed early in the season (early spring), when the plants are still prostrate, and remain in place for minimum 3 to 4 months. Regular checks and repairs of potential damages that would allow light to pass through must be done. Sheeting removal is immediately followed by an inspection of the managed area to check for any regrowth. If remaining plants or regrowth are found, manual removal is implemented as a follow up measure over 3 consecutive years.

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Material

Management: The adequate quantity of sheeting, blocking at least 99% of the light such as builders' black plastic or pool covers. Rope, cable, star pickets or heavy weights. Side-curtains made of black plastic.

If damages occur to the sheeting, plastic zip ties can be used to join the blankets together. Buoys can also be fixed to the corners of the blanket to delimitate the management area.

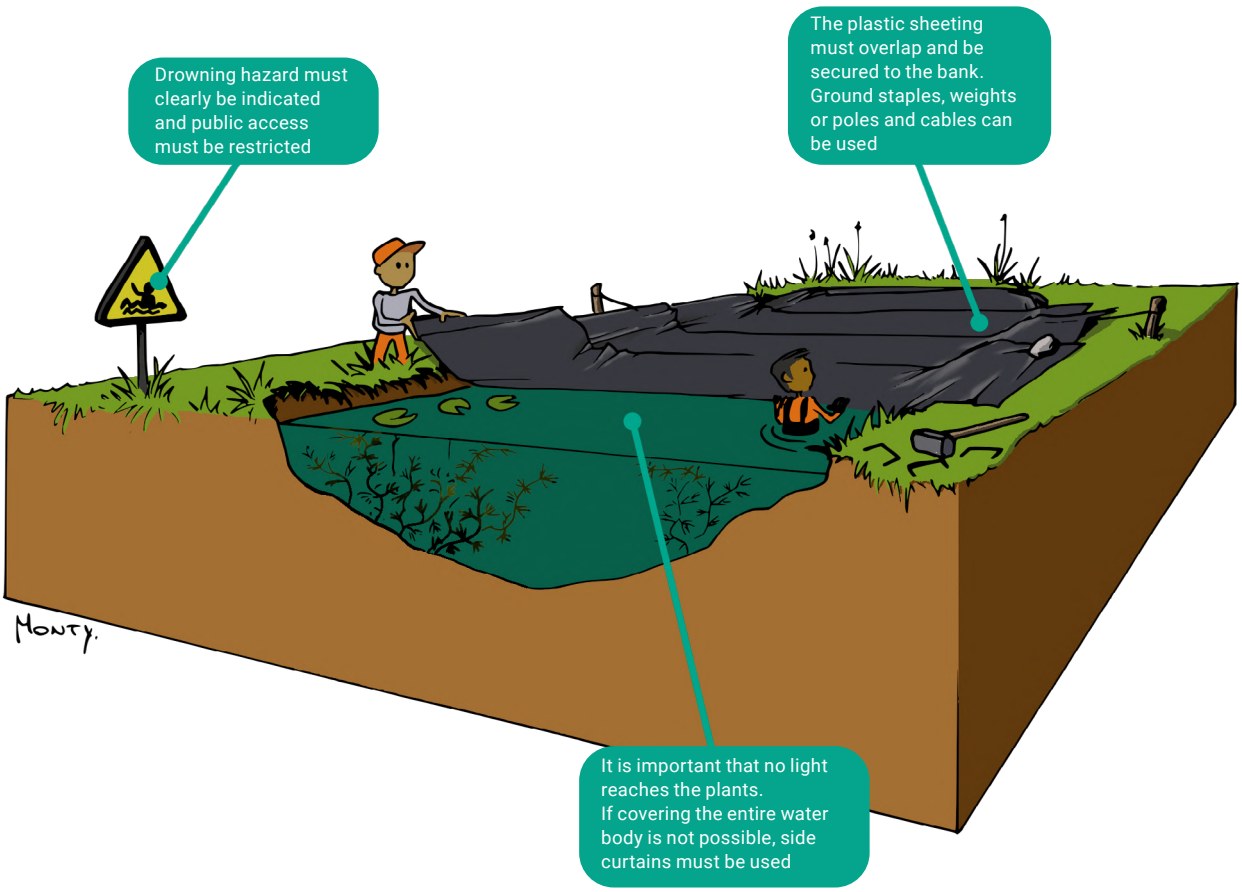

Fig 12. Placement of light-blocking floating covers to create high levels of shade and kill the plant

Light deprivation: benthic jute matting

- ✔ Local eradication or really good control can be achieved within a few months
- ✔ The method is suitable for both limited and large invaded areas
- ✔ The material is solid and biodegradable, thus does not require to be removed (eco-friendly and no removal costs)
- ✔ The jute enables native plants to grow through it which allows vegetation to reestablish. It also enables gas to escape
- ✖ This method is limited to stagnant waters
- ✖ The placement of the sheeting might be impracticable or impossible due to the presence of obstacles
- ✖ This method is likely to be detrimental to benthic organisms and affect fish spawning

Method description

The principle is to install bottom covers that both compress vegetation and exclude sunlight, causing the death of the plants. Jute matting, a natural and biodegradable vegetable fiber, is placed by divers or operators on the bottom of the water body. For large fanwort populations in deep waters, long strips of jute are deployed from a boat on the water surface which rapidly sink to the bottom. For smaller populations, sheets are manually placed on the weed bed by divers or operators. It is really important that no light reaches the plants from any adjacent area, gaps or at the edges of the sheeting. Divers or operators must therefore ensure the adequate placement of the matting and that strips overlap correctly. The use of large continuous pieces of sheeting is recommended whenever possible. The sheets must, then, be secured to the bottom using weights. Benthic covers are placed during winter, when the plants are prostrate, and are never to be removed as jute eventually disintegrates after 1 or 2 years. Eradication is, however, achieved after a few months. Once the jute disintegrated, inspections and manual removal are conducted to remove any plant regrowth, until none is found.

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Material

Management: The adequate quantity of jute matting rolls. It is important to ensure that the plant does not grow through the fabric's holes. Jute textile with mesh size 0.5 mm, 300 $g.m^{-2}$, is therefore recommended for fanwort. Weights, rocks, concrete blocks or sandbags. Boat and buoys to demarcate the managed area.

Non-biodegradable material such as woven synthetics, black plastic or polyethylene sheets has commonly been used as benthic covers for the management of fanwort. However, this type of material presents many significant disadvantages. For non-permeable material, gases can accumulate and lift the blankets, allowing light to reach the plants. Non-biodegradable material also requires to be removed, which generates additional costs. It also has a greater negative impact on living organisms and the ecosystem.

Fig 13. The fabric's holes must be small enough to prevent the plant from growing through the matting. Photo: Marie Patinet

DID YOU KNOW?

Drawdown, an effective method in Belgium?

In many places worldwide, water level drawdown has proven to be an effective method to achieve the eradication of some aquatic invasive plants such as *Cabomba caroliniana*, *Egeria densa* or *Myriophyllum* spp.

The principle is to drain a water body for a defined period of time to cause the death of all plant material by exposing it to drying or freezing conditions (during summer or winter). Nevertheless, to be successful and reach eradication, sediments must be exposed to extreme conditions for long periods of time (usually several months, depending on the species).

In Belgium, frequent rainfall along with temperate winter and summer temperatures might hinder the efficiency of the method, and therefore prevent eradication or even control to be achieved.

However, recently, the effects of climate change with associated lack of rainfall and exceptionally high temperatures for prolonged periods of time could give the opportunity to test or implement this method as a best practice. This remains, however, rather uncertain.

Fig 14. Rainwater puddles appearing after drawdown provide refuge for invasive aquatic plants. Photo: Etienne Branquart

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Hydrocotyle ranunculoides

Species description

Floating pennywort (*Hydrocotyle ranunculoides*) is a perennial aquatic plant species native to America. The species was introduced to Europe, including Belgium, through the aquatic nursery trade as a popular oxygenating plant for aquarium and garden ponds. The first record of floating pennywort's presence in the environment in Belgium dates from 1992. Disposal of aquarium and pond waste in water systems along with multiples escapes from aquatic nurseries are probably at the origin of the species' occurrence in the wild. Today, floating pennywort represents a problematic aquatic invasive species in many countries worldwide and is now listed as IAS of Union concern under the EU Regulation No 1143/2014. Its distribution on the Belgian territory is probably rather exhaustive due to the plant high detectability. At early development stages, the species can, however, easily be confused with native macrophytes like *Hydrocotyle vulgaris*.

Fig 15. *Hydrocotyle ranunculoides*. Photo: Kieft Ben

Photo: Etienne Branquart

Hydrocotyle ranunculoides

Floating pennywort grows well in both shallow stagnant or slow-moving freshwater such as ponds, ditches, streams, canals and marshes. The plant, rooted in mud, can grow up to 40 cm above the water surface and is able to colonise the banks of water systems. As a highly competitive invasive species, the plant has diverse environmental, social and economic impacts. This invader can form dense interwoven mats that completely cover the water surface. This has significant detrimental impacts on the ecosystem and biodiversity including through light exclusion, native plant community displacement and water quality modification. Social and economic effects include restriction of recreational activities (angling, boating), swimming hazards and management related costs.

Biological characteristics, reproduction and spread

Floating pennywort starts growing in spring, with its highest growth rate occurring during summer. During the winter months, the species usually remains dormant along banks, and regrows from persisting plants the following spring.

Reproduction of floating pennywort in western Europe is probably exclusively vegetative. When the plant breaks into fragments, naturally or because of human activity, those small fragments can form a new plant and, therefore, a new population, away from the initial invaded area. The species is, however, also known to produce viable seeds in its native range, although seed production has not yet been observed in Europe. Compared to many other aquatic weeds, floating pennywort has high and impressive spread capacities. Dispersal can occur through water flow or via fragments attached to boats and other water equipment. The species displays impressive regeneration capacities with new shoots developing within 1 or 2 weeks from one single fragment. Those high regeneration and dispersal abilities highlight the importance of the implementation of effective management measures.

Fig 16. Dense mat of floating pennywort covering the entire surface of the water body and causing many problems such as choking the pond of oxygen. Photo: Adrien Latli

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General considerations about management

A range of management options have successfully been used to control or eradicate this species. Local eradication of floating pennywort is considered achievable for small and large infestations. While the species is probably one of the easiest invasive water plant to manage, terrestrial forms rooted in the banks make the management more challenging as the plant is intermixed with riparian vegetation. In addition, it was suggested that the percentage of rooted plants within a population can influence management results: the greater the proportion of plants rooted in the substrate, the smaller the chances of eradication success. The eradication feasibility of floating pennywort populations must always be assessed on a case-by-case basis, considering site specificities, the invaded area, etc., and be thoroughly discussed within the management team.

Due to the species' ability to reproduce vegetatively by fragmentation, precautionary measures must be put in place prior to management to prevent fragment spread within the managed area or to other water systems. Managed areas are, therefore, isolated by physical barriers.

The harvested plant material must be safely disposed of away from the water and is either dried and incinerated, buried or composted. If important quantities of sediments are present (e.g. dredging), the harvested material is transported to refuse facilities. Material that has been in contact with the plant (e.g. waders, clothing) should be checked, cleaned and dried before going to another site. It is also recommended to restrict public access to the managed area to isolate the infestations as much as possible and limit the risk of spread.

Managed and downstream sites must remain under enhanced surveillance for a 5-year period after the implementation of the last treatment.

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Manual removal

- ✔ Local eradication can be achieved
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ The method is more suitable for small and early-detected infestations (<500 m²) or in small water systems
- ✖ Manual removal can create plant fragments with the risk to spread the species to uninvaded areas and other parts of the managed water body

Fig 17. Hand-pulling with waders and waterproof gloves. Photo: Marie Patinet

Fig 18. Operators using rakes and synthetic buckets to remove and stock the plant material. Photo: Marie Patinet

Fig 19. Small dumper truck used to transport the harvested plant material to the container. Photo: Dido Gosse

Fig 20. Large rake being pulled by a winch from the bank helping operators to remove important quantity of plant material. Photo: Adrien Latli

References

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Method description

The principle is to remove the whole plant from the ecosystem. Plants are pulled out by the roots by operators wading in shallow waters, from boats and from the bank. For large floating mats, tools such as large rakes pulled by a winch from the bank can facilitate the operation. This management strategy is conducted in spring and during the whole vegetative period. Operators must pay great attention not to fragment the plants as much as possible. They must also ensure to remove all individuals rooted on the banks. Manual removal of plant regrowth is repeated every month, following the initial removal, until the end of the vegetative phase. Several interventions are then necessary between June and November. Aftercare is repeated in the same way for the next following years, usually for 2 to 5 years.

Material

Management: Waders, small boats, manure or grappling hooks, rakes, winch and large rake, gloves

Transport: Buckets or synthetic bags, trucks, dumpers and containers

Precautionary measures: Hand net, floating booms, containment nets

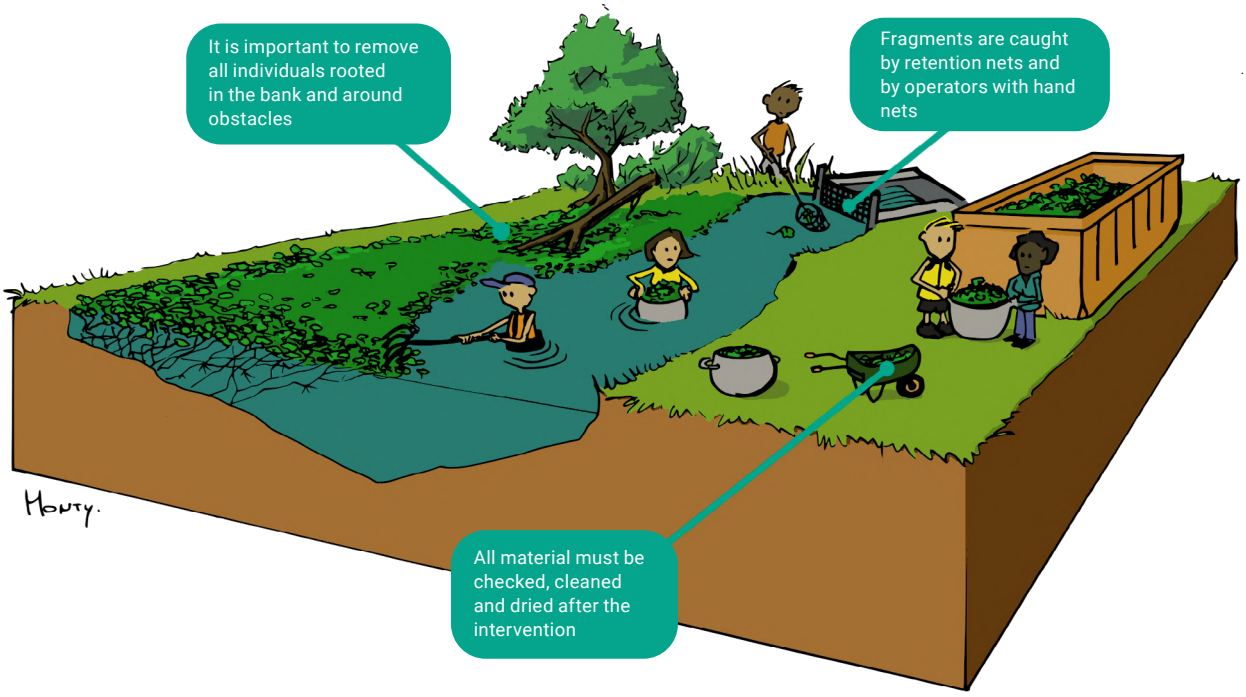

Fig 21. Manual removal of floating pennywort involving pulling out the plant by the root while wading through water

DID YOU KNOW?

Water level manipulation, a useful tool

Depending on site specificities, lowering or raising water level can be implemented prior to the manual removal of aquatic plant species such as *Cabomba caroliniana* and *Hydrocotyle ranunculoides* to facilitate the operation.

Adequately adapting the water level can provide significant advantages such as limiting water turbidity and mud creation through suction effects but also facilitating operator's movements by enabling to work from a boat or easily wade through water, limiting production of fragments, etc.

Care should be taken not to spread plant fragments if operators decide to lower the water level. The placement of mesh filters at the outlet is therefore necessary. Biofilters must be placed if pumping is required to prevent fragment spread, notably via the sewage system.

Fig 22. Lowering the water level will enable managers to walk through the water. Photo: Marie Patinet

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Mechanical removal: floating and terrestrial machines

- ✔ Local eradication can be achieved
- ✔ Rapid good control can be expected
- ✔ Mechanical removal is suitable for well-established populations and large water systems
- ✖ This method can only be implemented in sites where the entire invaded area is accessible to the machines
- ✖ Mechanical removal can create vast numbers of plant fragments with the risk to spread the species to uninvaded areas and other parts of the managed water system

Method description

The principle is to mechanically remove the whole plant from the ecosystem. Plants are either uprooted and collected by excavators on the bank or on floating pontoons or by specialised weed conver boats equipped with various attachments such as mechanically controlled rakes that scoop out plant material and unloaded it on the bank. While terrestrial machines are preferred for narrow water systems such as ditches or streams, conver boats are adopted for large water systems. Mechanical removal is possible to implement all year round, whenever the plant is visible, and is immediately followed by manual removal of remaining plants and fragments. Manual aftercare is then conducted several times during spring and summer to remove any regrowth and is repeated for the next following years, usually 2 to 5 years.

Material

Management: Excavators or weed conver boat, waders

Transport: Dumpers, trucks and containers

Precautionary measures: Hand net, floating booms, retention nets, mesh grids

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Fig 23. Excavators placed on the bank to remove floating pennywort from a narrow water system. Photo: Jérémie Guyon

Lagarosiphon major

Species description

Curly waterweed (*Lagarosiphon major*) is a perennial, submerged aquatic plant native to South Africa. The species was introduced to Europe, including Belgium, through the aquarium industry as a popular oxygenating plant for aquariums. The first records of the curly waterweed's presence in the environment in Belgium date back to 1993. Disposal of aquarium waste in water systems is probably at the origin of its escape in the wild. Today, the plant represents a problematic aquatic invasive species in many countries worldwide and is now listed as IAS of Union concern under the EU Regulation No 1143/2014. The species can easily be confused with other non-native plant species such as *Elodea nuttallii*. Its submerged form also makes the plant hardly detectable. As a result, its presence on the Belgian territory probably remains underestimated.

Fig 24. *Lagarosiphon major.* Photo: Q-Bank

Lagarosiphon major

Curly waterweed is mostly found in clear stagnant or slow-moving water systems such as freshwater lakes, large ponds and canals. The species thrives in water systems with sandy bottoms and high light intensity. As a highly competitive invasive species, the plant has diverse environmental, social and economic impacts. Curly waterweed, which can grow several meters long, can form dense and monospecific beds and colonise the whole water column. This has detrimental impacts on the ecosystem and biodiversity, including oxygen depletion, higher pH levels, complete light exclusion, and displacement of native plant community. Social and economic effects include restriction on recreational activities (angling, boating), swimming hazards, increased flooding risks and associated management costs.

Biological characteristics, reproduction and spread

In most of its introduced range, including Belgium, curly waterweed grows in the spring from rhizomes and shoots. It produces flowers and large masses of stems during summer. The species then becomes dormant in the winter months, but cold temperatures do not restrain its invasion.

Curly waterweed is a dioecious species. Its reproduction in western Europe is exclusively vegetative via female plants only. When the plant breaks into fragments, whether naturally or due to human activity, those small fragments can form a new plant and, therefore, a new population, away from the initial invaded area. The spread of this invasive weed can occur through fragments attached to boats or other water equipment. Fragments can remain viable outside water due to their high tolerance to desiccation. Those high dispersal abilities highlight the importance of the implementation of effective management measures.

Fig 25. Curly waterweed forming dense monospecific beds at the water surface. Photo : Saxifraga-Peter Meininger

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General considerations about management

A range of management options have successfully been used to control or eradicate this species. Achieving local eradication of both small and large infestations of curly waterweed is considered feasible due to highly effective and promising management methods, such as benthic jute matting (light deprivation). This management measure has probably become one of the dominant techniques for the management of curly waterweed as it enables the eradication of large populations and provides numerous advantages over other commonly used methods. However, curly waterweed exhibits a wide range of variability in its development and phenology, which can pose challenges in determining the optimal timing for effective management. The eradication feasibility of this species must, therefore, always be assessed on a case-by-case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce vegetatively by fragmentation, precautionary measures must be put in place prior to management to prevent fragment spread within the managed area or to other water systems. Managed areas are, therefore, isolated by physical barriers.

The harvested plant material must be safely disposed of away from water systems. Burial, drying (in the sun), or burning are suitable ways of disposal. Material that has been in contact with the plant (e.g. diving equipment, clothing) should be checked, cleaned and dried before being taken to another site. It is also recommended to restrict public access to the managed area to isolate the infestations as much as possible and limit the risk of spread.

Managed and downstream sites must remain under enhanced surveillance for a 5-year period after the implementation of the last treatment.

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Manual removal

- ✔ Local eradication can be achieved
- ✔ Manual removal is highly selective and will have minimal disturbance and impact on ecosystems and other organisms
- ✖ The method is only suitable for small and early-detected infestations
- ✖ There is a risk to create and spread fragments to uninvaded areas
- ✖ Scuba diving requires qualified operators

Method description

The principle is to remove the whole plant from the ecosystem. Plants are pulled out by the roots by scuba divers or snorkelers (deep water) or by agents wading (shallow water). Operators must pay great attention not to fragment the plants. This method is implemented in autumn, when the plant is more prostrate, in recently invaded sites or areas with low vegetative abundance. The managed site is surveyed 8 weeks after the initial manual removal to check for regrowth or plants that may have been overlooked. This management method generally needs to be frequently repeated over a 3 to 5-year period.

Material

Management: Diving equipment. Buoys to demarcate the managed area

Transport and stocking: Buckets or mesh bags

Precautionary measures: Hand net, floating booms, retention nets or bubble curtains

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Mechanical removal: floating machines

- ✔ Short-term control can be expected
- ✔ Mechanical removal is suitable for large scale infestations
- ✖ Eradication is unlikely or hardly achievable
- ✖ Mechanical removal can create plant fragments with the risk to spread the species to uninvaded areas and other parts of the managed water system
- ✖ Mechanical removal can affect fish and macroinvertebrates

Method description

The principle is to mechanically remove parts of the plant or, depending on the type of machinery, the entire plant from the ecosystem. Plants are cut by boats equipped with a cutting mechanism, to a limited depth of 2m. V-blades can also be pulled along the bottom of the water body to uproot the plants. Mechanical control is preferably carried out multiple times every year during spring and summer, when the plant is visible. This method is usually combined with other measures, such as the placement of benthic covers, to enhance its effectiveness.

Acting in a similar way to the v-blades, the harkboot, a boat equipped with a large rake on one side and another rake with inserted mesh on the other, could also be tested for this species. The large rake scrapes up the bottom of the water body to a depth of 10 to 15 cm while the rake with inserted mesh is used to collect the uprooted plant material and discharge it on the bank. The type of rake tines must be chosen accordingly with the type of substrate and the targeted species. For the management of curly waterweed, coarse tines will be preferred in clay beds while small tines will be favoured for sand beds. As different boat dimensions are available, this method can be applied for large or small infestations in deep or shallow waters (at least 0.6 m deep). If the method is implemented in slow-moving waters, it is recommended to work accordingly with the direction of the current to prevent re-infestation of cleaned-up areas to occur.

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Similarly, if mechanical removal is implemented in stagnant waters, the direction of the wind or the presence of hydraulic infrastructures, which may influence current, must be considered. As the weather and wind direction can change throughout the day, the working method must be adjusted accordingly. The harkboot must be stopped when hypoxia is observed by the operators. Mechanical removal is immediately followed by manual removal of plants that were inaccessible to the machines (e.g. plants rooted near the bank or obstacles).Remaining drifting plant fragments are also removed. Repeated mechanical removal is often necessary (at least once a year) over a few years (4 years) to notice a drastic reduction in population density. Regular site surveys must be implemented. Once good level of control is achieved and the infestations is limited, manual aftercare is implemented to remove regrowth.

Material

Management: The adequate boat

Transport and stocking: Buckets and trucks

Precautionary measures: Hand net, retention nets. A floating net with lead-line must also be placed at the downstream part of managed area and remain in place for at least 5 days following the operation.

Fig 26. Example of aquatic weed harvester being used for the management of invasive aquatic plant species. Photo : Wassersalat

Light deprivation: benthic jute matting

- ✔ Local eradication or really good control can be achieved within a few months
- ✔ The method is suitable for both limited and large invaded areas/water systems
- ✔ The material is biodegradable, thus does not require to be removed (eco-friendly and no removal costs)
- ✔ The jute enables native plants to grow through it which allows vegetation to reestablish. It also enables gas to escape
- ✖ This method is limited to stagnant waters
- ✖ The placement of jute matting might be impracticable or impossible in areas with obstacles
- ✖ The method is likely to be detrimental to benthic organisms and affect fish spawning

Method description

The principle is to install bottom covers that both compress vegetation and exclude sunlight, causing the death of the plants. Jute matting, a natural and biodegradable vegetable fiber, is placed by divers on the bottom of the water body. For large curly waterweed populations in deep waters, long strips of jute are deployed from a boat on the water surface and rapidly sink to the bottom. For smaller populations, sheets are manually placed on the weed bed by divers. It is really important that no light reaches the plants from any adjacent area, gaps or at the edges of the sheeting. Divers or operators must ensure the adequate placement of the matting and that strips overlap correctly. The use of large continuous pieces of sheeting is therefore recommended whenever possible. Weights are attached on the side of the jute to secure the covers to the bottom and help with accurate placement. Jute is never to be removed as it disintegrates after 1 or 2 years. Eradication is, however, achieved after 4 to 7 months. Benthic covers are placed when the plants are prostrate. If not possible, mechanical cutting can be implemented prior to the placement of the jute to reduce the biomass and facilitate the fixing of the material to the bottom. If cutting is implemented, operators must ensure that no fragment remains as there is a high risk that new plants will grow on top of the matting. Once the jute disintegrated, inspections and manual removal of remaining plants or any plant regrowth are conducted until the complete disappearance of the species.

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Material

Management: The adequate quantity of jute matting rolls. It is important to ensure that the plant does not grow through the fabric's holes. Jute textile 200 $g.m^{-2}$ is recommended. Weights, rocks, concrete blocks or sandbags. Boats and buoys to demarcate the managed area. Harvesters with sickle-bar cutting blades are used for mechanical cutting.

Non-biodegradable material such as woven synthetics, black plastic or polyethylene sheets has commonly been used as benthic covers for the management of fanwort. However, this type of material presents many significant disadvantages. For non-permeable material, gases can accumulate and lift the blankets, allowing light to reach the plants. Non-biodegradable material also requires to be removed, which generates additional costs. It also has a greater negative impact on living organisms and the ecosystem.

Precautionary measures: Hand net, floating booms, containment nets or bubble curtains (if mechanical cutting is conducted).

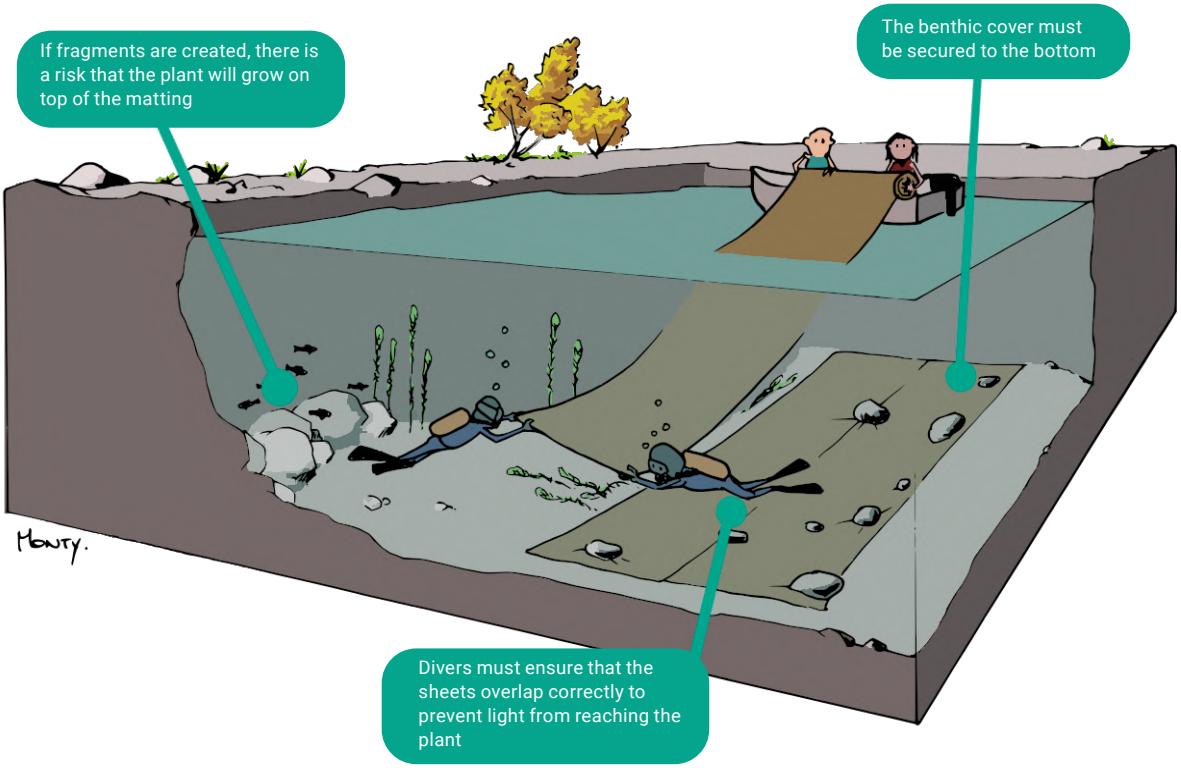

Fig 27. Jute matting application by divers in a deep water body

Ludwigia spp

Species description

The invasive water primrose (*Ludwigia grandiflora*) and floating primrose-willow (*Ludwigia peploides*) are both aquatic and semi-aquatic vascular plants native to South America. The species were introduced to Europe, including Belgium, through horticultural trade as popular ornamental plants for garden ponds. The first record of water primrose's and floating primrose-willow's presence in the environment in Belgium dates from 1984 and 1995 respectively. Disposal of pond waste and escape from cultivation are probably at the origin of their presence in the wild. Today, both *Ludwigia* spp. represent problematic aquatic invasive species in many countries worldwide and are now listed as IAS of Union concern under the (EU) Regulation No 1143/2014. The distribution of both species on the Belgian territory is probably rather exhaustive due to their high detectability.

Fig 28. *Ludwigia peploides*. Photo: KENPEI

Fig 29. *Ludwigia grandiflora*. Photo: Traumrune

Photo: Heliosphile/Shutterstock.

Ludwigia spp.

Ludwigia spp. thrive in stagnant or slow-moving freshwater habitats such as ponds, ditches and canals. The plants can grow up to 1m above the water surface and are able to colonise wet terrestrial environments such as banks or meadows. As highly competitive invasive species, the plants have diverse environmental, social and economic impacts. They can form dense mats that can completely cover the water surface. This has significant detrimental impacts on the ecosystem and biodiversity including through light exclusion, native plant community displacement and water quality modification. Social and economic consequences involve restriction of recreational activities (angling, boating), and management-related costs.

Fig 30. Water primrose invasion, expanding rapidly, can disturb human activities such as navigation. Photo : COULANGES/Shutterstock

Biological characteristics, reproduction and spread

Water primrose displays different growth forms and develops both under and above the water surface. During the initial growth phase, it produces stems that grow horizontally over the ground and the water surface. The stems, then, start growing vertically (up to 1m tall) during the second phase. The species grows in spring, and flowering mainly takes place between July and September. Floating primrose-willow also produces stems that can grow both vertically and horizontally. The species' leaves become apparent at the water surface in early spring. Flowering takes place from July to October. Emerging stems sink back to the bottom in November. The two species are amphibious and can develop up to 3m deep underwater and take root both in the sediments and banks. When colonizing terrestrial environments, both species can sometimes display an atypical creeping form. At the beginning of the growing season, these species are not easily detectable as they present small leaves.

Reproduction of *Ludwigia* spp. in western Europe is mainly vegetative. When the plant breaks into fragments, whether naturally or due to human activity, those stem fragments, measuring a few cm in lenght, can form a new plant, and therefore, a new population away from the initial invaded area. Fragmentation naturally occurs in autumn and winter, when the plants die off. Sexual reproduction is, however, also known to occur as both species can produce viable seeds. Each species produces fruits holding 40 to 50 seeds and exhibits important potential seed output (several thousand seeds/m²). The seeds of water primrose and floating primrose-willow can remain buoyant for 12 weeks and 2 weeks, respectively.

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Sexual reproduction of both species seems, however, to be less important compared to vegetative reproduction. Dispersal occurs via seed and fragment drift, flooding events as well as through fragments being attached to boats and other water equipment. Those high regeneration and dispersal abilities highlight the importance of the implementation of effective management measures.

Fig 31. Water primrose as a floating form during its first growth phase. Photo: Marie Patinet

Fig 32. Atypical creeping terrestrial form. Photo: Arnaud Monty

Fig 33. Mat of flowering water primrose during its second growth phase. Photo: Marie Patinet

Fig 34. Small leaves present at the beginning of the growing season. Photo: Arnaud Monty

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General considerations about management

Numerous and well-documented management options have successfully been used to control and, in some cases, eradicate water primrose and floating primrose-willow. Local eradication of both species is considered challenging, especially for large and dense infestations, but remains possible for early-detected populations. Their ability to colonise both aquatic and terrestrial environments makes management particularly difficult. In addition, the plants' strong roots and thick rhizomes make their removal quite challenging. As *Ludwigia* spp. require full light conditions to express an invasive character, promoting environmental shading through revegetation with native tree or shrub species can help prevent the (re)establishment of these invasive plants. The eradication feasibility of *Ludwigia* spp. populations must always be assessed on a case-by-case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce by seeds and fragments, precautionary measures must be implemented prior to management to prevent the spread of seeds and fragments into the environment and uninvaded areas. Managed areas are, therefore, isolated by physical barriers.

The harvested plant material must be safely disposed of far away from the water and any wet areas. It is either dried and incinerated, buried (at least 1m deep), or composted. Material that has been in contact with the plant and with the soil that may contain seeds (e.g. machines, nets) should be checked, cleaned and dried before going to another site.

Managed and downstream sites must remain under enhanced surveillance for a 5-year period after the last treatment.

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Manual removal

- ✔ Local eradication can be achieved but remains extremely complicated
- ✔ Manual removal is highly selective and will have minimal disturbance and impact on ecosystems and other organisms
- ✔ This method is also used as a follow-up method in larger-scale eradication programs, when the regrowth is limited
- ✖ The method is only suitable for small and early-detected infestations (< 50m^2)
- ✖ There is a risk to spread fragments to uninvaded areas

Method description

The principle is to remove the whole plant from the ecosystem without breaking the stems or leaving root fragments in the sediments. Plants are pulled out by the roots or dug up with tools by operators either wading in shallow waters, operating from boats or working from the bank. Due to the plant's thick rhizomes and strong roots, digging up could be more effective. Operators must pay great attention not to fragment the plants, but also to remove the entire root system and all individuals also present on the banks. This management strategy is conducted in late spring to prevent seed production. Manual removal is repeated every month during the vegetation period (from May to October) for at least 5 successive years. Water drawdown can be implemented prior to manual removal to facilitate the operation. Containment nets (1m deep) must be installed to prevent fragment spread and must be checked regularly, ideally on a daily basis, to remove fragments that have been caught.

Material

Management: Waders, small boats, spades, rakes.

Transport and stocking: Buckets or waterproof bags, tarpaulin, trucks and wheelbarrows

Precautionary measures: Hand net, containment nets (mesh size < 1cm)

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Mechanical removal

- ✔ Rapid good control can be expected
- ✔ Mechanical removal is suitable for well-established populations and large/deep water systems
- ✖ This method can only be implemented in sites where the entire invaded area is accessible to the machines
- ✖ Mechanical removal can create vast numbers of plant fragments with the risk to spread the species to uninvaded areas and other parts of the managed water system
- ✖ Eradication is highly unlikely

Method description

The principle is to mechanically remove the whole plant from the ecosystem. Plants are uprooted and collected either by excavators equipped with a clawed or mowing bucket from the bank or by floating machines equipped with a hydraulic controlled rack. While terrestrial machines are preferred for narrow water systems such as ditches or streams, floating machines are adopted for large water systems. Mechanical removal is implemented in spring to prevent seed production and is immediately followed by manual removal of remaining plants and fragments. If mechanical removal using terrestrial machines is implemented, lowering the water level prior to the operation can facilitate the exercise. This management method generally needs to be repeated for minimum 2 years to achieve eradication. This action is followed by manual aftercare to remove any regrowth during 3 to 5 consecutive years.

References

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Material

Management: Excavators with a clawed/mowing bucket or floating harvester machines with a hydraulic controlled rack

Transport and stocking: Buckets or waterproof bags, tarpaulin, trucks, dumpers and wheelbarrows

Precautionary measures: Hand net, containment nets (mesh size <1cm)

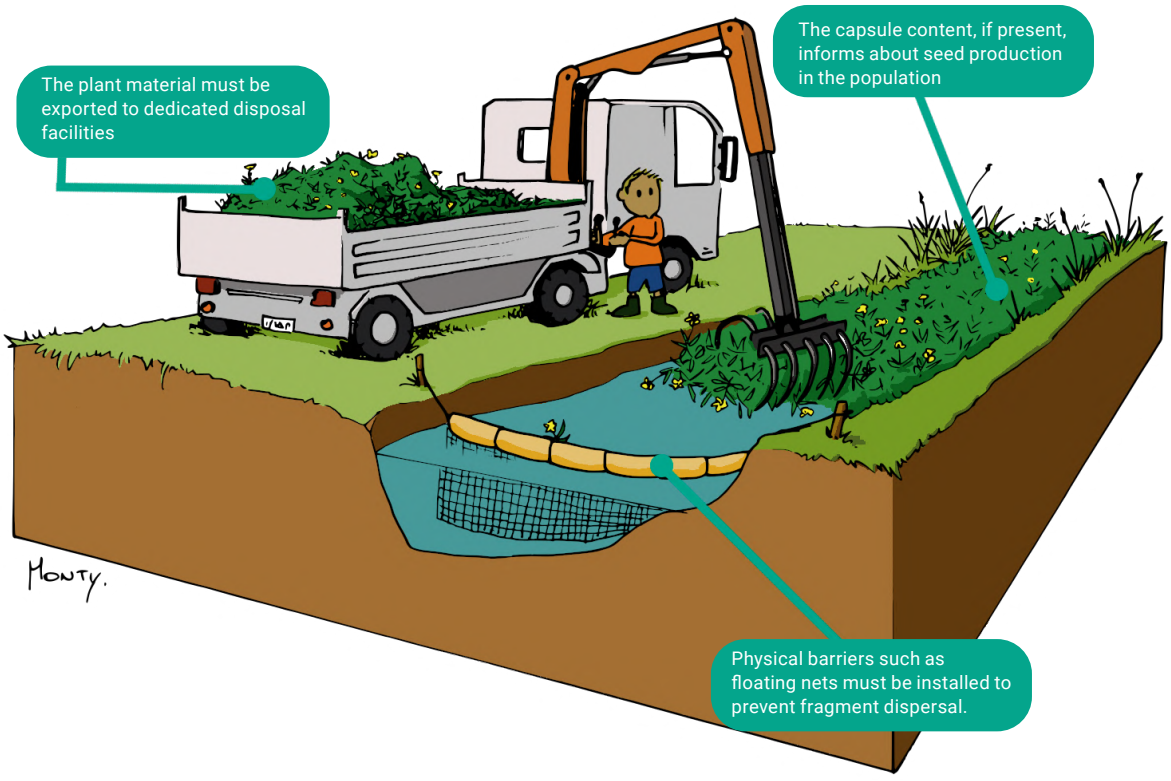

Fig 35. Mechanical removal of *Ludwigia* spp.

Substrate removal: mechanical dredging

- ✔ This is one of the fastest methods to achieve good levels of control
- ✔ This method is suitable for large infestations
- ✔ Mechanical dredging can be implemented when maintenance dredging of the water body is required
- ✖ Local eradication is possible but unlikely
- ✖ This method can only be implemented in sites where the whole area is accessible to the machines
- ✖ Dredging can create vast numbers of plant fragments with the risk to spread the species to uninvaded areas
- ✖ This method can have high negative impacts on aquatic living organisms
- ✖ Disposal sites must be found for the storage of contaminated sediments
- ✖ This method is expensive due to the use of machinery and the need to transport sediments to dedicated disposal sites

Method description

The principle is to remove the bottom sediments contaminated with any parts of the invasive plant such as roots, stems, seeds, etc. Excavators equipped with cleaning bucket thumb are used for excavation. It is strongly recommended to remove a 40cm-layer of sediments to reduce the chance for the species to re-establish. This method is often preceded by a water drawdown or a complete drainage (if possible), during which care should be taken not to spread plant fragments. Mechanical dredging is preferably conducted in late spring or early summer, when the plant is visible but before the start of its accelerating growth phase (August-September). Operators must pay great attention not to fragment the plants (as much as possible). Manual removal is implemented as a follow-up measure for a minimum of 2 to 3 years to remove any regrowth or seedlings. Finding an adequate disposal site for the storage of contaminated sediments must be done before the start of this management action.

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Material

Management: Excavators with cleaning bucket, digger

Transport and stocking: Buckets or waterproof bags, tarpaulin, trucks, dumpers and wheelbarrows

Precautionary measures: Hand net, containment nets (mesh size <1cm)

Fig 36. Mechanical dredging of water primrose after a complete drainage of the water body. Photo: Arnaud Monty

Light deprivation: bank cover

- ✔ Local eradication can be achieved
- ✔ Drastic biomass reduction can occur in a short amount of time
- ✖ This method is suitable for small populations on terrestrial environments
- ✖ The method is not selective and will impact other living organisms

Method description

The principle is to install bank covers that both compress vegetation and exclude sunlight, causing the death of the plants. Sheets are manually placed by operators on the entire population that has colonised the bank and terrestrial environments. It is crucial to ensure that no light reaches the plants through gaps or at the edges and intersections of the sheeting. Operators must ensure the adequate placement of the bank covers and that strips overlap correctly. The use of large continuous pieces of sheeting is therefore recommended whenever possible. The material is then anchored to the bank. The sheeting is placed in spring or summer and remains in place for a few weeks or months. Manual removal is then implemented as a follow-up measure to remove any regrowth. This method can also be implemented for populations where hand removal is complicated.

Material

Management: The adequate quantity of light-blocking sheeting such as black plastics, PVC or nylon tarp. Weights, rocks, concrete blocks or sandbags.

References

Guérin, M. and Provendier, D. (2014) *Gestion des plantes exotiques envahissantes.* ONEMA, Plantes et cité.

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Myriophyllum aquaticum

Species description

Parrot's feather (*Myriophyllum aquaticum*) is a perennial aquatic or semi-aquatic plant that has both a submerged and an emergent form. The species, native to South America, was introduced to Europe, including Belgium, through the aquarium industry as a popular plant for aquarium and garden ponds. The first record of the parrot's feather's presence in the environment in Belgium dates back to 1983. Disposal of aquarium and/or pond waste in water systems is probably at the origin of its escape in the wild. Today, parrot's feather is recognised as a problematic aquatic invasive species in many countries worldwide and is now listed as IAS of Union concern under the (EU) Regulation No 1143/2014. The species can be confused with other plant species such as its close relative *Myriophyllum rubricaule*. Its presence on the Belgian territory probably remains underestimated, especially due to its presence in private gardens.

Fig 37. *Myriophyllum aquaticum*. Photo: Q-Bank

Photo: Dido Gosse

Myriophyllum aquaticum

Parrot's feather mostly thrives in nutrient-rich stagnant freshwater and grows best in shallow and muddy water bodies such as ponds, ditches and marshes. The species can also colonise wet banks. As a highly competitive invasive species, the plant has diverse environmental, social and economic impacts. It has the ability to form dense mats that completely cover the water surface, which has significant detrimental effects on the ecosystem and biodiversity. These impacts include light exclusion, native plant community displacement, water quality degradation and higher siltation. Social and economic effects include restriction of recreational activities (angling, boating), and management related costs.

Biological characteristics, reproduction and spread

Parrot's feather grows from overwintering rhizomes that produce long shoots creeping over the sediment and reaching the water surface as temperature increases. Emergent stems can extend up to 30 centimeters above the water surface. As the season progresses, emergent leaves tend to dry out. The plant dies back to the rhizomes (the roots remain alive) in fall and survives mild winter conditions such as infrequent and short periods of frost. The plant however does not seem to tolerate harsh winter conditions.

Parrot's feather is a dioecious species which reproduction in Western Europe is exclusively vegetative via female plants only. When the plant breaks into fragments, be it naturally of because of human activity, those fragments, as small as a few millimeters, can form a new plant, and therefore a new population, away from the initial invaded area. Spread of parrot's feather can happen through flooding events, fragments attached to boats or other water equipment. Fragments can regenerate within a few weeks and can remain viable for 1 year under moist conditions. Those high regeneration and dispersal abilities highlight the importance of the implementation of effective management measures.

Fig 38. Parrot's feather invading different parts of the pond due to the spread of fragments. Photo: Dido Gosse

References

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General considerations about management

A wide range of management options have been used to control or eradicate this species. Local eradication of large and even small parrot's feather infestations is considered hardly achievable due to the species ability to regenerate from small fragments and colonise both aquatic and wet terrestrial environments, making management extremely difficult. The eradication feasibility of this species must, therefore, always be assessed on a case-by-case basis, considering site specificities and population size, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce vegetatively by fragmentation, precautionary measures must be implemented prior to management to prevent teh spread of fragment within the managed area or to other water systems. Managed areas are, therefore, isolated by physical barriers.

The harvested plant material must be safely disposed of away from water systems. It can be either dried and incinerated, buried (on dry land), or composted off-site. It is recommended to dry the harvested material on a tarpaulin to avoid leaving the plant material in contact with the ground. If transported to disposal facilities, plant material must be placed in secured and thick bags. Material that has been in contact with the plant (e.g. machinery, clothing) should be checked, cleaned and dried before being taken to another site. It is also recommended to restrict public access to the managed area to isolate the infestations as much as possible and limit the risk of spread.

Managed and downstream sites must remain under enhanced surveillance for a 5-year period after the implementation of the last treatment. As the parrot's feather is shade-intolerant, promoting environmental shading through revegetation with native plant can help prevent the (re)establishment of this invasive species.

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Fig 39. Parrot's feather produces long creeping shoots. Photo: Etienne Branquart

Fig 40. Parrot's feather colonising the bank. Photo: Marie Patinet

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Manual removal

- ✔ Local eradication can be achieved
- ✔ Good control can be expected
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ The method is only suitable for small and early-detected infestations
- ✖ There is a risk to create and spread fragments to uninvaded areas
- ✖ Manual removal is time-consuming, labor intensive and requires skilled operators

Method description

The principle is to remove the whole plant from the ecosystem. Plants are carefully pulled out by operators walking in the water, from the bank or from a small boat. Operators must pay great attention to minimise shoot fragmentation as much as possible. Manual removal is only implemented in recently invaded sites or in areas with low vegetative abundance, and in shallow waters. It is strongly recommended to repeat the operation shortly after the initial manual removal, once sediments have settled, to ensure that no plants have been overlooked. This management strategy is conducted between March and October. It is repeated every 6 weeks during spring, summer, and fall for the first year of the management programme. A 5-year manual aftercare is then necessary to eliminate regrowth. Operators must remove all or most of the plant material, including rhizomes, to ensure the effectiveness of this method.

Material

Management: Professional operators, small boats, waders, rakes

Transport and stocking: Buckets or mesh bags

Precautionary measures: Hand net (to collect floating fragments), retention nets. A hardware cloth screen must also be placed at the upstream and downstream parts of the managed area, and remain in place for 5 days following the operation.

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Substrate removal: mechanical dredging

- ✔ This is one of the fastest methods to achieve good levels of control
- ✔ This method is suitable for large infestations
- ✔ Mechanical dredging can be implemented when maintenance dredging of the water body needs to be done
- ✖ High costs are expected due to use of machinery and the need to move sediments to dedicated disposal sites
- ✖ Disposal sites must be identified for the storage of contaminated sediments before the start of the work
- ✖ This method can only be implemented in sites where the whole area is accessible to the machines and where drawdown can be implemented
- ✖ Dredging can generate a large number of plant fragments which increases the risk to spread the species to uninvaded areas
- ✖ This method can have high negative impacts on aquatic living organisms

Method description

The principle is to remove the bottom sediments contaminated with all parts of the invasive plant such as roots, rhizomes and stems. Excavators equipped with cleaning bucket thumb are used for excavation and must remove at least 15 to 25 cm of sediment to prevent regrowth. This method is preceded by a water drawdown (< 0.5 m) or a complete drainage (if possible), during which care should be taken not to spread plant fragments to other areas via the sewage systems. Mechanical dredging is preferably conducted from spring to early summer.

References

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Wersal, R.M. (2010) *The conceptual ecology and management of parrot feather* [Myriophyllum aquaticum *(Vell.) Verdc.*]. PhD thesis. The Faculty of Mississippi State University.

The ideal management timing is when the plant is visible, and therefore easy to detect, but before the start of its high development phase. Operators must be extremely careful to minimise plant fragmentation and to remove as much plant material as possible. Follow-up methods such as repeated manual removal to progressively eliminate regrowth or the placement of light-blocking sheeting over the substrate, are implemented.

Material

Management: Excavators with cleaning bucket, light-blocking covers

Transport and stocking: Buckets, dumpers, wheelbarrows, trucks, containers

Precautionary measures: Hand net, containment nets, biofilters

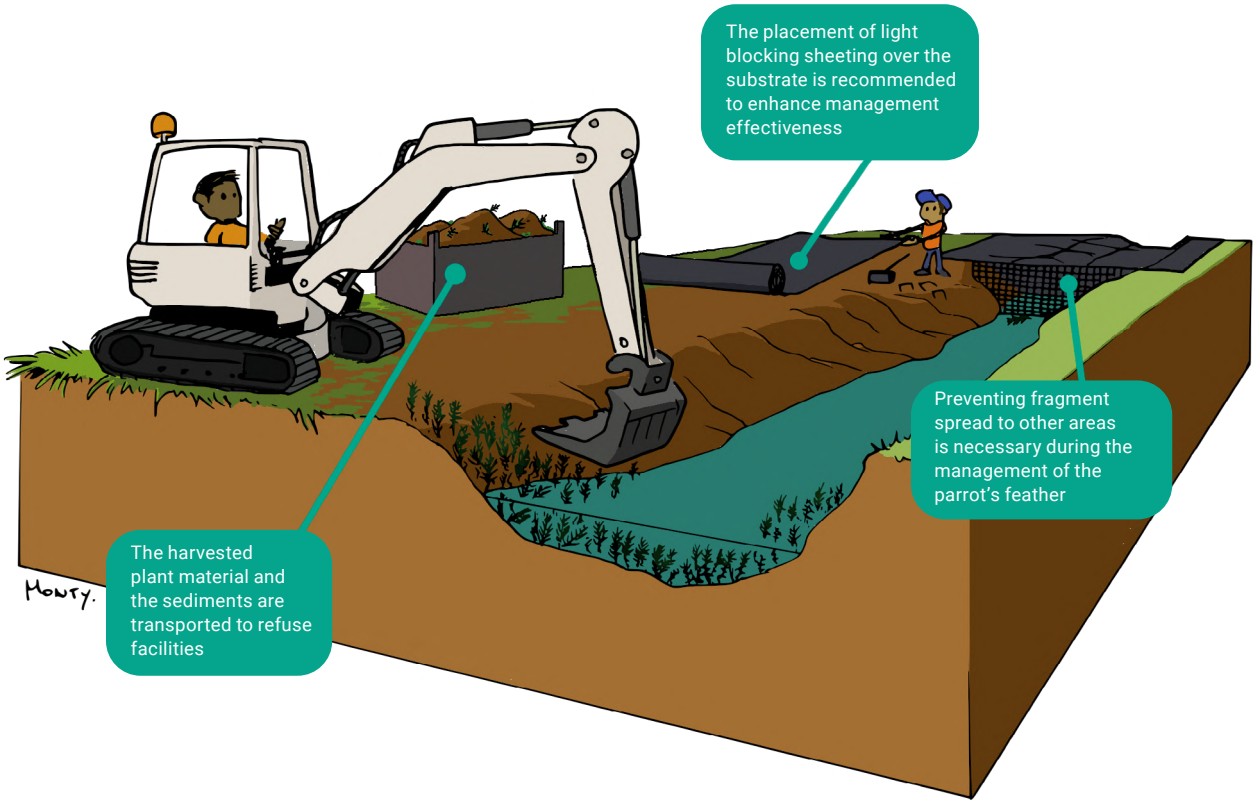

Fig 41. Mechanical dredging of parrot's feather

Light deprivation: benthic and bank plastic cover

- ✔ Local eradication or really good control can be achieved
- ✔ The material is solid and durable and, can be reused in other sites
- ✖ The method is suitable for small populations and recently invaded areas
- ✖ The use of this method is only limited to stagnant waters and areas free of obstacles
- ✖ The whole infestation must be covered as re-colonisation will occur if invaded places are overlooked
- ✖ The method is not selective and will have an impact on other living organisms
- ✖ This method is likely to be detrimental to benthic organisms and affect fish spawning

Method description

The principle is to install bottom and bank covers that both compress vegetation and exclude sunlight, causing the death of the plants. Sheets are manually placed by operators on the bottom of shallow water bodies. It is really important that no light reaches the plants from any adjacent area, gaps or at the edges of the sheeting. Operators must ensure the adequate placement of the benthic cover and that sheets overlap correctly on the bottom. The use of large continuous pieces of sheeting is therefore recommended whenever possible. They must also ensure that banks are well covered by the sheeting as the species also occurs on the edges of water systems. The material must, then, be secured to the bottom and to the banks. As gases can accumulate when using non-permeable material, maintaining the sheet with heavy weights or using timber frames to leave a small gap between the bottom and the blanket is required. Benthic covers are placed during winter, when the plants are prostrate and left in place for 4 to 12 months. Regular checks for potential damages that would allow light to pass through must be done. The sheeting must be removed when local eradication or really good control is achieved. Manual removal is immediately implemented as a follow up measure to remove remaining plants and is repeated throughout the years until no regrowth is observed.

Material

Management: The adequate quantity of light-blocking sheeting such as woven synthetics, geotextile, black plastic sheets and nylon tarp or similar material. Heavy weights, rocks, concrete blocks or sandbags.

If damages occur to the sheeting, plastic zip ties can be used to join the blankets together.

References

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DID YOU KNOW?

What about jute matting?

While plastic materials have commonly been used for the management of parrot's feather, more ecofriendly and permeable materials such as hessian fabrics could potentially replace those materials. Indeed, jute matting has successfully been used for the eradication or good control of other invasive aquatic species such as *Lagarosiphon major*.

However, really few cases refer to the use of jute matting as a successful mean to control or eradicate parrot's feather populations. While it could be argued that jute matting is likely to help for the control of many aquatic invasive plant species, concerns remain over possible recolonization from individuals rooted in the bank which would question the effectiveness of this method for this particular species.

Fig 42. Jute matting. Photo: Auckland Museum

References

Caffrey, J. *et al.* (2010) A novel approach to aquatic weed control and habitat restoration using biodegradable jute matting. *Aquatic Invasions*, 5(2), 123–129.

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Environmental management: ecosystem shift

- ✔ Local eradication can be achieved
- ✔ Rapid results are expected
- ✖ This method is only suitable for small or medium water bodies, with low conservation value
- ✖ The method involves the complete replacement of an ecosystem by another, resulting in highly modified and vulnerable environments

Method description

The principle is to transform the existing aquatic ecosystem into another ecosystem that is unsuitable for the survival or establishment of the aquatic plant. This requires drying out and refilling the water body with adequate substrate, using machinery, and planting or sowing native terrestrial plants. The selection of the new ecosystem should take into account local conditions, plant availability, and regional conservation objectives to mitigate the loss of biodiversity. Discussions with stakeholders such as conservationists and local authorities can help to guide the decision-making process toward the most suitable new ecosystem. During the process, it is crucial to avoid introducing alien species with the substrate, and ideally, the substrate should be taken from the same site to minimise those risks. A new pond, near the previous one, can be dug up to compensate for habitat loss. In that case, it is important to prevent the introduction of the aquatic alien species in the new pond. Due to the possible legal and practical constraints (e.g. sites with conservation, cultural, historical value), the major impacts on aquatic organisms and the potential risks of introducing terrestrial invasive species, this method should only be considered after all the other management possibilities have been rejected. Ecosystem shift is only suitable for already degraded water bodies where no species of interest remain and where parrot's feather has taken over the whole water system. Once the new ecosystem is established, regular monitoring and checks should be conducted over a 3-year period to ensure that no regrowth occurs.

Material

Management: Excavators or large diggers and dumpers.

References

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Myriophyllum heterophyllum

Species description

Broadleaf watermilfoil (*Myriophyllum heterophyllum*) is a perennial aquatic or semi-aquatic plant that has both a submerged and an emergent form. The species, native to North America, was introduced to Europe, including Belgium, through the aquarium industry as a popular ornamental plant for aquarium and garden ponds. The first record of broadleaf watermilfoil's presence in the environment in Belgium dates from 1993. Disposal of aquarium or pond waste in water systems is probably at the origin of its escape in the wild. Today, broadleaf watermilfoil represents a problematic aquatic invasive species in many countries worldwide and is listed as IAS of Union concern under the (EU) Regulation No 1143/2014. At vegetative stage, the species can be confused with other plant species of the same genus. Its distribution on the Belgian territory is still very limited but probably remains underestimated.

Fig 43. *Myriophyllum heterophyllum*. Photo: Q-Bank

Photo: Penguin

Myriophyllum heterophyllum

Broadleaf watermilfoil thrives in nutrient-rich stagnant or slow-moving freshwater such as ponds, ditches and canals. As a highly competitive invasive species, the plant has diverse environmental, social and economic impacts. This invader can form dense mats and extensive populations that can completely cover the water surface. This has significant detrimental impacts on the ecosystem and biodiversity, including light exclusion, native plant community displacement, and water quality modification. Social and economic effects include restriction of recreational activities (angling, boating), and management related costs.

Biological characteristics, reproduction and spread

Broadleaf watermilfoil overwinters and experiences rapid growth during spring, although emergent leaves may only become apparent in late summer. As an evergreen species, it can be observed throughout the year and is highly resistant to both high summer or cold winter temperatures. The plant, which can take root at depth of 2 to 3 meters, produces flowers between June and September, although flowering appears to be exceptional under Belgian conditions.

Reproduction of broadleaf watermilfoil in western Europe is probably exclusively vegetative. When the plant breaks into fragments, either naturally or due to human activity, those small fragments can form a new plant, and therefore a new population, away from the initial invaded area. While the plant is also known to produce viable seeds in some cases, seed production has not yet been observed in Europe. The spread of broadleaf watermilfoil can occur through flooding events, fragment drift within water systems or via fragments attached to boats and other water equipment. Fragments can remain viable for a considerable amount of time, and are able to regenerate, even under moist and dry conditions, as the species is highly tolerant to desiccation. Those high regeneration and dispersal abilities highlight the importance of the implementation of effective management measures.

Fig 44. Population of broadleaf watermilfoil covering the water surface. Photo : Matt Keevil

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General considerations about management

A wide range of management options have been used to control or eradicate broadleaf watermilfoil. Local eradication of both small and large infestations is considered challenging but achievable due to the species' ability to regenerate from small fragments and to take root at important depths. The eradication feasibility must always be assessed on a case-by-case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce vegetatively by fragmentation, precautionary measures must be implemented before undertaking management activities to prevent fragment spread within the managed area or to other water systems. Managed areas are, therefore, isolated by physical barriers.

The harvested plant material must be safely disposed of away from water systems and is either dried and incinerated, buried (on dry land) or composted off- site. If transported to refuse facilities, it is recommended to dry the harvested material on a tarpaulin to avoid leaving the plant material in contact with the ground. Material that has been in contact with the plant (e.g. machinery, clothing) should be checked, cleaned and dried before being taken to another site. It is also recommended to restrict public access to the managed area to isolate the infestations as much as possible and limit the risk of spread.

Managed and downstream sites must remain under enhanced surveillance for a 5-year period after the implementation of the last treatment.

Fig 45. The emergent growth form. Photo : Jean-Marc Vallières

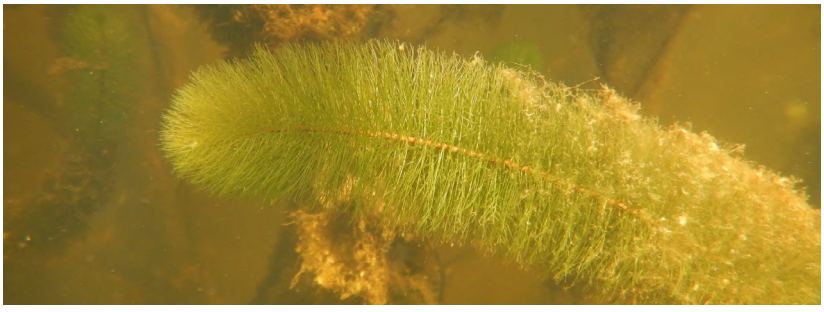

Fig 46. The submerged growth form. Photo : Matt Keevil

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Manual removal

- ✔ Local eradication can be achieved
- ✔ Good control can be expected
- ✔ Manual removal is highly selective and will have minimal disturbance and impact on ecosystems and other organisms
- ✖ The method is only suitable for small infestations
- ✖ There is a risk to create and spread fragments to uninvaded areas
- ✖ Manual removal is time-consuming, labor intensive and requires skilled operators

Method description

The principle is to remove the whole plant from the ecosystem. Plants are pulled out by scuba divers or operators walking in the water, working from the bank or from a small boat. Manual removal is implemented in recently invaded sites, areas with low vegetative abundance and shallow waters. It is strongly recommended to repeat the operation shortly after the initial manual removal, once sediments have settled, to ensure that no plants have been overlooked. This management strategy is conducted between March and October, and is repeated every 6 weeks during spring, summer and fall for the first year of the management programme. It is then followed by a 5-year manual aftercare to eliminate regrowth. Operators must pay great attention not to fragment the plants and to remove most of the plant material for this method to be worth implementing.

Material

Management: Small boats, waders, rakes, diving equipment

Transport and stocking: Buckets or mesh bags

Precautionary measures: Hand net, containment nets. A hardware cloth screen must also be placed at the upstream and downstream parts of the managed area and remain in place for 5 days following the operation.

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Mechanical removal: floating machines

- ✔ Rapid control can be expected
- ✔ Depending on the machinery used, mechanical removal is suitable for most situations
- ✖ This method can only be implemented in sites where the vast majority of the invaded area is accessible to the machines
- ✖ Mechanical removal can create vast numbers of plant fragments with the risk to spread the species to uninvaded areas and other parts of the managed water system
- ✖ Depending on the type of machinery used, mechanical removal can negatively affect fish communities through oxygen depletion

Method description

The principle is to mechanically remove the whole plant from the ecosystem. Plants are uprooted by a weed conver boat. One concrete example of machine used is the harkboot, a boat equipped with a large rake on one side and another rake with inserted mesh on the other. The large rake scrapes up the bottom of the water body while the rake with inserted mesh is used to collect the uprooted plant material and discharge it temporarily on the bank. The selection of rake tines should be based on the type of substrate and the targeted species.For the management of broadleaf watermilfoil, coarse tines will be preferred in clay beds while small tines will be favoured in sand beds. As different boat dimensions are available, this method can be conducted in large or small infestations present in deep or shallow waters (at least 0.6 m deep). If the method is implemented in running waters, it is recommended to work in accordance with the direction of the current to prevent re-infestation of cleaned-up areas to occur. Similarly, if mechanical removal is implemented in stagnant waters, the direction of the wind or the presence of hydraulic infrastructures, which may influence current, must be taken into account. As the weather and wind direction can change throughout the day, the working method must be adjusted accordingly. Mechanical control is preferably implemented in late fall to preserve native macrophytes and eliminate the competitive advantage of *M. heterophyllum*.

References

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Mechanical removal is immediately followed by the manual removal of plants that were inaccessible to the machines (e.g. plants rooted near the bank or obstacles). Remaining drifting plant fragments are also removed. Operators must pay great attention to remove as much plant material as possible. Repeated mechanical removal is often required (at least once a year), over a few years, and regular site surveys must be conducted. Once a good level of control is achieved and that the infestation is limited, manual aftercare is implemented to remove regrowth.

Material

Management: Adequate boat

Transport and stocking: Containers and trucks

Precautionary measures: Hand net, containment nets. A floating net with lead-line must also be placed at the downstream part of the managed area and remain in place for 5 days following the operation.

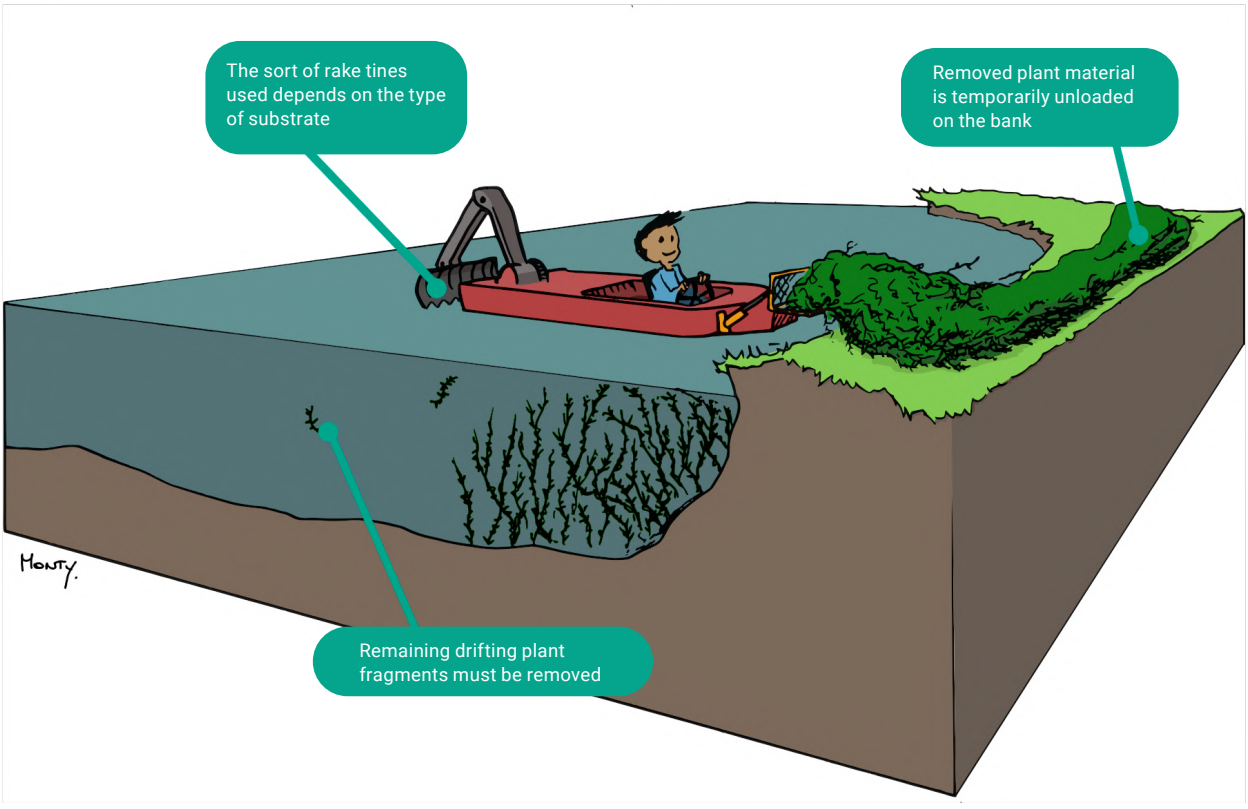

Fig 47. Mechanical removal of broadleaf watermilfoil using the harkboot

Substrate removal: mechanical dredging

- ✔ This is one of the fastest methods to achieve good levels of control
- ✔ This method is suitable for large infestations
- ✔ Mechanical dredging can be implemented when maintenance dredging of the water body is required
- ✖ High costs are expected due to use of machinery and the need to move sediments to dedicated disposal sites
- ✖ Disposal sites must be found for the storage of contaminated sediments before the start of the work
- ✖ This method can only be implemented in sites where the whole area is accessible to the machines and where drawdown can be implemented
- ✖ Dredging can create vast numbers of plant fragments with the risk to spread the species to uninvaded areas
- ✖ This method can have high negative impacts on aquatic living organisms

Method description

The principle is to remove the bottom sediments contaminated with all parts of the invasive plant such as roots and stems. Excavators equipped with cleaning bucket thumb are used for excavation and the removal of at least 15 to 25 cm of sediment to prevent regrowth. This method is preceded by a water drawdown (< 0.5 m) or a complete drainage (if possible) during which care should be taken not to spread plant fragments to other areas via the sewage systems. Mechanical dredging is conducted when the plant is prostrate (around March). Operators must pay great attention not to fragment the plants and to remove as much plant material as possible. Follow-up methods such as repeated manual removal to progressively eliminate regrowth or the placement of light-blocking sheeting over the substrate are implemented.

Material

Equipment: Excavators with cleaning bucket

Transport and stocking: Buckets, trucks, dumpers and containers

Containment: Hand net, containment nets, biofilters

References

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Light deprivation: benthic jute matting

- ✔ Local eradication or really good control can be achieved within a few months
- ✔ The method is suitable for both limited and large invaded areas
- ✔ The material is solid and biodegradable, thus does not require to be removed (eco-friendly and no removal costs)
- ✔ The jute enables native vegetation to grow through it, which allows native plant species to reestablish. It also enables gas to escape
- ✖ This method is limited to stagnant waters
- ✖ The placement of jute matting can be impracticable or impossible in sites where obstacles are present
- ✖ The method is likely to be detrimental to benthic organisms and affect fish spawning

Method description

The principle is to install bottom covers that both compress vegetation and exclude sunlight, causing the death of the plants. Jute matting, a natural and biodegradable vegetable fiber, is placed by divers or operators on the bottom of the water body. For large populations of broadleaf watermilfoil in deep waters, long strips of jute are deployed from a boat on the water surface and rapidly sink to the bottom. For smaller populations, sheets are manually placed on the weed bed by divers or operators. It is really important that no light reaches the plants from any adjacent area, gaps or the edges of the sheeting. Divers or operators must ensure the adequate placement of the matting and that strips overlap correctly. The use of large continuous pieces of sheeting is therefore recommended, whenever possible. The sheets must then be secured to the bottom using weights. Benthic covers are placed during winter, when the plants are prostrate, and are never to be removed as jute eventually disintegrates after 1 or 2 years. Eradication is, however, achieved within a few months. Once the jute has disintegrated, inspections and manual removal are conducted to remove any plant regrowth, until none is found.

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Caffrey, J. *et al.* (2010) A novel approach to aquatic weed control and habitat restoration using biodegradable jute matting. *Aquatic Invasions*, 5(2), 123–129.

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Material

Management: The adequate quantity of jute matting rolls. It is important to ensure that the plant does not grow through the holes of the fabric. Jute textile with mesh size 0.5 mm, 300 $g.m^{-2}$, is therefore recommended. Weights, rocks, concrete blocks or sandbags. Boat and skilled operators or scuba divers.

Non-biodegradable materials such as PVC plastics, woven synthetics or fibreglass 'stabilising paper' have commonly been used as benthic covers for the management of broadleaf watermilfoil. However, this type of material presents many significant disadvantages. For non-permeable material, gases can accumulate and lift the blankets, allowing light to reach the plants. Non-biodegradable material also requires to be removed, which generates additional costs. It also has a greater negative impact on living organisms and the ecosystem.

While available information on the use of jute matting as a successful measure to manage broadleaf watermilfoil is quite limited, it is likely that this technique will be effective on this invasive weed.

Fig 48. The placement of covers is preferably implemented in small areas as covering large areas can rapidly become expensive. Photo : Eric Keith

DID YOU KNOW?

Hydro Venturi, an effective tool

The hydro-venturi system consists in applying a powerful water jet to uproot the plants. The floating plants are then removed from the water. The hydro venturi has successfully been used for the control (significant reduction in plant biomass) and the eradication of diverse invasive aquatic weed species such as *Cabomba caroliniana* and *Myriophyllum* spp. The system also displays significant advantages over similar mechanical removal techniques including fragment reduction, reduced plant regrowth, high level of acceptability by stakeholders, etc.

Some limitations of such system must, however, also be acknowledged. While expensive and non-selective, the use of hydro venturi requires skilled operators and preparatory work. Its efficiency is also highly dependent on sediment type and water depth.

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AQUATIC SPECIES OF THE LIFE RIPARIAS ALERT LIST

Aponogeton distachyos

Fig 49. *Aponogeton distachyos*. Photo: Eigenes Werk

Species description

Cape-pondweed (*Aponogeton distachyos*) is a submerged and floating perennial aquatic plant native to South Africa. The species was introduced to Europe, including Belgium, through the horticultural trade as a popular ornamental plant for garden ponds and botanical gardens. The first records of cape-pondweed's presence in the environment in Belgium appear to date back to 1993. Intentional introduction in water systems is probably at the origin of its escape into the wild. Today, while emerging in some countries like Belgium, the plant might become a problematic aquatic invasive species in the near future. It is therefore a species of the LIFE RIPARIAS alert list. Although easily detectable, its presence on the Belgian territory probably remains underestimated due to a lack of recorded observations and monitoring efforts.

Photo: H. Zell

Aponogeton distachyos

Cape-pondweed grows in stagnant or slow-moving waters up to 1.5 m deep, often rich in nutrients such as streams, ponds or ditches. As an emerging invasive species, the plant might cause diverse environmental, social and economic impacts in the near future. For instance, this invader has the ability to form dense mats on the surface of the water, with subsequent detrimental impacts on the ecosystem and biodiversity through light restriction, modification of water quality and vegetation composition. The species also facilitates algal blooms and alters stream flows. Social and economic effects might include restriction of recreational activities (angling, boating), increased risks of flooding, and management-related costs.

Biological characteristics, reproduction and spread

This species, which develops from a tuber, has semi-persistent floating leaves. Flowering of cape-pondweed occurs twice; once in spring and a second time in autumn. In some parts of its introduced range, the plant sometimes appears to go dormant during the summer months, but this is not always the case. Cape-pondweed overwinters in sediments as seeds and tubers, although flowering during all winter is possible if temperatures allow it (mild weather). The species is not resistant to drought and cold temperatures. Exposition to those conditions could result in high mortality.

Fig 50. Cape-pondweed forming a mat on the surface of a stream. Photo: Marie Patinet

References

Branquart, E. *et al.* (2021) *Belgian alert lists of alien aquatic plants and crayfish.* LIFE RIPARIAS project.

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In western Europe, cape-pondweed reproduces both sexually and asexually. The species has a vast system of tuberous rhizomes, and vegetative expansion is possible via rhizomes and tubers. Sexual reproduction relies on seed production. Seeds are contained in fruits which are buoyant and, therefore, able to float for a limited amount of time before releasing the seeds, which will, in turn, germinate on the water surface. On average, each inflorescence can produce several hundred seeds. Seed survival time remains rather uncertain but appears to be relatively short. Spread of this invasive weed mainly occurs through seed drift within water systems but also via human activities with viable plant material (seeds or tubers) being attached to boats, waders or any other water equipment. However, as the species is vulnerable to drought, it is likely that transported plant material will not survive long during overland transportation. The species' high regeneration and dispersal abilities highlight the importance of implementing effective management measures.

Fig 51. Monitoring and manual removal of a cape-pondweed population in Belgium. Photo: Marie Patinet

General considerations about management

Very few management options have been tested to control and eradicate the species, with manual removal being the most suitable available measure. There is, however, a lack of available information on cape-pondweed management. Local eradication of cape-pondweed is believed to be achievable for small infestations in confined water bodies, although really effective management techniques are still being sought for this species. Nevertheless, the eradication feasibility of populations must be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce both sexually and asexually, precautionary measures must be implemented before management to prevent spread within the managed area or to other water systems. Because seeds are transported downstream, management must begin with upstream infestations and progress downstream. Management actions are also initiated before the species sets seeds. Finally, managed areas are also isolated by physical barriers.

The harvested plant material must be safely disposed of far away from the water and is either composted or transported to disposal sites. Material that has been in contact with the plant as well as with the substrate that may contain seeds (e.g. clothing, tools, shoes), should be checked, cleaned and dried before being taken to another site.

While information on seed viability are lacking, the precautionary principle is applied. Managed areas and downstream sites must therefore remain under enhanced surveillance with regular monitoring for at least 5 years after the last treatment.

Manual removal

- ✔ Local eradication can be achieved
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ The method is only practical for really small infestations
- ✖ Manual removal is time-consuming and labor intensive

Method description

The principle is to remove the whole plant from the ecosystem. Depending on the substrate and water depth, plants are either dug out or pulled out by the roots by operators walking in the water, working from a boat or from the bank. This management strategy, conducted during the vegetative period, begins with upstream infestations and progresses downstream. Operators must verify that seeds are not being produced and must avoid creating rhizome fragments. They must also ensure that all tubers and rhizomes are removed from the sediments to prevent regrowth. Frequent checks are conducted to remove plants that have been overlooked, as well as seedlings and regrowth from tubers and rhizomes. Manual removal must be repeated until no seedling and regrowth occur.

Material

Management: Waders, gloves, garden fork, rakes

Transport: Bags

Precautionary measures: Containment net

References

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Crassula helmsii

Species description

New Zealand Pigmyweed (*Crassula helmsii*) is an aquatic perennial plant that can grow in submerged, amphibious and terrestrial forms. The species, native to Australia and New Zealand, was introduced to Europe, including Belgium, through horticultural trade as a popular oxygenating plant for aquarium and garden ponds. The first record of New Zealand Pigmyweed's presence in the environment in Belgium dates back to 1982. Disposal of aquarium and pond waste in water systems is probably at the origin of its escape into the wild. Today, New Zealand Pigmyweed represents a problematic aquatic invasive species in many countries worldwide but is not listed as an IAS of Union concern under the (EU) Regulation No 1143/2014. The species was therefore included in the LIFE RIPARIAS alert list. Its distribution on the Belgian territory probably remains underestimated notably due to its rapid spread as well as its submerged form which makes it hardly detectable.

Fig 52. *Crassula helmsii.* Photo: Q-Bank

Photo: Jérémie Guyon

Crassula helmsii

New Zealand Pigmyweed thrives in a wide variety of habitats but mostly occurs in still or slow-moving waters such as ponds, rivers, wetlands or ditches. It can also be found on damp soils such as riverbanks or muddy edges of ponds. As a highly competitive invasive species, the plant has diverse environmental, social and economic impacts. This invader can form dense mats that completely cover the water surface. This has significant detrimental impacts on the ecosystem and biodiversity including through native plant community displacement, species richness reduction, severe water quality modifications causing fish kills and inadequate habitats for invertebrates and amphibians. Social and economic effects include drowning hazards as water bodies are mistaken as land, detrimental impacts on aquaculture and fisheries, restriction of recreational activities (angling, boating), and management related costs.

Fig 53. The submerged form reaching the water surface. Photo: Jérémie Guyon

Fig 54. Large pond completely invaded by the New Zealand Pigmyweed. Banks have also been colonised. Photo: Marie Patinet

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Biological characteristics, reproduction and spread

New Zealand Pigmyweed displays 3 different growth forms with its morphology varying depending on the growth form. While the species is able to establish itself as a submerged plant at depths of 3m, it can also develop an emergent form creating stands of crowded stems in shallow waters (around 50cm deep). The semi-terrestrial form consists in creeping or erected stems with leaves. New Zealand Pigmyweed is winter green and has the ability to grow throughout the whole year, with no dormant periods. In Belgium, flowering occurs from July to September.

Reproduction of New Zealand Pigmyweed in western Europe is mostly vegetative. When the plant breaks into fragments, either naturally or because of human activity, those small fragments (one node on a stem as small as 5 mm) can form a new plant, and therefore a new population, away from the initial invaded area. Fragments can remain viable for more than a year. In some regions of its introduced range (UK), the plant is also known to produce turions (shoots with short internodes) in autumn, which float on the water surface. It remains, however, unclear whether turions are produced in Belgium. While New Zealand Pigmyweed produces viable seeds in its native range, seed production is only occasionally observed in Europe. Whether persistent seedbanks are formed still remains unclear. Spread of New Zealand Pigmyweed mainly occurs through fragment drift within water systems or fragments attached to animals, boats, waders or any other water equipment. The species' high regeneration and dispersal abilities highlight the importance of the implementation of effective management measures.

Fig 55. The emergent form growing in shallow waters and forming large stands. Photo: Marie Patinet

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General considerations about management

Various management options have been used to control or even eradicate the species, in somes cases. However, New Zealand Pigmyweed remains one of the most challenging species to manage, with its eradication considered hardly achievable, even for small infestations. Due to the considerable risk of spreading the species, management options are highly restricted. Management goals must, therefore, be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce vegetatively through fragmentation, precautionary measures must be implemented prior to management to prevent fragment spread within the managed area or to other water systems. As the risk of further spread when managing this species is particularly high, it is strongly recommended to fence the treated area to restrict access and prevent further spread by wildlife or people. Those fences must remain in place until eradication is achieved.

The harvested plant material must be safely disposed of far away from the water and is either incinerated or safely composted. Material that has been in contact with the plant (e.g. material, clothing, etc.) must be checked, cleaned and dried before being taken to another site. Exposing equipment to hot water (45°C) for 15 minutes has proven to be highly effective as it results in 90% mortality of plant material within 1 hour following treatment.

Managed areas and downstream sites must remain under enhanced surveillance with regular monitoring taking place every 3 to 6 months for at least 5 years after the last treatment.

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Light deprivation: terrestrial and benthic plastic cover

- ✔ Local eradication or really good control can be achieved
- ✔ The material is solid and durable and can be reused in other sites
- ✖ The method is only suitable for small populations and recently invaded areas
- ✖ This method is limited to stagnant waters and to areas that are free from obstacles
- ✖ The whole invaded area must be covered by the sheeting as re-colonisation will occur if infested places are overlooked
- ✖ The method is not selective and will have high impact on other living organisms
- ✖ This method is likely to be detrimental to benthic organisms and affect fish spawning

Method description

The principle is to install bottom and terrestrial plastic covers that both compress vegetation and exclude sunlight, causing the death of the plants. A blanket is placed over the whole invaded area and on the banks as the species also occurs on the edges of water systems. It is essential to cover the entire infestation to prevent recolonisation to occur after the removal of the sheeting. As New Zealand Pigmyweed displays a high tolerance to shade, it is important that no light reaches the plants from any adjacent area, gaps or at the edges of the sheeting. Operators must ensure the adequate placement of the benthic cover and that sheets overlap correctly on the bottom. The use of large continuous pieces of sheeting is therefore recommended whenever possible. The blanket is then strongly secured to the bottom of the water system and to the bank. Blankets must be placed early in the season (April) and remain in place for minimum 3 months. A 6-month period is, however, recommended.

Fig 56. New Zealand Pigmyweed establishing itself around obstacles. Photo : Dr Morley Read/ Shutterstock

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van der Loop, J. *et al.* (2019) *Risk assessment of Australian swamp stonecrop* (Crassula helmsii) *in Europe.* Europe FLORON.

This method is only implemented in sites free from obstacles, as the species establishes itself around those obstacles, where the placement of the sheeting is impractical or impossible. Regular checks for potential damages that would allow light to pass through must be done. Once the sheeting is removed, all dead plant material is evacuated from the site with great care. Immediate manual removal must be implemented as a follow-up measure to remove remaining plants or regrowth. The treated area must be surrounded by physical barriers to prevent fragment spread.

Wilton-Jones, G. (2005) Control of New Zealand pygmyweed *Crassula helmsii* by covering with black polythene at the Lodge RSPB Reserve, Bedfordshire, England. *Conservation Evidence*, 2, 63-63.

Material

Management: The adequate quantity of light-blocking sheeting such as black polythene, pool covers or similar material. Rope, cable, star pickets or heavy weights. If damages occur to the sheeting, plastic zip ties can be used to join the blankets together.

More ecofriendly and biodegradable materials such as jute matting could potentially be used for the management of New-Zealand Pigmyweed. This material has successfully been used for the eradication of other invasive aquatic species such as *Lagarosiphon major*. Although there is limited information available on the use of jute matting as a management measure for New Zealand Pigmyweed, one trial in Ireland showed that low density infestations could be successfully treated with double layers of jute matting.

Precautionary measures: Physical barriers using 5mm wire mesh are necessary to prevent fragment spread.

Fig 57. New Zealand Pigmyweed colonising the bank of the water body. Photo : Emmanuel Delbart

DID YOU KNOW?

Flooding with salt water

Flooding the invaded area with salt water has been found to be a very effective technique to achieve local eradication of New Zealand Pigmyweed populations.

This measure is, however, area-dependent as it can only be implemented in sites where water can be retained and with access to a source of saline water (e.g. near the coast). It is important to note that New Zealand Pigmyweed displays a certain tolerance to brackish water.

Mite to the rescue: a promising biological agent

Research has demonstrated that the gall-forming mite (*Aculus crassulae*), a host specific biological control agent, has the capacity to reduce New Zealand Pigmyweed reproductive success. In 2018, the mite was released in a few infested sites in the UK, and is still being closely monitored.

Nevertheless, the release of non-native biological agents in the environment involves serious risks with possible unintended consequences and damages such as attacks and indirect effects on non-target species, or spread of the biological agent to new areas. Thorough risk assessments must, therefore, be conducted before the release of such agents.

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Environmental management: ecosystem shift

Method description

✔ Local eradication can be achieved

✖ This method is only suitable for small or medium water bodies with low conservation value

✖ The method involves the complete replacement of an ecosystem by another, resulting in highly modified and vulnerable environments

✖ Ecosystem shift is not always feasible due to diverse practical constraints

The principle is to transform the existing aquatic ecosystem into another ecosystem that is unsuitable for the survival or establishment of the aquatic plant. This involves drying out and refilling the water body with adequate substrate. It is recommended to fill the pond approximately 15% higher than the initial depth. This management measure is conducted in late winter (February or March). Planting or sowing native terrestrial plants is then implemented. The selection of the new ecosystem should take into account local conditions, plant availability, and regional conservation objectives to mitigate the loss of biodiversity. Discussions with stakeholders such as conservationists and local authorities can help to guide the decision-making process toward the most suitable new ecosystem.

Fig 58. Active revegetation is an essential approach to limit or prevent the re-establishment of invasive species and to successfully restore native plant communities. Photo : bolu84/Shutterstock

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A new pond can be dug up to compensate for habitat loss. In that case, it is important to prevent the introduction of the managed or new aquatic alien species in the new pond. Due to possible legal and practical constraints (e.g. sites with conservation, cultural, historical value) as well as the major impacts on aquatic organisms and the potential risks of introducing terrestrial invasive species, this method should only be considered after all the other management possibilities have been rejected. Ecosystem shift is, therefore, only suitable for already degraded water bodies where no species of interest remain and where New Zealand Pigmyweed has taken over most of the water system. Once the new ecosystem is in place, regular monitoring and checks should be conducted over a 3-year period to ensure that no regrowth occurs.

Material

Management: Excavators and large diggers and dumpers.

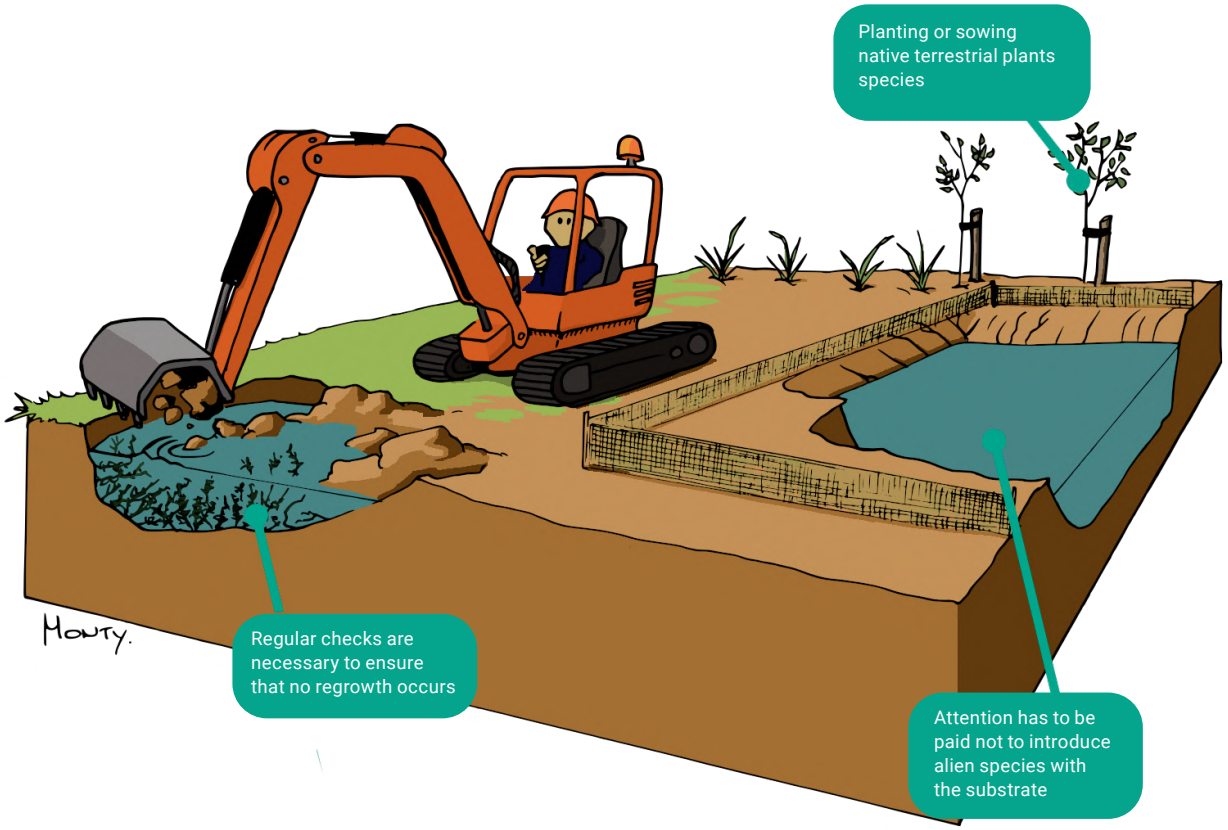

Fig 59. Ecosystem shift requires to refill the pond with substrate

DID YOU KNOW?

The ecosystem resilience approach

The complete eradication of the New Zealand Pigmyweed is extremely challenging and, in most cases, unachievable. Alternative control approaches now concentrate on preventing or limiting the plant regrowth by reinforcing and restoring the native ecosystem. Restoring abiotic conditions and introducing native species that will strongly compete with the New-Zealand Pigmyweed or create shade can break the dominance of the invasive plant and limit its development.

The ecosystem resilience approach, notably studied and promoted by the LIFE Resilias project, is increasingly being adopted and favoured over the very time-consuming, expensive and often ineffective "traditional" control measures such as manual or mechanical removal. This management technique can also be applied to control other invasive alien plant species such as *Myriophyllum* spp.

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Fig 60. The invasive *Myriophyllum aquaticum* may be outcompeted by native vegetation through light deprivation and nutrient limitation. Photo : Etienne Branquart

Elodea densa

Fig 61. *Elodea densa*. Photo : LIFE RIPARIAS

Species description

Greater pondweed (*Elodea densa*, syn. *Egeria densa*) is a perennial submerged aquatic plant native to South America. The species was introduced to Europe, including Belgium, through the aquarium industry as a popular plant for aquariums and garden ponds. The first records of the greater pondweed's presence in the environment in Belgium date back to 1999. Disposal of aquarium waste in water systems is probably at the origin of its escape into the wild. Today, while emerging in some countries, the plant is already a problematic aquatic invasive species in several countries worldwide. As a result, it has been included in the LIFE RIPARIAS alert list. The distribution of greater pondweed on the Belgian territory is likely underestimated as the plant can easily be confused with other non-native species such as *Elodea nuttallii.* Additionally, its submerged form makes it challenging to detect.

Photo: harrylurling

Elodea densa

Greater pondweed thrives in a wide variety of freshwater habitats, ranging from acidic to alkaline conditions, but mostly develops in shallow, still or slow-moving waters such as rivers, streams, ponds or lakes. Although light demanding, the plant has the ability to grow in deep (taking root up to 10m deep) and turbid waters. As a highly competitive invasive species, greater pondweed has diverse environmental, social and economic impacts. This invader can form dense and monospecific populations and colonise the whole water column. This has detrimental impacts on the ecosystem and biodiversity through light exclusion, native plant community displacement and water movement restriction. Social and economic effects include restriction of recreational activities (angling, boating), swimming hazards, increased land flooding risks and management related costs.

Biological characteristics, reproduction and spread

In its introduced range, including Belgium, flowering of greater pondweed occurs in late spring (June) and once again in autumn (October), with flowers extending above the water surface. These 2 flushes are then followed by a reduction of the plant's biomass as branches decompose.

Greater pondweed is a dioecious species. Its reproduction in western Europe is probably exclusively vegetative via male plants only. When the plant breaks into fragments, either naturally or because of human activity, those small fragments (containing double nodes) can form a new plant, and therefore, a new population away from the initial invaded area. In its native range, the plant can also reproduce by seeds. The spread of this invasive weed mainly occurs through fragment drift within water systems, flooding events or via human activities with fragments being attached to boats, waders or other water equipment. These fragments can remain viable in water for a considerable period and can withstand desiccation for up to 10 hours. The species' high regeneration and dispersal abilities emphasize the importance of implementing effective management measures.

Fig 62. Greater pondweed invasion

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General considerations about management

Various management options have been used to control or eradicate the species. Local eradication of greater pondweed is considered complicated once the species has established. However, highly effective and promising management methods such as jute matting have successfully been used for the control and eradication of similar species, such as *Lagarosiphon major*. Although not yet documented in the literature for the management of greater pondweed populations, this technique is likely to be an effective measure. Nevertheless, the eradication feasibility of greater pondweed populations must be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce vegetatively through fragmentation, precautionary measures must be implemented prior to management to prevent fragment spread within the managed area or to other water systems. The managed areas are, therefore, isolated by physical barriers. The harvested plant material must be safely disposed of away from water systems and is either dried or composted. Material that has been in contact with the plant (e.g. diving equipment, clothing) should be checked, cleaned and dried before being taken to another site. It is also recommended to restrict public access to the managed area to isolate the infestations as much as possible and limit the risk of spread.

Managed and downstream sites must remain under enhanced surveillance for a 5-year period after the implementation of the last treatment.

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Manual removal

- ✔ Local eradication can be achieved
- ✔ Manual removal is highly selective and will have minimal disturbance and impact on ecosystems and other organisms
- ✖ The method is only suitable for small and early-detected infestations
- ✖ There is a risk to create and spread fragments to uninvaded areas
- ✖ Scuba diving requires qualified operators

Method description

The principle is to remove the whole plant from the ecosystem. Plants are pulled out by the roots by scuba divers or operators walking in the water, working from boats or from the bank. Operators must pay great attention not to fragment the plants. This method is implemented in autumn, when the plant is more prostrate but still visible, in recently invaded sites or areas with low vegetative abundance. This management method generally needs to be frequently repeated over a period of 3 to 5 year. The managed site is surveyed 8 weeks after the initial manual removal to check for regrowth orw plants that would have been overlooked.

Material

Management: Diving equipment (deep water) or operators with waders (shallow water), boats. Buoys to demarcate the managed area

Transport and stocking: Buckets or mesh bags

Precautionary measures: Hand net, floating booms, containment nets or bubble curtains

References

Lafontaine, R.M. *et al.* (2013) *Risk analysis of the Brazilian Waterweed* Egeria densa Planch. The Royal Belgian Institute of Natural Sciences.

Millane, M. and Caffrey, J. (2014) *Risk Assessment of* Egeria densa. Inland Fisheries Ireland and the National Biodiversity Data Centre.

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Mechanical removal: floating machines

- ✔ Rapid good control can be expected
- ✔ Mechanical removal is suitable for many situations, even well-established and large populations in deep or shallow waters
- ✖ Eradication is probably unlikely or hardly achievable
- ✖ Mechanical removal can create plant fragments with the risk to spread the species to uninvaded areas and other parts of the managed water system
- ✖ Mechanical removal can negatively affect fish communities through oxygen depletion

Method description

The principle is to mechanically remove the whole plant from the ecosystem. Plants are uprooted by a weed conver boat. One concrete example of machine used is the harkboot, a boat equipped with a large rake on one side and another rake with inserted mesh on the other. The large rake scrapes up the bottom of the water body to a depth of 10 to 15 cm while the rake with inserted mesh is used to collect the uprooted plant material and discharge it temporarily on the bank. The selection of rake tines should be based on the type of substrate and the targeted species. Mechanical control is preferably implemented several times per year (up to 4 times) between April and October, when the plant is visible. As different boat dimensions are available, this method can be conducted for large or small infestations in deep or shallow waters (at least 0.6 m deep). If the method is implemented in running waters, it is recommended to take into account the direction of the current to prevent re-invasion of cleaned-up areas.

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Similarly, if mechanical removal is implemented in stagnant waters, the direction of the wind or the presence of hydraulic infrastructures, which may influence the current, must be considered. As the weather and wind direction can change throughout the day, the working method must be adjusted accordingly. The harkboot must be stopped and management postponed when hypoxia is observed by the operators. Mechanical removal is immediately followed by manual removal of plants that were inaccessible to the machines (e.g. plants rooted near the bank or obstacles). Remaining drifting plant fragments are also removed. Repeated mechanical removal is often necessary (at least once a year) over a few years (4 years) to notice a drastic reduction of the population. Regular site surveys must be implemented. Once a good level of control is achieved and the infestation is limited, manual aftercare is implemented to remove regrowth.

Material

Management: The adequate boat

Transport and stocking: Buckets and trucks

Precautionary measures: Hand net, containment nets. A floating net with lead-line must also be placed at the downstream part of the managed area and remain in place for at least 5 days following the operation.

Fig 63. Depending on the type of machine, the harvested plant material can either be stocked on board or unloaded on the bank. Photo: Matt Green

Light deprivation: benthic jute matting

- ✔ Local eradication or really good control can be achieved
- ✔ The method is suitable for both limited and large invaded areas/water systems
- ✔ The material is biodegradable and does not require to be removed (eco-friendly and no removal costs)
- ✔ The jute enables native plants to grow through it, allowing vegetation to reestablish. It also enables gas to escape
- ✖ This method is limited to stagnant waters.
- ✖ The placement of jute matting can be impracticable or impossible if important obstacles are present
- ✖ This method is likely to be detrimental to benthic organisms and affect fish spawning

Method description

The principle is to install bottom covers that both compress vegetation and exclude sunlight, causing the death of the plants. Jute matting, a natural and biodegradable vegetable fiber, is placed by divers or operators on the bottom of the water body. For large populations in deep waters, long strips of jute are deployed from a boat on the water surface and rapidly sink to the bottom. For smaller populations, sheets are manually placed on the weed bed by divers or operators. It is really important that no light reaches the plants from adjacent area, gaps or the edges of the sheeting. Divers or operators must ensure the adequate placement of the matting and that the strips overlap correctly. The use of large continuous pieces of sheeting is therefore recommended whenever possible. Weights are attached to the side of the jute to secure the covers to the bottom and assist with accurate placement. Jute must not be removed as it disintegrates after 1 or 2 years. Eradication is, however, achieved after 5 to 7 months. Benthic covers are placed in winter when the plants are prostrate. If not possible, mechanical cutting can be implemented before the placement of the jute to reduce the biomass and facilitate the fixing of the material to the bottom. If cutting is implemented, operators must ensure that no fragment remain, as there is a high risk that new plants will grow on top of the matting. Once the jute has disintegrated, inspections and manual removal of remaining plants or any regrowth are conducted until the complete disappearance of the species.

Material

Management: The adequate quantity of jute matting rolls. Weights, rocks, concrete blocks or sandbags. Boats. Buoys to demarcate the managed area.

Precautionary measures: Hand net, floating booms, retention nets or bubble curtains (if mechanical cutting is conducted).

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DID YOU KNOW?

Introduction of living organisms: sterile grass carp, a good idea?

The introduction of sterile grass carp (*Ctenopharyngodon idella*) has proven to be an effective method to achieve good control or, in some cases, eradication of some aquatic invasive species such as *Egeria densa*. However, this method remains controversial due to the severe impact this non-native fish can have on the ecosystem. Great care should be taken if introduction of grass carp is undertaken.

The principle is to introduce a generalist herbivore to control invasive plant populations amongst other plant species. Sterile grass carp (triploid), sourced from certified fish farms that provide pathogen-free animals, are introduced into closed, secured and controlled water bodies for a limited period of time. The fish must be removed when the expected result is achieved. The timing for removal will depend on the evolution of invasive plant populations. The efficacy of grass carp in controlling invasive plant species populations is dependent on its feeding preferences. Studies have found that while greater pondweed is highly palatable to grass carp, fanwort and curly waterweed are among the least preferred food choices. An appropriate stocking density is therefore important to mitigate the risk of selective feeding on other plant species. The recommended stocking density is a minimum of 25-30 adult triploid sterile grass carp ha^{-1} (evaluation for fanwort). This is, however, only an estimation as the appropriate stocking density depends on many variables such as fish availability, fish weight, size, and the invasion state. If a correct stocking density is chosen, a single application of grass carp is sufficient for effective control. This method is not recommended for sites with high conservation value due to the significant negative impacts of grass carp on plant communities and invertebrates. If the targeted invasive plant persists after fish removal, further follow-up techniques must be implemented until no regrowth occurs.

Fig 64. Sterile grass carp (*Ctenopharyngodon idella*). Photo : Rostislav Stefanek/Shutterstock

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Pontederia cordata

Species description

Pickerelweed (*Pontederia cordata*) is a rhizomatous perennial aquatic plant native to the American continent. The species was introduced to Europe, including Belgium, through the horticultural trade as a popular ornamental plant for garden ponds. The first records of pickerelweed's presence in the environment in Belgium remain rather unclear but appear to date back to the 1980s. Intentional introduction and disposal of aquarium waste in water systems are probably at the origin of its escape into the wild. Today, while emerging in some countries such as Belgium, the plant is already considered a problematic aquatic invasive species in several countries worldwide. It is therefore a species of the LIFE RIPARIAS alert list. Although easily detectable, its distribution on the Belgian territory is probably underestimated due to a lack of recorded observations and monitoring efforts.

Fig 65. *Pontederia cordata*

Photo:: Marie Patinet

Pontederia cordata

Pickerelweed grows in shallow, stagnant waters such as marshes, ponds or lake edges. The plant can either be free-floating, with stems emerging above the surface, or rooted in water system margins up to depths of 40cm. As an emerging invasive species in Belgium, the plant might cause, in the near future, diverse environmental, social and economic impacts. For instance, in some parts of its introduced range, it has been observed that this invader has the ability to rapidly form dense mats with detrimental impacts on the ecosystem and biodiversity. It notably strongly competes with key plant species and can alter vegetation composition. Pickerelweed has also been found to provoke important water pond evaporation, which could raise concerns for habitats that are already subject to low water level or seasonal water shortage. Social and economic effects include restriction of recreational activities (angling, boating) and management-related costs.

Biological characteristics, reproduction and spread

In Belgium, flowering of pickerelweed occurs between June and August, with flowers extending above the water surface. In some parts of its native range, flowering is almost continuous.

Reproduction of pickerelweed in western Europe is partially vegetative through fragmented rhizomes. When the plant's rhizomes break into fragments, whether naturally or because of human activity, these small fragments can form a new plant, and therefore a new population away from the initial invaded area. The species also reproduces by seeds, which are contained in fruits (one seed per fruit). The fruits are buoyant and have the ability to float during approximately 2 weeks. While seeds do not seem to be affected by the absence/presence of light to germinate, they appear to require cold stratification. Higher germination rates have also been observed under flooded conditions (underwater). Seeds do not seem to survive for more than 1 year. The spread of this invasive weed mainly occurs through the drift of fragments and seeds within water systems, but also via human activities or zoochory. The species' high regeneration and dispersal abilities highlight the importance of implementing effective management measures.

Fig 66. Pickerelweed invasion forming a dense mat. Photo : Etienne Branquart

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General considerations about management

Very few management options have been implemented to control and eradicate the species. Available information on management remains highly limited. Local eradication of pickerelweed is considered achievable for small infestations. However, the feasibility of eradicating populations must be assessed on a case-by-case basis, considering site specificities, and thoroughly discussed within the management team.

Due to the species' ability to reproduce through seeds and fragmentation, precautionary measures must be implemented before management to prevent seed and fragment spread. It is essential to initiate management actions before seed production. Managed areas are also isolated by physical barriers.

The harvested plant material must be safely disposed of far away from water and moist areas and is either composted or dried before incineration. Material that has been in contact with the plant as well as soil that may contain seeds (e.g. machines, nets), should be checked, cleaned and dried before being taken to another site. It is recommended to restrict public access to the managed area in order to isolate the infestations as much as possible and limit the risk of spread.

Managed and surrounding areas must remain under enhanced surveillance for a period of 3 to 5 years after the implementation of the last treatment.

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Fig 67. Pickerelweed population colonising the edges of a large pond. Photo : Marie Patinet

Manual/mechanical removal

- ✔ Control and local eradication can be achieved
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ The method is only practical for small and early-detected populations
- ✖ Manual removal is time-consuming and labor intensive

Method description

The principle is to remove the whole plant from the ecosystem. Plants are dug out in a way that all plant material is removed from the soil, including roots and rhizomes. This management strategy can be carried out manually or with the use of machinery. It is performed during the vegetative period but before seed production. If seed production has already occurred, it is necessary to remove the flowers to prevent seed dispersal. Operators must ensure that every part of the plant is removed as it will regrow from fragments of rhizome. Manual removal is repeated annually for several years to progressively eliminate seedlings and regrowth from remaining rhizomes. The measure is maintained until no regrowth and seedling are observed.

Material

Management: Spades or little diggers, gloves

Transport: Bags

Fig 68. Manual removal of pickerelweed populations. Photo : Etienne Branquart

References

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Saururus cernuus

Species description

Lizard's tail (*Saururus cernuus*) is an aquatic and semi-aquatic perennial plant that has both a submerged and an emergent form. The species, native to North America, was introduced to Europe, including Belgium, through the horticultural trade as an ornamental plant for garden ponds. The first records of lizard's tail's presence in the environment in Belgium date back to 1977. Disposal of pond waste in water systems is probably at the origin of its escape into the wild. Today, while emerging and uncommon in Belgium, the plant might become a problematic aquatic invasive species in the near future. However, the species is not yet listed as an IAS of Union concern under the (EU) Regulation No 1143/2014. It is therefore a species of the LIFE RIPARIAS alert list. Although easily detectable, its distribution on the Belgian territory is probably underestimated due to a lack of recorded observations and monitoring efforts.

Fig 69. *Saururus cernuus*

Photo: Etienne Branquart

Saururus cernuus

Lizard's tail thrives in stagnant or slow-moving waters such as marshes, pond, streams and along the banks of water systems. The species is highly tolerant to changes in water levels and resistant to frost. As an emerging invasive species, the plant has the potential to cause diverse environmental, social and economic impacts. For instance, this invader has the ability to form dense mats on the surface of the water, with subsequent detrimental impacts on the ecosystem and biodiversity through light restriction, habitat degradation or by competing with native plant communities. Social and economic effects include restriction of recreational activities (angling, boating) and management related costs.

Biological characteristics, reproduction and spread

The plant can develop a rather fragile submerged vegetative form on the bottom of shallow waters and a robust erected form reaching heights of 120 cm on water margins. In western Europe, flowering occurs in summer, from June to September. The plant, then, dies back during winter and emerges from rhizomes the next growing season.

In its introduced range, including Belgium, lizard's tail probably exclusively reproduces by rhizome extension (vegetative reproduction), with really long rhizomes that can reach up 5m long. Rhizome and stem fragments can form a new plant, and therefore a new population, away from the initial invaded area. The species is also known to reproduce by seeds, which are contained in fruits (1 to 4 seeds per fruit). Fruits are able to float for a short amount of time (usually a few hours) before sinking back to the bottom. However, in Belgium, seed germination does not seem to occur as seedlings have not been observed yet. Spread of this invasive species probably only occurs through fragmented rhizomes drift within water systems. The species' high regeneration and dispersal abilities highlight the importance of implementing effective management measures.

Fig 70. Important invasion of lizard's tail in a pond in Belgium. The plant has already colonised different parts of the water body. Photo : Etienne Branquart

References

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Delay, J. and Petit, D. (2006) *Houttuynia cordata* Thunberg et *Saururus cernuus* L. nouvelles espèces de notre environnement urbain. *Bulletin de la Société botanique de France*, 59(3), 3-14.

General considerations about management

Very few management options have been implemented to control and eradicate the species. Available literature on this topic remains highly limited. Local eradication of lizard's tail is considered achievable for small infestations. The eradication feasibility must, however, be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce vegetatively through fragmentation, precautionary measures must be implemented before management to prevent fragment spread within the managed area or to uninvaded areas. Managed areas are also isolated by physical barriers.

The harvested plant material and the sediments (in case of dredging) must be safely disposed of far away from the water and composted in dry zones. Checks of the composted zones must be done to ensure that no regrowth occurs. Material that has been in contact with the plant (e.g. machines, nets) should be checked, cleaned and dried before being taken to another site.

Managed and surrounding areas must remain under enhanced surveillance for a period of 3 to 5 years after the implementation of the last treatment.

Fig 71. Early detection of lizard's tail invasion. The site could be subject to rapid management responses. Photo : Dido Gosse

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Manual removal

- ✔ Control and potential local eradication can be achieved
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ The method is only practical for small and early-detected populations
- ✖ Manual removal is time-consuming and labor intensive

Method description

The principle is to remove the whole plant from the ecosystem. Plants are dug out in a way that all plant material is removed from the soil, including roots and rhizomes. This management strategy, which can be carried out manually or with machinery, is conducted during the vegetative period. Operators must ensure that every part of the plant is removed as regrowth can occur from fragments of rhizome. Manual removal is repeated 3 times a year over multiple years to progressively eliminate regrowth from remaining rhizomes. It is implemented until no further regrowth is observed.

Material

Management: Spades or little diggers, gloves and waders

Transport: Bags and buckets

References

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Dutartre, A. (2010) *Importance de la prévention et de la détection précoce.* Journée d'échanges sur les plantes aquatiques exotiques envahissantes dans le bassin de la Loire, Poitiers.

Tiaki Tāmaki Makaurau Conservation Auckland. (2022) Saururus cernuus - Lizard's tail. https://www.tiakitamakimakaurau.nz/protect-and-restore-our-environment/pests-in-auckland/pest-search/saucer/ [Accessed: 17th November 2022].

Substrate removal: mechanical dredging

- ✔ Local eradication can be achieved
- ✖ The method is effective for small populations
- ✖ This method can only be implemented in sites where the whole area is accessible to the machines
- ✖ Dredging can create a large number of fragments which increases the risk to spread the species to uninvaded areas
- ✖ This method can have high negative impacts on aquatic living organisms

Method description

The principle is to remove the bottom sediments contaminated with all parts of the invasive plant such as roots, stems, seeds, etc. Excavators equipped with cleaning bucket thumb are used for excavation. Mechanical dredging is conducted in autumn (October/November) when the plant is more prostrate. The infested site must be dredged at depths of 1.5m to 2m is thisto ensure the removal of all root fragments. Operators must establish a 3m buffer zone surrounding the infested area. The contaminated area, including the buffer zone, must then be physically delimitated before dredging. Great care must be taken to prevent root fragments as much as possible. This action is immediately followed by manual removal of remaining fragments and plants that might have been overlooked. Any regrowth occurring during the following years is manually removed. Manual removal is implemented until no further regrowth is observed.

Material

Managment: Excavators equipped with cleaning bucket thumb, rakes, pickets

Transport and stocking: Buckets or mesh bags, trucks and containers

Precautionary measures: Hand net, floating booms, containment nets

References

Centre de ressources espèces exotiques envahissantes. (2017) *Base d'informations* – Saururus cernuus. http://especes-exotiques-envahissantes.fr/espece/saururus-cernuus/#1458311762057-246ee81f-ef40 [Accessed: 17th November 2022].

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Zizania latifolia

Species description

Manchurian wildrice (*Zizania latifolia*) is an aquatic and semi-aquatic perennial plant native to China. The species was introduced to Europe, including Belgium, as an ornamental plant for garden ponds, and to serve as a cover for wildfowl. The first records of Manchurian wildrice's presence in the environment in Belgium date from 2009. Escape from cultivation is probably at the origin of its current presence in the wild. Today, while emerging and uncommon in Belgium, the plant might become a problematic aquatic invasive species in the near future. The species is, therefore, a species of the LIFE RIPARIAS alert list. Manchurian wildrice can easily be confused with other plant species including native macrophytes such as *Typha* spp. Its distribution on the Belgian territory is probably underestimated due to a lack of recorded observations, monitoring efforts, and possible confusion with look-alike species.

Fig 72. *Zizania latifolia*.
Photo: Marie Patinet

Photo: anna_efimova

Zizania latifolia

Manchurian wildrice grows well (reaching heights of up to 4m) in shallow stagnant waters such as ponds, ditches, wetlands, and the edges of water systems. As an emerging invasive species in Belgium, the plant has the potential to cause diverse environmental, social and economic impacts. Already highly invasive in some parts of its introduced range (northern Europe and New-Zealand), this invader has the ability to form dense monocultures with subsequent detrimental impacts on the ecosystem and biodiversity. The species can strongly compete with and exclude native plant communities. Social and economic effects include the loss of pastures due to the formation of swampy areas, obstruction of drainage systems, and management-related costs.

Biological characteristics, reproduction and spread

While Manchurian wildrice appears to flower in summer in some parts of Europe (e.g. Lithuania), flowering has not yet been observed in Belgium. Growth is limited in winter and new shoots emerge from underground rhizomes. Manchurian wildrice forms strong and deep root systems with far-reaching rhizomes. The species seems to tolerate frost, drought and heavy water pollution but is sensitive to shade, and requires intense light to grow well.

Reproduction of Manchurian wildrice in Belgium appears to be exclusively vegetative via rhizomes and tillers. Rhizome fragments can form a new plant, and therefore a new population, away from the initial invaded area. The species is also known to reproduce sexually through seed production in its native range, although seed-set has not yet been recorded in Belgium. Spread mainly occurs through fragments of rhizome being transported with watercourses or via human activities with fragments being attached to boats, waders or other water equipment. The species' exceptional capacity for regeneration and dispersal highlight the critical importance of implementing effective management measures.

Fig 73. Manchurian wildrice on the edges of a pond. Photo : Etienne Branquart

References

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Liatukas, Z. and Vaclovas, S. (2009) *Zizania latifolia*—a new alien-plant in Lithuania. *Botanical Lithuanica*, 15, 17–24.

A few management options have been used to control and eradicate the species, but their effectiveness has been limited. There is, however, a lack of available literature on specific management measures for this invasive species. Local eradication of Manchurian wildrice is considered hardly achievable, even for small infestations, as any rhizome fragment will regrow. The eradication feasibility of populations must, therefore, be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce vegetatively by fragmentation, precautionary measures must be implemented before initiating management actions to prevent fragment spread within the managed area or to other water systems. Managed areas are, therefore, isolated by physical barriers.

The harvested plant material must be safely disposed of away from the water and is either buried (6m deep) or destroyed (e.g. dried and incinerated). Plant material must not be composted, even on dry land, as it is highly likely that the plant will regrow. Material that has been in contact with the plant (e.g. tools, clothing) should be checked, cleaned and dried before being taken to another site.

Managed and downstream areas must remain under enhanced surveillance for a period of10 years after the implementation of the last treatment. Regular checks and monitoring activities should be carried out during this period. Eradication can be considered as achieved after 10 years without any signs of regrowth.

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Fig 74. Manchurian wildrice on the edges of a pond. Photo : Etienne Branquart

Manual and mechanical removal

- ✔ Control of small and early-detected populations can be achieved
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ Local eradication is unlikely, even for small populations
- ✖ The method is only suitable for small and early-detected infestations
- ✖ There is a risk to spread fragments to uninvaded areas

Method description

The principle is to remove the whole plant from the ecosystem. Plants are dug out in a way that all plant material is removed from the soil, including roots and rhizomes. This management strategy, which can be carried out manually or with machinery, can be conducted all year round. Operators must ensure that all parts of the plant are removed as new plants will develop from fragments of rhizome. Tearing out the plant with bare hand is extremely complicated and will be ineffective, and probably increase the risk of propagation in water systems, as the plant is really well-rooted with tough rhizomes. Adequate material and tools must therefore be used for manual and mechanical removal of Manchurian wildrice. This management method is repeated during multiple years to progressively remove regrowth from remaining rhizomes and new shoots from potential fragments. Manual or mechanical removal is maintained until no further regrowth is observed, which usually takes a few years.

Material

Management: Sharp spades or mechanical diggers, waders

Transport and stocking: Buckets, trucks and containers

Precautionary measures: Hand net, floating booms, containment nets

Fig 75. Manchurian wildrice's roots and tough rhizomes. Photo : Etienne Branquart

References

Champion, P.D. and Hofstra, D.E. (2010) Manchurian wild rice (*Zizania latifolia*) biomass allocation and implications for control. In: *17Th Australasian Weeds Conference. New Zealand*, pp. 318-320.

Northland Regional Council. (2022) *Manchurian wild rice, Poaceae* - Zizania latifolia. https://www.nrc.govt.nz/environment/weed-and-pest-control/pest-control-hub/?pwsystem=true&pwid=65 [Accessed: 10th November 2022].

RIPARIAN SPECIES OF EU CONCERN

Heracleum spp.

Species description

The invasive giant hogweed (*Heracleum mantegazzianum*), Persian hogweed (*Heracleum persicum*) and Sosnowsky's hogweed (*Heracleum sosnowskyi*, syn. *Heracleum pubescens*) are 3 terrestrial perennial plants native to western Caucasus, eastern Caucasus and western Asia (Iran, Iraq and Turkey) respectively. The species were introduced to Europe, including Belgium, for horticulture and apiculture but also as agricultural crops (Sosnowsky's hogweed). The first record of non-native hogweeds in the environment in Belgium dates back to the late 1940s and concerns the giant hogweed. Spread from cultivated plants in private or botanical gardens, along with accidental introductions of seeds through soil transportation, are probably at the origin of their escape into the wild. Today, the 3 plants represent problematic invasive alien species in many countries worldwide and are now listed as IAS of Union concern under the (EU) Regulation No 1143/2014. The distribution of the giant hogweed on the Belgian territory is probably rather exhaustive due to its high detectability and active monitoring efforts. The other two *Heracleum* species have never been found in Belgium so far, but their presence cannot be excluded due to misidentification risks, as the 3 hogweed species are genetically and morphological close to each other.

Fig 76. The 3 hogweed species are similar in appearance and are, therefore, complicated to differentiate. *Heracleum mantegazzianum* remains, however, the most widely distributed in Belgium. Photo: Huhu Uet

Photo: Etienne Branquart

Heracleum spp.

Hogweeds thrive along waterways and in artificial and semi-natural habitats such as roadsides, gardens and grasslands. These competitive species, which can reach heights of 4-5 meters, have diverse environmental, social and economic impacts. They can form large monospecific stands that negatively affect ecosystems and biodiversity through native plant exclusion, species richness reduction, riverbank erosion, modification of soil biota, etc. One of the main concerns regarding their establishment, is probably the risk it poses to human health as all 3 species produce phototoxic sap. Direct contact with these plants can result in severe and permanent damage to human skin, especially when exposed to UV radiation, including severe burns, blisters, scars, hyperpigmentation, and other injuries that may require hospitalization. From an economic perspective, impacts include management and healthcare related costs. In Germany, annual healthcare costs associated with human exposure to the toxic sap amounts to 1 million euros.

Biological characteristics, reproduction and spread

Flowering of all 3 species takes place between June and August, with several thousands hermaphrodite flowers developing on a single plant. These flowers are then pollinated by various insect species. By July, fruits appear, each containing 1 seed which germinates in early spring and mainly emerges from fertilisation between 2 plants (self-fertilisation has also been observed).

Fig 77. Giant hogweed can grow to 4 to 5 meters tall. Photo : Dido Gosse

References

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European and Mediterranean Plant Protection Organization. (2020) PM 9/9 (2) *Heracleum mantegazzianum, H. sosnowskyi and H. persicum. OEPP/EPPO Bulletin*, 50 (3), 515–524.

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While the plants can live for more than 10 years (Persian hogweed has a longer lifespan than the other 2 species), they usually start producing flowers when they are 3 to 5 years old. Unlike Persian hogweed which can flower multiple times before dying, Sosnowsky's and giant hogweed die after flowering once. All 3 species overwinter, with the leaves fading during cold months, and regrow from overwintering roots the next growing season. In western Europe, hogweeds propagate exclusively by seeds. On average, one plant produces around 20,000 to 100,000 seeds, which fall near the parent plant (within a few meters) and are dispersed by wind over short distances. Spread over long distances (several kilometers) occurs though waterways, where seeds have been found to float for 3 days, and through the transport of soil contaminated by seeds. Seeds can remain viable for at least 5 years, forming persistent seedbanks. The plants have an important reproductive potential as the majority of the seeds produced engender healthy new plants capable of forming new populations, even away from the initial invaded area. The vast majority of the seeds are found in the upper soil layer (from 0 to 5 cm deep). Unlike giant hogweed and Sosnowsky's hogweed, Persian hogweed is thought to be capable of vegetative reproduction when sexual reproduction is unsuccessful. Scientific information remains, however, highly limited. Hogweeds' high regeneration and dispersal abilities highlight the importance of implementing effective management measures.

Photo: Jérémie Guyon


Photo: Dragan Marjanovic

Fig 78. The phototoxic sap contained in hogweeds can cause serious damages to the skin such as severe case of phytophotodermatitis.


Photo: grisdee/shutterstock

Mullerova, J. and Parker, C. (2022) Heracleum mantegazzianum *(giant hogweed), CABI Compendium.* https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.26911 [Accessed: 10th October 2022].

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General considerations about management

Numerous and well-documented management options have successfully been used to control and eradicate hogweeds. Local eradication of the 3 species is considered achievable, even for large and dense infestations. The feasibility of eradicating hogweed populations must, however, always be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce through seeds, precautionary measures must be adopted prior to management to prevent seed spread in the environment and uninvaded areas. The plants should ideally be managed before seed production, and the harvested material must be safely disposed of away from the water and piled up on the site to dry and decompose. If there are inflorescences and seeds, they should be placed in trash bags, which are then burned or exposed to the sun in a secure location.

Material that has been in contact with soil that may contain seeds (e.g. clothing, spades) should be checked and cleaned before going to another site. Due to the phototoxic sap, operators must avoid direct contact with the plant. Adequate and protective clothing and equipment must be used during management. It is also essential to protect the eyes. Skin that has been exposed to sap must immediately be washed with soap and water and protected from exposure to UV. It is recommended to apply sun cream prior to management actions. After any management action, equipment, clothing and skin must immediately be washed thoroughly and exposure to sunlight is discouraged. For limited invasions, it could be recommended to work after sunset to limit the risks associated with exposure to UV. Operators must not hesitate to seek medical advice if contact with sap has occurred.

Managed sites must remain under enhanced surveillance and be monitored at the end of each growing season for a 7-year period (10 years for Persian hogweed) following the last treatment.

Fig 79. Giant hogweed invasion. Photo : Helena56/Shutterstock

Manual removal: root cutting

- ✔ Local eradication of small and early-detected populations can be achieved
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ The method is time consuming for the control of large infestations (>200 individuals)
- ✖ Manual removal requires long-term management due to the persistent seedbank
- ✖ Operators are exposed to health hazards. The use of skilled operators with protective clothing is necessary

Method description

The principle is to remove the plants from the ecosystem and exhaust the seed bank while preventing seed production. The roots are cut by operators, causing the immediate death of the plant. Roots should be cut at a depth of 15 to 20 cm below ground level whenever possible, with a minimum depth of 10 cm below soil level. Management must be conducted early in the growing season (April - May) before umbel production, when the size of the plant is still limited. For tall and large individuals, the upper part can be removed to facilitate root cutting. The treatment has to be repeated in mid-summer to remove seedlings or individuals that would have been overlooked and ensure that no plants are producing seeds. Manual removal is then continued for several years to progressively exhaust the seedbank until no seedling is found. In case of large populations, plants older than 1 year old should be prioritized for management and small seedlings can be left on site to be managed the following year. If management is implemented too late (start of seed-setting), umbels must be separated from the stem, collected, and destroyed (e.g. burned).

Material

Management: Spades with sharp blades or hoe. Loppers can be used to cut upper parts of large individuals

Transport and stocking: Bags to stock flowers or seed heads (if relevant).

Safety equipment: Adequate clothing including long sleeves and waterproof gloves, trousers, boots as well as eye protection is essential. It is strongly recommended to have access to clean water and soap in case of contact with sap.

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Fig 80. Operators must wear protective clothing and equipment during management to prevent exposure to the dangerous phototoxic sap. Photos : Jérémie Guyon

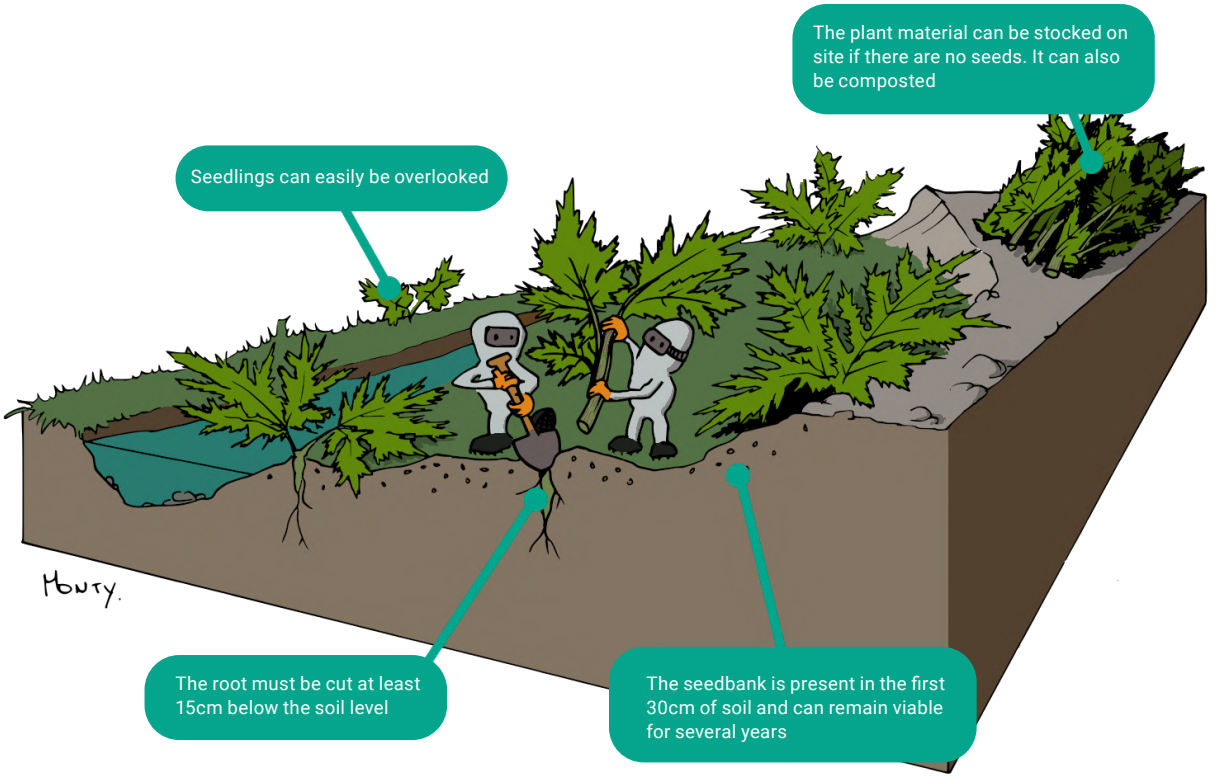

Fig 81. Manual removal of hogweeds. Operators sever the tap root below soil level to kill the plant

Mechanical removal: repeated ploughing

- ✔ Local eradication can be achieved if a long-term treatment is conducted
- ✔ Good control can be expected rapidly
- ✔ The method is effective for large populations (>1000 individuals)
- ✖ This method can only be implemented in specific sites where access with heavy machinery is possible
- ✖ Ploughing must be repeated several times a year

Method description

The principle is to mechanically destroy the root system of the plant to cause its death. Plants are uprooted by heavy machinery through deep ploughing of the soil (20 to 30 cm deep) in agricultural lands. The method effectively kills the plant and reduces seed germination by burying seeds at depths that prevent germination (germination is hindered if seeds are covered by 25 cm of soil). Ploughing is implemented in spring (around May) and is repeated 3 to 5 times a year until no regrowth or seedlings are found, which usually takes a few years. This method can also be implemented in autumn as winter freezing temperatures can encourage root stock degradation. Regular monitoring is conducted, and manual removal is carried out as a follow-up measure if limited regrowth or seedlings are observed.

Material

Management: Agricultural machinery for ploughing. Any plowing equipment such as tractors with plough machine.

Transport and stocking: Bags to stock flowers or seed heads are also required (if relevant).

Safety equipment: Adequate clothing including long sleeves, trousers, boots as well as eye protection as sap can be ejected in the machine (although less likely than during manual removal). It is strongly recommended to have access to clean water and soap in case of contact with sap.

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Grazing

- ✔ Good control can be expected rapidly
- ✔ Grazing requires few resources
- ✖ Local eradication can be achieved in the long term but remains hardly achievable by grazing alone
- ✖ This method is not recommended in sites with conservation value or in riparian zones
- ✖ Frequent inspections of both livestock and fencing are required

Method description

The principle is to introduce generalist herbivores to control hogweed populations among other plant species. Livestock is released in a closed environment for a limited period of time. Grazing is similar to cutting, with the animals feeding on visible plant parts (above the soil), which eventually depletes nutrient reserves and prevents flowering and seed production. Livestock is released in early spring (April) when plants are still young and fresh, as they are more palatable, and remains all summer before being removed during winter months (from November to April). This operation must be repeated for at least 2 years to achieve efficient control or for at least 7 years to achieve potential eradication (when the seed bank is depleted). It is recommended to use livestock that is already accustomed to eating hogweeds, as animals usually require some time before they start feeding on these plant species. Once used to it, hogweeds become one of their preferred food. It is recommended to have a dense grazing pressure at first (spring) and to reduce the pressure (end of June) when plants are weak and biomass is diminished. Another method, applied for large and dense infestations, consists in implementing a couple of heavy but short grazing interventions where animals are repeatedly moved over between a few sites during the growing season. Livestock is then removed once stands of hogweeds have significantly been reduced. For the management of dense infestations, it is recommended to implement mowing prior to releasing livestock to encourage the establishment of other plant species, so that animals have a mixed diet.

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Pysek, P. et al. (eds.) (2007). *Ecology and Management of Giant Hogweed* (Heracleum mantegazzianum). UK, CABI.

When fencing the managed site, operators must ensure that areas where seeds might have been dispersed are also included. Since the phototoxic sap contained in hogweeds can cause inflammation of the skin, lips, eyeball, etc., choosing the livestock wisely is important. Livestock with pigmented or hairy skin is strongly recommended. Animals must regularly be checked for any health issues caused by the sap. If some individuals display signs of poisoning such as blistering or swelling of genital organs, mouth, eyes or ears, they must immediately be temporarily removed from the field. Regular checks for ungrazed areas where plants could develop and produce seeds are necessary, and manual removal (root cutting) should be implemented if needed. Managing the invaded areas neighbouring the pasture that are inaccessible to the livestock is also necessary. This method is not recommended in sites with conservation value or in riparian zones, as intense grazing can have significant negative impacts on vegetation.

Material

Livestock: Black-faced sheep. The recommended animal density is a minimum of 20-30 sheep/ha in spring, followed by 5-10 sheep/ha in late June. This is, however, only an estimation as an appropriate stocking density depends on many variables such as invasion state, type of livestock used, timing, etc.

Equipment: Fencing such as electric wire or steel fences. Nutrient supplements such as minerals might also be needed.

Fig 82. Hogweed populations can be controlled by black-faced sheep through grazing. Invaded areas found outside the pasture and, therefore, inaccessible to livestock must also be managed. Photo : Richard Webb

DID YOU KNOW?

Other possible techniques to manage hogweed species

Terrestrial covers

Light deprivation using an opaque polythene cover is one of the multiple techniques used to control or eradicate limited hogweed populations. This method, effectively killing both the plants and the seeds, should be implemented at the beginning of the vegetative period when the size of the plants is still limited. This allows for easy fixation of the blanket to the ground. Regular checks for damages are recommended. While a year is sufficient to kill the plants, it is however necessary to leave the cover in place for several years to kill all the seeds (if a seed bank is present). Alternatively, manual removal (root cutting) is an effective option for similar situations, such as small stands. However, it requires more interventions and is likely to be more time-consuming. It is important to note that using an opaque polythene cover can be quite expensive and may have a non-negligible impact on other non-targeted plant and animal species.

Mowing

Mowing can be implemented as a management strategy for large and well-established hogweed populations. It is repeated 3 to 5 times over multiple years during the growing season to deplete nutrient reserves as well as prevent flowering and seed production. Repetitive scything can be implemented in areas where mowing would be unsuitable (e.g. riverbanks, slopes). To prevent the spread of seeds, it is crucial not to mow when the plants have flowers or seed heads. If flower heads are present, they should be removed prior to mowing and safely disposed of. It is important to note that while mowing can effectively prevent seed production and subsequent spread, it may lead to an increase in plant density and does not result in the plants' death.

Fig 83. Placement of terrestrial covers on a small giant hogweed population. Photo : Etienne Branquart

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Pysek, P. *et al.* (eds.) (2007). *Ecology and Management of Giant Hogweed* (Heracleum mantegazzianum). UK, CABI.

Impatiens glandulifera

Species description

Himalayan balsam (*Impatiens glandulifera*) is an annual terrestrial plant native to the Himalayas. The species was introduced to Europe, including Belgium, as an ornamental plant for gardens. The first record of Himalayan balsam in the environment in Belgium dates back to 1939. Natural spread from cultivated plants in private gardens, along with intentional releases in the natural environment are probably at the origin of its establishment in the wild. Today, Himalayan balsam represents a problematic invasive species in many countries worldwide and is now listed as IAS of Union concern under the (EU) Regulation No 1143/2014. Knowledge of its distribution on the Belgian territory is probably rather exhaustive due to its high detectability and active monitoring efforts. However, the species can be challenging to notice until it starts flowering.

Fig 84. *Impatiens glandulifera.*
Photo : James T M Towill

Photo: Jérémie Guyon

Impatiens glandulifera

Himalayan balsam thrives in nutrient rich habitats and is mainly found in riparian zones such as alluvial forests, meadows, along waterways, as well as in artificial and semi-natural habitats such as ditches and grasslands. This shallow-rooted species can grow up to 2.5m in height and forms dense stands, causing detrimental impacts on the ecosystem and biodiversity. These impacts include riverbank erosion, light exclusion, displacement of native plants, and disruption of pollination processes for native plants due to its attractiveness to pollinators. Social and economic effects include access restriction to waterways for recreational activities and management related costs.

Biological characteristics, reproduction and spread

In Belgium, Himalayan balsam flowers between June and October. The plant has self-compatible flowers which attract many pollinator species due to their high nectar sugar production. It, then, dies back in autumn, leaving the ground bare, and does not survive frost. Seedlings begin to grow in April. As for all annual plant species, flowering, germination, seed production and death happens all in the same year.

In western Europe, Himalayan balsam propagates exclusively by seeds, with a germination rate of around 80%. Each plant produces approximately 2,500 seeds contained in capsules. These capsules, once mature, open explosively when disturbed (e.g. when touched), expelling the seeds up to 7m away from the mother plant. The seed bank remains viable for approximately 2 years, although observations from some regions indicate that seeds might sometimes be able to survive for up to 3 years. Seed dispersal over long distances occurs via waterways with seeds being transported in the sediments or floating along watercourses. Recreational activities can also contribute to seed dispersal. Those very high regeneration and dispersal abilities highlight the importance of implementing effective management measures.

Fig 85. Himalayan balsam can grow in many different habitats. Photo: Dido Gosse

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General considerations about management

Various management options have successfully been used to control and eradicate this species. Local eradication of Himalayan balsam is considered achievable for limited or even large infestations. The feasibility of eradicating Himalayan balsam populations must, however, always be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce by seeds, precautionary measures must be implemented before initiating management to prevent seed spread within the managed area or to uninvaded sites. Because seeds are easily transported downstream, management must begin with source populations in upstream areas, and gradually progress downstream along riverbanks and floodplain habitats. It is essential to initiate management actions before seed production to limit reproductive output as much as possible.

The harvested plant material must be safely disposed of away from water systems and is either dried, burned, buried (at least 1m deep) or composted. If left to dry on site, it is recommended to avoid leaving the plant material in contact with the ground. If a large amount of plant material is piled up to compost, it must be covered by a tarpaulin to prevent regrowth. Only vegetative and pre-flowering plant parts can be piled up on site. If the plant material is transported off site, it must be treated by adequate waste disposal infrastructures. Material that has been in contact with soil that may contain seeds (e.g. shoes, vehicles) should be checked and cleaned before going to another site.

Managed and downstream sites must remain under enhanced surveillance for a period of 3 years after the implementation of the last treatment.

Fig 86. Himalayan balsam invading the banks of water systems.and the edges of agricultural lands Photo: Jérémie Guyon

Metro Vancouver. (2021) *Best management practices for Himalayan Balsam in the Metro Vancouver Region.* Metro Vancouver and the Invasive Species Council of Metro Vancouver.

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Manual removal

- ✔ Local eradication of early-detected populations can be achieved
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ The method is only practical for sites with small patches disseminated within the native vegetation
- ✖ Manual removal is a time-consuming and labor-intensive method that needs to be carried out until the seed bank is completely exhausted.

Method description

The principle is to remove the whole plant from the ecosystem. Plants are pulled out by the stem by operators. If the plant breaks during the process, operators should ensure the complete pulling of the plant to incorporate the roots, as the species can regrow from broken stems. Manual removal is conducted at the start of the flowering period (May, June, July) to prevent seed production. The optimal time for removal is when the first flowering buds appear. This management strategy must be repeated 4 and 8 weeks after the initial removal to eliminate potential regrowth, seedlings or plants that would have been overlooked. Additional removal may be required during autumn as some plants can germinate late in the season. As numerous seeds can be produced by a few individuals only, it is crucial to ensure the destruction of the vast majority of the population every year. Manual removal must be repeated twice a year until the depletion of the seedbank (usually 2 to 3 years).

Fig 87. Manual removal of the Himalayan balsam with the help of volunteers. Photo: Jérémie Guyon

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Metro Vancouver. (2021) *Best management practices for Himalayan Balsam in the Metro Vancouver Region.* Metro Vancouver and the Invasive Species Council of Metro Vancouver.

Material

Management: Padded gloves, wheelbarrows and rakes. Tools such as shovels might be required if working on compacted soils.

Transport: Trucks (if the harvested plant material is transported off site)

Precautionary measures: tarpaulin

Sarat, E. et al. (2015) Les espèces exotiques envahissantes dans les milieux aquatiques : connaissances pratiques et expériences de gestion - Expériences de gestion. ONEMA, UICN, GT IBMA and Irstea. Report number: 2

Fig 88. Himalayan balsam populations in woodland. Photo: INTREEGUE Photography/Shutterstock

Mechanical removal: brush cutting

- ✔ Local eradication can be achieved
- ✔ Good control can be expected rapidly
- ✔ The method is effective and adequate for large infestations
- ✖ Brush cutting must be repeated several times a year

Fig 89. Brush cutting of Himalayan balsam followed by the removal of the harvested plant material from the stream. Photo : Jérémie Guyon

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Metro Vancouver. (2021) *Best management practices for Himalayan Balsam in the Metro Vancouver Region.* Metro Vancouver and the Invasive Species Council of Metro Vancouver.

Method description

The principle is to mechanically remove visible parts of the plant from the ecosystem. Plants must be cut at ground level, below the lowest node, to prevent regeneration, using machinery. This method is implemented for large infested sites with dense patches before the flowering period (April, May) or with the first blossoms (June), to prevent seed production. Brush cutting (or manual removal depending on the situation) must be repeated 4 to 8 weeks after the initial removal to eliminate any regrowth or plants that would have been overlooked. Manual removal is implemented as a follow-up measure to remove any remaining individuals (if limited number). For larger populations, brush cutting must be repeated twice a year until no regrowth occurs, following the exhaustion of the seed bank, which usually takes 2 to 3 years.

Sarat, E. *et al.* (2015) *Les espèces exotiques envahissantes dans les milieux aquatiques : connaissances pratiques et expériences de gestion - Expériences de gestion.* ONEMA, UICN, GT IBMA and Irstea. Report number: 2

Material

Management: Hand-held brush cutter, strimmer, flail or agricultural machinery (for larger populations)

Transport: Trucks (if the harvested plant material is transported off site)

Precautionary measures: Tarpaulin

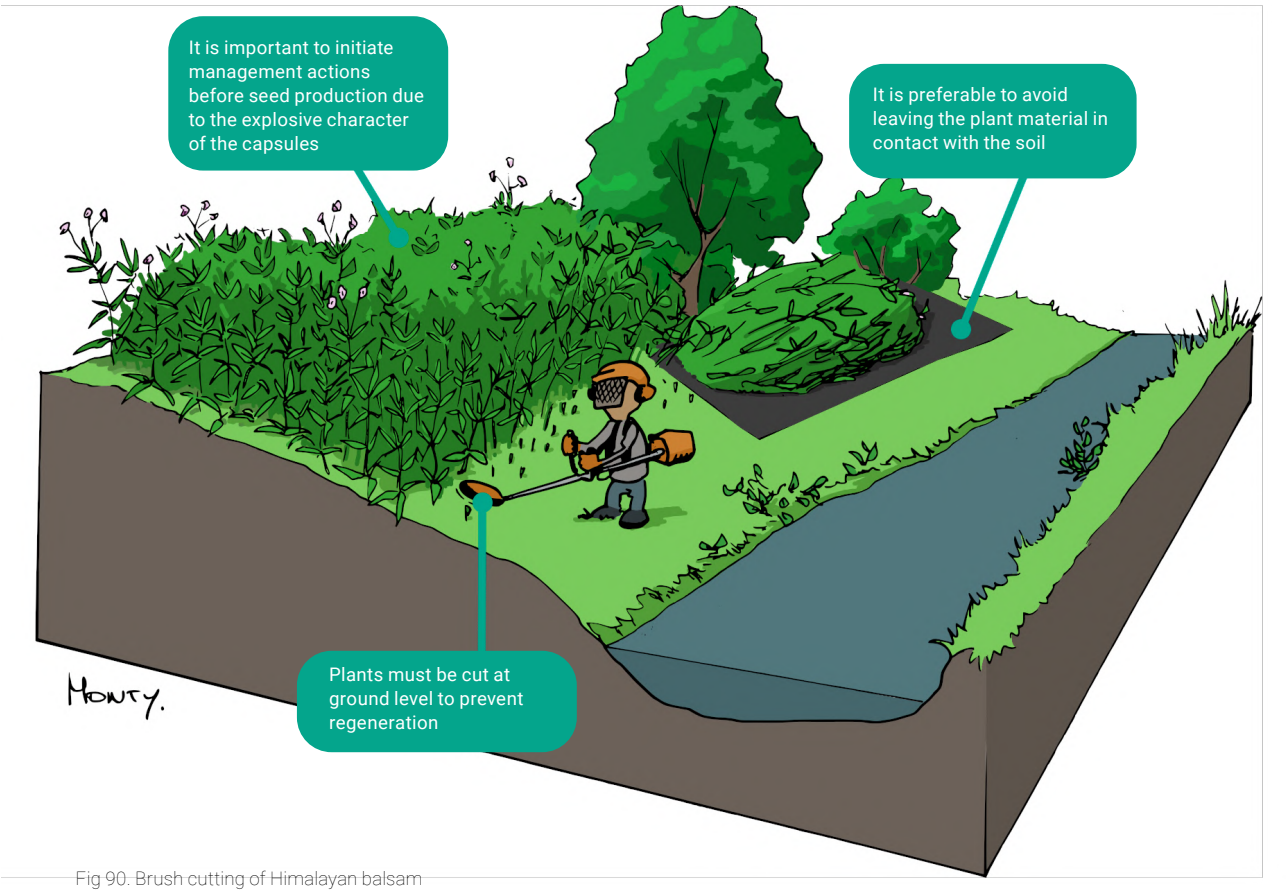

Fig 90. Brush cutting of Himalayan balsam

Grazing

- ✔ Local eradication can be achieved in the long term
- ✔ Good control can be expected rapidly
- ✔ Grazing requires few resources
- ✔ Livestock can access steep areas which are inaccessible to machinery and managers
- ✖ Local eradication can be achieved in the long term but remains hardly achievable by grazing alone
- ✖ This method is not recommended in sites with high conservation value or in riparian zones
- ✖ There is a risk of seed spread to uninvaded areas

Method description

The principle is to introduce generalist herbivores to control Himalayan balsam populations among other plant species. Livestock is released in a closed environment for a limited period of time. Grazing is similar to cutting, as the animals feed on visible plant parts (above the soil) which eventually depletes nutrient reserves as well as prevents flowering and seed production. Livestock is released in early spring (April), before seed production, and remains throughout the growing season. Grazing is continued until no regrowth occurs (minimum 2 years). Infested areas that are not accessible to livestock (e.g. behind fences) must be manually managed to avoid re-colonisation. This method is only implemented in semi-natural habitats such as grassland and is not recommended in sites with conservation value or in riparian zones as intense grazing can have significant negative impact on ecosystems.

Material

Livestock: Sheep or cattle. Sheep, however, appear to be a better option as they graze close to the ground (below the lowest node).

Equipment: Fencing such as electric wire or steel fences, shelters, water supply.

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Koenigia polystachya

Species description

Himalayan knotweed (*Koenigia polystachya*) (syn: *Persicaria wallichii*, *Polygonum polystachyum*, *Rubrivena polystachya*) is a perennial terrestrial plant native to the Himalayas. The species was introduced to Europe, including Belgium, as an ornamental plant for gardens and public green spaces. The first record of Himalayan knotweed in the environment in Belgium dates back to 1898. Natural spread from cultivated plants in private gardens is probably at the origin of its escape into the wild. Today, Himalayan knotweed represents a problematic invasive species in many countries worldwide and was recently listed as IAS of Union concern under the (EU) Regulation No 1143/2014. Its distribution on the Belgian territory probably remains underestimated as the species can easily be confused with other knotweed species such as *Fallopia japonica*, widely distributed and highly invasive in Belgium.

Fig 91. *Koenigia polystachya.*
Photo : Nele Van Hemelen

Photo: Emmanuel Delbart

Koenigia polystachya

Himalayan knotweed thrives in nutrient-rich habitats as well as moist and disturbed soils such as roadside, ditches but also wetlands and riparian areas. This rhizomatous invader, growing to heights of 40 to 120 cm, can form large and persistent colonies causing detrimental impacts on the ecosystem and biodiversity. The plant, which strongly competes with other species for space and resources, can exclude native vegetation, prevent tree seedlings development, encourage river bank erosion, reduce species richness and can lead to important population declines in species of high conservation value. Social and economic impacts include damages to human infrastructures (as the plant can grow through concrete), access restriction to waterways for recreational activities, maintenance and management related costs.

Biological characteristics, reproduction and spread

In Belgium, Himalayan knotweed flowers between July and October and produces seeds around September. The above-ground plant material, which is not resistant to frost, dies back in winter, leaving brown stems and an important quantity of leaves that form dense mats on the ground. New shoots emerge from mid-spring until late summer.

Reproduction of Himalayan knotweed in western Europe is mainly vegetative. When the plant breaks into fragments, either naturally or because of human activity, those fragments, as small as 1 cm long, can form a new plant, and therefore a new population, away from the initial invaded area. The plant can also reproduce sexually by seeds. However, seed production appears to be rather rare in its introduced range. Seed germination requirements and viability remain unknown. Spread of this invasive weed can happen through seeds, rhizome and stem fragments being dispersed by waterways, flooding events, wind, animal movement or human activity. Those high regeneration and dispersal abilities highlight the importance of implementing effective management measures.

Fig 92. Invasion of Himalayan knotweed. Photo : Emmanuel Delbart

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General considerations about management

Various management options have successfully been used to control and eradicate this species. Local eradication of Himalayan knotweed is considered complicated, even for small infestations due to its extensive underground rhizome structure and its capacity to produce new plants from any rhizome or stem fragment. It also requires long-term management efforts. The feasibility of eradicating Himalayan knotweed populations must, therefore, be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce by seeds and fragments, precautionary measures must be implemented before management to prevent spread within the managed area or to uninvaded areas.

The harvested plant material must be safely disposed of far away from water systems or moist areas and is either destroyed (incinerated), dried or deeply buried (min 5m). If left to dry, the plant material cannot be in contact with the ground. It is therefore either safely placed on tarpaulins or on concrete surfaces, where public access is restricted. Plant material must not be left on site or composted and is safely transported in adequate containers. Material that has been in contact with the plant (e.g. clothing, shoes) should be checked, cleaned and dried before being taken to another site.

Managed and downstream sites must remain under enhanced surveillance for a minimum period of 5 years after the last treatment.

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Manual removal

- ✔ Local eradication can be achieved if conducted in the long term
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ The method is only practical for sites with small and recent infestations (young plants with limited rhizome systems)
- ✖ Manual removal is time-consuming and labor intensive

Method description

The principle is to remove the whole plant from the ecosystem. Plants are pulled out by the roots by operators. Manual removal is conducted in areas where the substrate allows for this technique to be implemented (e.g. loose and soft substrate). It is recommended for workers to collaborate in pairs - one handling the spade while the other pulls out the rhizomes. This management strategy is carried out once a month between April and September and is repeated every year for several years (minimum 3 years) to eliminate new shoots. Operators must ensure the removal of as much of the root system as possible. The use of tools is often necessary.

Material

Management: Spades

Transport: Trucks, bags

Precautionary measures: Bags and tarpaulin (if dried)

References

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Washington State Department of Agriculture. (2005) *2005 Washington State integrated knotweed management plan*. WSDA.

Light deprivation: terrestrial cover

- ✔ Good control can be achieved
- ✔ Drastic biomass reduction can occur in a short amount of time
- ✖ This method is suitable for managing small populations in sites free from obstacles
- ✖ When used independently, this method is insufficient to achieve complete eradication
- ✖ The method is not selective and will impact other living organisms

Method description

The principle is to install bank covers that both compress vegetation and exclude sunlight, causing the death of the plants. Sheets of thick, light-blocking material are manually placed by operators over the entire population. Highly resistant material must be used to prevent the risk of the plant breaking and growing through the sheeting. Several layers of adequate sheeting will be required. The use of a single continuous piece of sheeting over pre-cut sheets for each layer is recommended whenever possible to prevent the risk of plant development between overlapping sheets. All plants must be cut at ground level prior to covering. The sheeting must extend at least 7m beyond the managed infestation. The material is secured to the ground by deeply burying its edges (50cm). Sheeting is placed in winter or early spring and remains in place for minimum 2 years (more than 5 years is recommended). Frequent checks are necessary to ensure that new stems are not appearing along the edges of the sheeting and that no damage to the cover has occurred. Manual removal is then implemented during a few years as a follow-up measure to ensure that no regrowth occurs.

Material

Management: The adequate quantity of thick and heavy light-blocking sheeting such as black plastics or recycled conveyor belt. Loppers or a machete, duct tape, rocks, sandbags or stakes

Fig 93. Himalayan knotweed population managed using terrestrial covers. Photo: Marijke Thoonen

References

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Soll, J. (2004) Controlling knotweed (Polygonum cuspidatum, P. sachalinense, P. polystachyum and hybrids) in the Pacific Northwest. The Nature Conservancy.

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Lysichiton americanus

Species description

American skunk cabbage (*Lysichiton americanus*) is a perennial semi-aquatic and aquatic plant native to North America. The species was introduced to Europe, including Belgium, as an ornamental plant for gardens. The first record of American skunk cabbage in the environment in Belgium probably dates from the early 2000s. Natural spread from cultivated plants in private gardens is probably at the origin of its escape into the wild. Today, American skunk cabbage represents a problematic invasive species in many countries worldwide and is now listed as IAS of Union concern under the (EU) Regulation No 1143/2014. Its distribution on the Belgian territory is still limited and probably rather exhaustive due to its high detectability. However, there is a possibility that some populations in private properties remain undetected.

Fig 94. *Lysichiton americanus*.
Photo : Walter Siegmund

Photo: John C Evans

Lysichiton americanus

American skunk cabbage grows in transition areas between aquatic, riparian and terrestrial habitats such as swamps, peat bogs, marshes and along water systems. The plant has diverse environmental and economic impacts. With a potential height of 1.5m, it forms dense clusters of vegetation, and its large leaves create a dense canopy. This has significant detrimental impacts on biodiversity by excluding light, displacing native plants, and potentially leading to the local extinction of certain moss and vascular plant species. Moreover, the plant can also pose health risks due to the presence of calcium oxalate crystals in its sap, which can cause skin irritation. From an economic perspective, the main impact is related to the costs associated with management strategies.

Biological characteristics, reproduction and spread

This invasive species, which can live up to 75 years, emerges in early spring, with flowering occurring before leaves appear. This slow growing plant will only start producing flowers and seeds once they reach 3 years old, or more. The species forms fleshy rhizomes that grow deep into the soil.

In western Europe, American skunk cabbage reproduces almost exclusively by seeds. Once mature, seeds fall to the ground and germinate the following spring near the mother plant (although some seeds can remain dormant for many years). On average, each spadix produces 300 to 650 seeds, which can, in turn, contribute to the formation of a significant seed bank in the soil. These seeds can remain viable for a minimum of 8 years. the spread of this species mainly occurs through seed dispersal via waterways, animals, or intentional planting. There are also concerns regarding its ability to establish from root or rhizome fragments. Those dispersal abilities highlight the importance of implementing effective management measures.

Fig 95. American skunk cabbage is mostly found in damp habitats. Photo : Oleg Kovtun Hydrobio/ shutterstock

References

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General considerations about management

A limited number of management options have successfully been used to control or eradicate the species with digging and application of herbicides being the only effective options. However, the use of chemical control options for managing invasive plant species is not recommended due to the risk of side effects on the natural environment, and is even legally prohibited in some regions. Local eradication of American skunk cabbage is considered achievable for small infestations but requires long-term efforts and management. The feasibility of eradicating American skunk cabbage populations must always be assessed on a case-by-case basis, considering site specificities, population size, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce by seeds, precautionary measures must be implemented before initiating management to prevent seed spread within the managed area or to uninvaded sites. Initiating management actions before seed production or removing flower heads before they set seeds are essential measures to prevent unintentional transportation.

The harvested plant material must be safely disposed of far away from water systems and damp habitats, and is either dried, burned or composted. Material that has been in contact with the soil that may contain seeds (e.g. shoes, machinery) should be checked, cleaned and dried before being taken to another site. It is also advisable to restrict public access to the managed area in order to isolate the infestations and minimise the risk of spread. Operators should avoid direct contact with the plant as the sap contains calcium oxalate crystals, which can cause skin irritation.

Managed sites must remain under enhanced surveillance and be monitored every 2 years for a minimum of 10 years following the implementation of the last treatment.

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Fig 96. American skunk cabbage can colinise diverse habitats. Photo: Jérémie Guyon (top) and Milan Sommer./shutterstock

Manual removal

- ✔ Local eradication can be achieved if manual removal is conducted in the long term
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ The method is only practical for small infestations
- ✖ Manual removal is time-consuming, labor intensive and must be conducted until the seed bank is exhausted

Method description

The principle is to remove the whole plant from the ecosystem. Plants are dug up in a way that all plant material, including rhizomes, is removed from the soil. This management strategy, which can be carried out manually or with machinery, is conducted in early summer and must be repeated in late summer. It is recommended to remove the plant inflorescences before digging up the plant to prevent seed dispersal. With the help of a spade, operators dig around the plant until rhizomes appear and cut the roots found under the rhizomes. The plant can then be removed. For large populations, manual removal only targets mature plants. Manual removal must be repeated twice a year, for at least 8 years, to progressively exhaust the seed bank. Operators must ensure that the whole plant is removed as there is concern over possible vegetative reproduction.

Material

Management: Spades or little digger if machinery is used, protective clothing such as long sleeves, trousers and gloves.

Transport: Bags

References

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RIPARIAN SPECIES OF THE LIFE RIPARIAS ALERT LIST

Erythranthe guttata

Species description

Monkeyflower (*Erythranthe guttata)* is a perennial riparian plant native to North America. In some situations, however, the plant seems to behave as an annual plant. The species was introduced to Europe, including Belgium, though the horticultural trade as an ornamental plant for gardens. The first records of monkeyflower in the environment in Belgium date back to 1953. Natural spread from cultivation is probably at the origin of its escape into the wild. Today, while emerging and uncommon in Belgium (though increasing), the plant might become a problematic invasive species in the near future. However, the species is not listed as IAS of Union concern under the (EU) Regulation No 1143/2014. It has, therefore, been included in the LIFE RIPARIAS alert list. Monkeyflower can easily be confused with *Mimulus* spp. Its distribution on the Belgian territory is likely underestimated due to a lack of recorded observations, monitoring efforts, and possible confusion with look-alike species.

Fig 97. *Erythrante guttata.* Photo : Andreas Rockstein

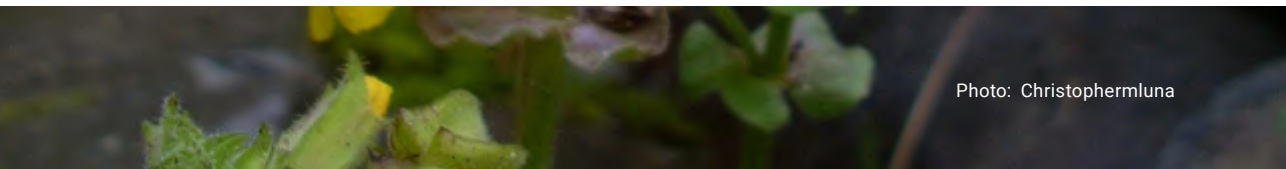

Photo: Christophermluna

Erythranthe guttata

Monkeyflower thrives in moist habitats such as along streams, rivers, and wet pastures. The species can also colonise disturbed areas, and exhibits tolerance to various types of substrates, including contaminated soils containing toxic substances such as copper. As an increasingly widespread invasive species in Belgium, the plant might soon cause diverse environmental, social and economic impacts. Although assessed as having moderate impacts on ecosystems and biodiversity, this invader can form dense mats that can crowd out nearby plant species. Economic effects will probably include management related costs.

Biological characteristics, reproduction and spread

Flowering of monkeyflower occurs in summer, approximately between June to October).

Reproduction of monkeyflower in western Europe is partially vegetative through stolons or rhizomes. When the plant breaks into fragments, either naturally or because of human activity, those fragments of a few cm long can form a new plant, and therefore a new population, away from the initial invaded area. The species also reproduces through seeds, which are contained in fruits (a few hundred in each fruit). These fruits burst open to release the seeds by the end of the growing season. Monkeyflower forms a persistent seed bank, with seeds germinating in fall. The spread of the plant is facilitated by the wind and waterways, which can transport both seeds and fragments. The species' high regeneration and dispersal abilities highlight the importance of implementing effective management measures.

Fig 98. Monkeyflower growing in an inhospitable environment and spreading along a stream

References

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General considerations about management

A few management options have been used to control and eradicate the species, although there is a lack of available literature on this topic. Local eradication of monkeyflower is considered achievable for small populations. Nevertheless, the feasibility of eradicating populations must be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce by seeds and vegetatively through fragmentation, precautionary measures must be implemented before initiating management activities to prevent seed and fragment spread within the managed area or to uninvaded sites. It is essential to initiate management actions before seed production. Managed areas are also isolated by physical barriers (wherever relevant).

The harvested plant material must be safely disposed of away from water systems and moist areas. It can either be incinerated or dried in bags or exposed to sunlight. Material that has been in contact with the plant and with soil that may contain seeds (e.g. shoes) must be checked, cleaned and dried before being taken to another site. It is recommended to restrict public access to the managed area in order to isolate the infestations as much as possible and limit the risk of spread.

Managed and downstream sites must remain under enhanced surveillance for a period of 5 years after the implementation of the last treatment.

Fig 99. Monkeyflower growing in the middle of a shallow stream increases the risk of seed and fragment spread with the current

Tokarska-Guzik, B. and Dajdok, Z. (2010) *Invasive alien species fact sheet* – Mimulus guttatus. NOBANIS.

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Manual removal

- ✔ Local eradication can be achieved
- ✔ The method is suitable for the management of both small and large populations
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ Manual removal is is time-consuming, labor intensive and must be conducted until the seed bank is exhausted

Method description

The principle is to remove the whole plant from the ecosystem. Plants are dug out in a way that all plant material is removed from the soil, including roots. Tearing out the plant with bare hand is not recommended as the plant is fragile and breaks easily, which can increase the risk of fragment spread. Adequate material and tools must therefore be used for manual removal of monkeyflower to ensure the complete removal of the plant. It is also strongly recommended to work with skilled and experienced operators as the species can be challenging to spot and identify. This management strategy is conducted before seed production. Manual removal is repeated over multiple years to progressively eliminate regrowth from remaining fragments, seedlings (until the exhaustion of the seed bank) or plants that would have been overlooked. Operators must avoid leaving the ground bare as it can favour seed germination. Reinforcing and restoring the native ecosystem by introducing native species that will strongly compete with the monkeyflower is therefore recommended.

Material

Management: Waders, spades and gloves.

Transport: Bags and buckets

Precautionary measures: Containment net and hand net

References

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Houttuynia cordata

Species description

Chinese lizard tail (*Houttuynia cordata*) is a terrestrial and semi-aquatic perennial and rhizomatous plant native to Asia. The species was introduced to Europe, including Belgium, through the horticultural trade as a popular ornamental plant for gardens and ponds. In some other parts of the world, the species was also introduced for medicinal and culinary purposes. The first records of Chinese lizard tail in the environment in Belgium remain rather uncertain. Disposal of garden waste, along with natural escape from cultivation are probably at the origin of its current presence in the wild. Today, while emerging and uncommon in Belgium, the plant might become a problematic invasive species in the near future. It has therefore been included in the LIFE RIPARIAS alert list. Although easily detectable, its presence on the Belgian territory is probably underestimated due to a lack of recorded observations and monitoring efforts.

Fig 100. *Houttuynia cordata.*
Photo : Σ64

Houttuynia cordata

Chinese lizard tail grows in moist habitats such as wetlands, on the banks of ponds and waterways but also in shaded sites such as cool forest environments. As an emerging invasive species in Belgium, the plant might soon cause diverse environmental, social and economic impacts. In some parts of its introduced range (North America and New-Zealand), the plant has already displayed some invasive tendencies. This invader forms dense groundcovers that can have detrimental effects on the ecosystem and biodiversity by displacing native plant species. Economic effects include costs associated with management as the species appears to be extremely complex to manage.

Biological characteristics, reproduction and spread

In western Europe, flowering of Chinese lizard tail occurs in early summer. The plant, which resists well to frost, dies back to the rootstock during winter months. In warmer regions, the species can be semi-evergreen. A cultivar with tricolor leaves is also currently available via the horticultural trade in Europe. It has, however, not yet been observed in the wild in Belgium.

Reproduction in western Europe is principally vegetative through the cutting or division of rhizomes and creeping stems. When the plant breaks into fragments, either naturally or because of human activity, those small fragments can form a new plant, and therefore, a new population away from the initial invaded area. The species can also reproduce by seeds, which are contained in fruits (4 to 18 in each fruit). As the fruits are apomictic, no fertilisation is required for seed development. Whether Chinese lizard tail produces viable seeds in Europe and permanent seedbanks remains uncertain and requires further research. Spread mainly occurs through fragments being transported by water courses or human activities. The species' high regeneration and dispersal abilities highlight the importance of implementing effective management measures.

Fig 101. Invasion of Chinese lizard tail forming dense canopy. Photo : Meneerke bloem

References

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General considerations about management

Few management options have been implemented so far to control and eradicate the species, with manual removal and the application of herbicides being the dominant methods. However, the use of chemical control options to manage invasive plant species is not recommended due to the risk of side effects on the natural environment, and is even legally prohibited in some regions. There is also a lack of available literature on management measures for this species. Local eradication of Chinese lizard tail is considered hardly achievable, even for small infestations, due to its impressive propagation abilities and high resistance to herbicides. The feasibility of eradicating populations must, therefore, be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce vegetatively through fragmentation, precautionary measures must be implemented before initiating management to prevent fragment spread within the managed area or to uninvaded. The harvested plant material must be safely disposed of far away from water and moist areas, and is destroyed (incinerated). Material that has been in contact with the plant and the contaminated soil should be checked, cleaned and dried before being taken to another site. It is recommended to restrict public access to the managed area in order to isolate the infestations as much as possible and limit the risk of spread.

Managed and surrounding areas must remain under enhanced surveillance for a period of 5 years after the implementation of the last treatment.

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Manual removal

- ✔ Control and potential local eradication can be achieved
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ The method is only practical for small and early-detected populations
- ✖ Manual removal is time-consuming and labor intensive

Method description

The principle is to remove the whole plant from the ecosystem. Plants are dug out in a way that all plant material is removed from the soil, including roots and rhizomes. This management strategy is conducted at the beginning of the regrowth phase, which occurs in spring. Operators must ensure that all parts of the plant are removed as the species cn regrow from fragments. Manual removal is repeated at regular intervals over multiple years to progressively eliminate regrowth from fragments and rhizomes. This process is continued until no further regrowth is observed.

Material

Management: Spades, gloves and garden forks

Transport: Bags and buckets

References

Environment Bay of Plenty. (2003) *Pest plant control - ground cover - pest plants: Chameleon plant* (Houttuynia cordata). National Pest Plant Accord.

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DID YOU KNOW?

Terrestrial plastic covers as a management measure

Light deprivation using black plastic or polythene sheets is one possible option to manage small areas invaded by Chinese lizard tail. The principle is to install covers that both compress vegetation and exclude sunlight, causing the death of the plants. All plants must be cut prior to covering. It is really important that no light reaches the plants from any adjacent area, gaps or the edges of the sheeting. Operators must, therefore, ensure the adequate placement of the sheeting and that strips overlap correctly. The use of large continuous pieces of sheeting is recommended whenever possible. Additionally, the sheets should be properly secured and firmly fixed to the ground. Regular inspections to check for any damages or breaches are highly recommended.

It is important to note that there is limited literature available regarding the use of terrestrial covers for managing Chinese lizard tail. Consequently, there is a lack of information regarding management outcomes and specific technical details, such as adequate time period during which covers must remain in place.

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Fig 102. It is necessary to check for any damages that would allow the plant to grow through the sheeting. Photo: Marijke Thoonen

Petasites japonicus var. giganteus

Species description

Giant butterbur (*Petasites japonicus var. giganteus*) is a perennial riparian plant native to Asia. The species was introduced to Europe, including Belgium, though the horticultural trade as an ornamental plant for gardens. The first records of giant butterbur in the environment in Belgium date back to 1989. Disposal of garden waste and natural spread from cultivation are probably at the origin of its escape into the wild. Today, while emerging and uncommon in Belgium, the plant might become a problematic invasive species in the near future. It is therefore a species of the LIFE RIPARIAS alert list. Giant butterbur can easily be confused with native plant species such as *Petasites hybridus*. Its distribution on the Belgian territory is probably underestimated due to a lack of recorded observations, monitoring efforts and possible confusion with look-alike species.

Fig 103. *Petasites japonicus var. giganteus*. Photo : Dominicus Johannes Bergsma

Photo: Jérémie Guyon

Petasites japonicus var. giganteus

Giant butterbur is mostly found in moist habitats such as along ponds and streams, shady woodlands, ditches and wet meadows. The plant thrives in partially shaded areas. As an emerging invasive species in Belgium, the plant might soon cause diverse environmental, social and economic impacts. In some parts of its introduced range (northern Europe), the plant has already displayed some invasive tendencies. This invader has the capability to form dense stands, which can have detrimental effects on the ecosystem and biodiversity. It displaces native plant species, restricts light availability, and contributes to soil erosion. Economic effects involve management costs associated with controlling, eradicating and mitigating the spread of the plant.

Biological characteristics, reproduction and spread

Flowering of giant butterbur occurs in early spring, before the leaves emerge. The plant then dies back in late fall, leaving bare ground, and emerges from rhizomes the next growing season.

Giant butterbur is a dioecious species. Its reproduction in western Europe is exclusively vegetative via fragmentation of thick rhizomes. When the rhizome breaks into fragments, either naturally or because of human activity, those small fragments can form a new plant, and therefore a new population, away from the initial invaded area. In its native range, giant butterbur is also known to reproduce by seeds, although production of viable seed does not occur in Belgium as only male individuals have been observed so far. The spread of giant butterbur mainly occurs through the transportation of rhizome fragments by waterways, particularly during flooding events. The species' remarkable regenerative and dispersal abilities emphasise the importance of implementing effective management measures to control its spread and impact.

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Fig 104. Giant butterbur invasion in a private property forming dense stands. Photo: Marie Patinet

General considerations about management

Few management options have been implemented so far to control and eradicate the species. There is also a lack of available literature on this topic. Local eradication of giant butterbur is considered hardly achievable for well-established populations. The feasibility of eradicating populations must, however, be assessed on a case by case basis, considering site specificities, and be thoroughly discussed within the management team.

Due to the species' ability to reproduce vegetatively through fragmentation, precautionary measures must be implemented before management to prevent fragment spread within the managed area or to uninvaded areas. The harvested plant material must be safely disposed of far away from water systems and moist areas, and is either destroyed (incinerated) or placed in trash bags to be buried. Material that has been in contact with the plant (e.g. machines and equipment) should be checked, cleaned and dried before being taken to another site.

Managed and surrounding areas must remain under enhanced surveillance for a period of 5 years after the implementation of the last treatment.

Tualatin Watershed Invasive Species Team. (2021) *Weed watchers guide invasive plant species of the Tualatin river watershed.* TWIST.

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Fig 105. Giant butterbur reproduces through fragmentation of thick rhizomes. Photo: Marie Patinet

Fig 106. Flowering of giant butterbur occurs before the leaves emerge. Photo: Jérémie Guyon

Manual removal

- ✔ Control and potential local eradication can be achieved
- ✔ Manual removal is highly selective and will have minimal impact on ecosystems and other organisms
- ✖ The method is only practical for small and early-detected populations
- ✖ Manual removal is time-consuming and labor intensive

Method description

The principle is to remove the whole plant from the ecosystem. Plants are dug out in a way that all plant material is removed from the soil, including roots and rhizomes. This management strategy, which can be carried out manually or with machinery, is conducted during the vegetative period. Operators must ensure that all parts of the plant are removed as the species will resprout from fragments of rhizome. Manual removal is repeated at regular intervals over multiple years to progressively remove regrowth from remaining rhizomes. It is implemented until no regrowth occurs.

Material

Management: Spades or little diggers, gloves

Transport: Bags

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Tualatin Watershed Invasive Species Team. (n.d) *Best management practices – Japanese butterbur* – Petasites japonicus. TWIST, Tualatin Soil and Water Conservation District.

Fig 107. Very large kidney-shaped and irregularly toothed leaves that can measure up to 150 cm in diameter. Photo: Marie Patinet

CHAPTER IV – Case studies

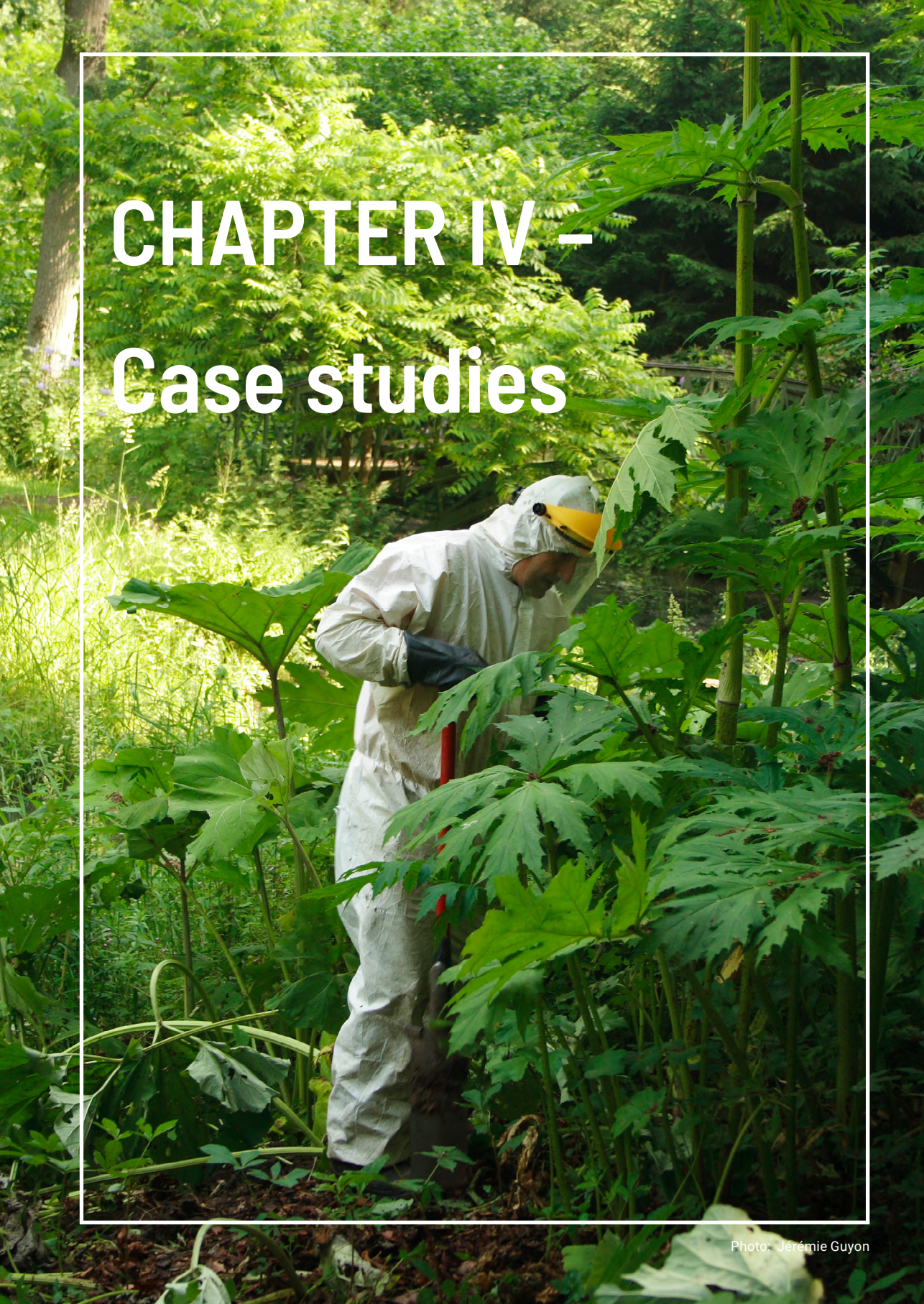


Photo: Jérémie Guyon

Case study: *Cabomba caroliniana* Sint-Pauwels

Situation before management

Fanwort invaded a 1200 m² ditch filled with water and with a maximum depth of 1.20 m, located along a residential street near the center of the village of Sint-Pauwels (Fig. 108). The ditch, which is owned by the municipality of Sint-Gillis-Waas, has a conservation status due to its cultural and historical value.

The invasive plant was observed in the ditch for the first time in 2003. Disposal of aquarium material containing fanwort is probably at the origin of its presence in the ditch as several goldfish were found in the water body. A few years were required to gather information and resources necessary for management, which allowed fanwort to develop and occupy the whole site in 2018, right before the start of management actions.

Management objectives

As this record of fanwort in the wild was the first in Belgium since 1998, both the municipality and the province agreed to aim for the eradication of the plant. Although the ditch is not connected to the hydrographic network and, therefore, poses little risk for the dispersal of the plant, the invasive capacities of fanwort along with the population size led the operators to invest important human and financial resources in this project.

Management actions were implemented and co-financed by the municipality of Sint-Gillis-Waas and the province of East Flanders. Monitoring efforts were conducted by RATO, a non-profit organisation. Due to the conservation status of the ditch, which prohibits any physical transformation of the site, operators decided to proceed with the implementation of dredging work, followed by light deprivation techniques.

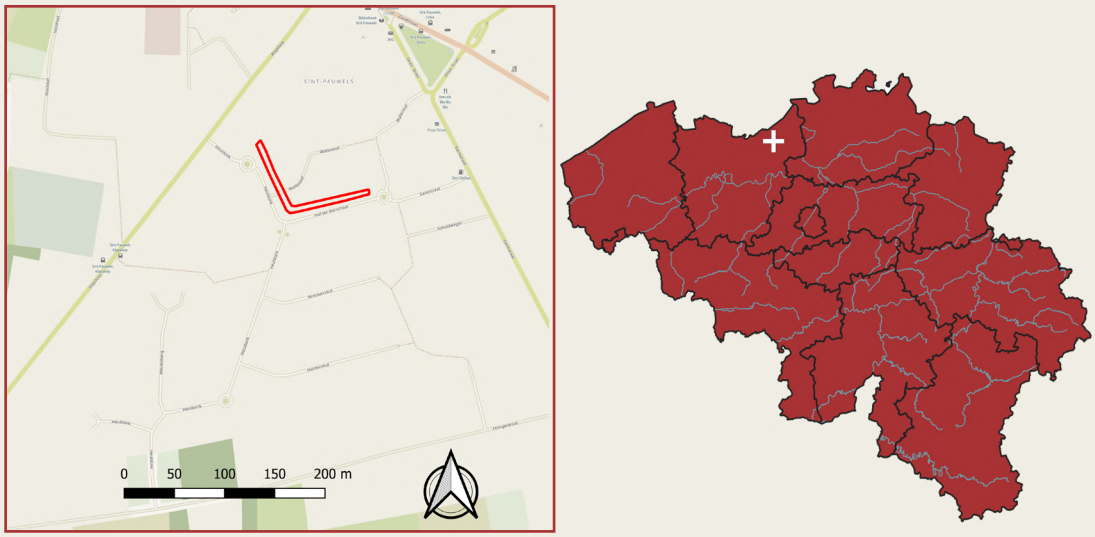


Fig 108. The invaded site is a ditch located in Sint-Pauwels. Map: OpenStreetMap

Management actions

Due to the historical and cultural value of the ditch, clear communication with the local community was an important part of the management before the start of any action.

In summer 2018, one day was required to drain the ditch and evacuate the fish. The pump was equipped with a filter to prevent fragment spread.

A complete dredging of the site was conducted to a depth of 20 to 60 cm (Fig. 109). The removed sediments were transported 6 km away from the ditch, in an industrial zone. These operations alone costed approximately 40 000€.

Despite a dry summer, the ditch refilled with underground water within only 2 weeks. As a result, dense fanwort populations were able to redevelop (Fig. 110). Due to the important population size, operators decided to implement light deprivation techniques on the entire site rather than manual removal.

In February 2019, another drawdown took place. The visible vegetation was removed through manual removal and brush cutting. A geotextile light-blocking cover was then installed on the whole site (Fig. 111).

The placement of the cover was divided into 2 steps: firstly, one 5m large sheet covering the whole infestation was placed. Four 10m sheets, overlapping the first one, were then installed.

Finally, a concrete tube was installed on the sheeting to allow operators to easily control the presence/absence of fanwort the following years without having to remove the whole geotextile (Fig. 112). In September 2022, the tube was drained using a pump, and the cover inside the tube, was removed. No fanwort was observed in this test zone.

The whole geotextile cover, which remained in place for 3 years, was therefore removed from the ditch in September 2022.

Fig 109. Dredging work was implemented on the whole invaded area. Photo: Provincie Oost-Vlaanderen dienst Integraal Waterbeleid

Fig 110. Despite dredging, fanwort was still present in autumn 2018. Photo: Provincie Oost-Vlaanderen dienst Integraal Waterbeleid

Results and prospects

No fanwort was observed in the ditch after the implementation of the 2 management actions. Nevertheless, active surveillance and monitoring of the site are conducted in order to prevent any resurgence of the plant. Although further fanwort invasions have since been discovered in other sites, all the resources devoted with the goal to eradicate the plant from the ditch have been useful to curb the invasion of the species in Belgium.

The success of this local eradication is closely related to the site characteristics which allowed for dredging work and the placement of a geotextile light-blocking cover. Those methods are not always suitable for all sites, notably because the whole treated area must be accessible to the machines in case of dredging. In running waters, the placement of covers is often impracticable.

Acknowledgments

All the information contained in this case study has been provided and compiled by Adrien Delforge, Tim Adriaens and Koen Van Roeyen.

Fig 111. Geotextile light-blocking covers were placed in order to compress vegetation and exclude sunlight during a few years. Photo: Provincie Oost-Vlaanderen dienst Integraal Waterbeleid

Fig 112. The concrete tube enabled operators to verify the effectiveness of the management without removing the fabric from the whole treated area. Photo: Provincie Oost-Vlaanderen dienst Integraal Waterbeleid

Case study: *Crassula helmsii*

Zedelgem

Situation before management

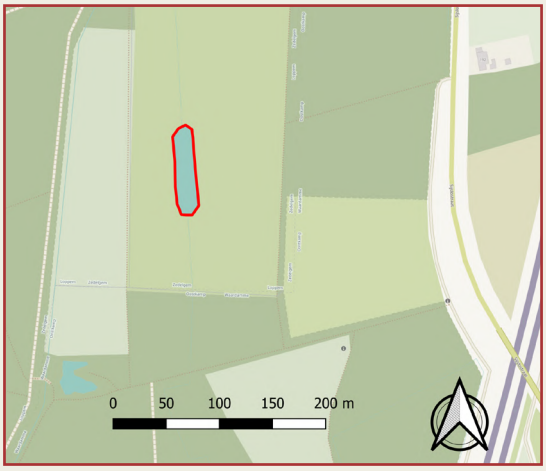
New Zealand Pigmyweed invaded a 1600 m² pond, located in the Doeveren nature reserve in Zedelgem (Fig. 113). The nature reserve is owned by Natuurpunt. Banks are periodically disturbed due to grazing by Galloway cattle in winter.

The banks were reshaped in 2017, which led to a complete loss of the vegetation. This provided pioneer species with opportunities to establish themselves on the banks, including the New Zealand Pigmyweed which was already present in several sites in the surrounding areas.

The nature reserve is frequently visited by diverse users, although visitors should not get access to the pond as it is away from any path. Several bird species, notably geese, are known to move between the site and other potentially invaded sites nearby, promoting the dispersal of the New Zealand Pigmyweed.

Management objectives

Due to the well-known highly invasive nature of the New Zealand Pigmyweed, Natuurpunt Zedelgem decided to monitor the site after bank reshaping work, as the plant was present in the surrounding areas. Although enhanced surveillance was initiated early in the process of invasion, which enabled early detection, the eradication of the plant was not considered as a management objective. Indeed, the complete eradication of the New Zealand Pigmyweed is extremely challenging and reinvasion risk is undoubtedly high. The main objective was therefore to limit the progression of the New Zealand Pigmyweed to enable the establishment of native pioneer species. Due to the conservation value of the site, refilling the pond (ecosystem shift) with substrate was not considered as a suitable management option.



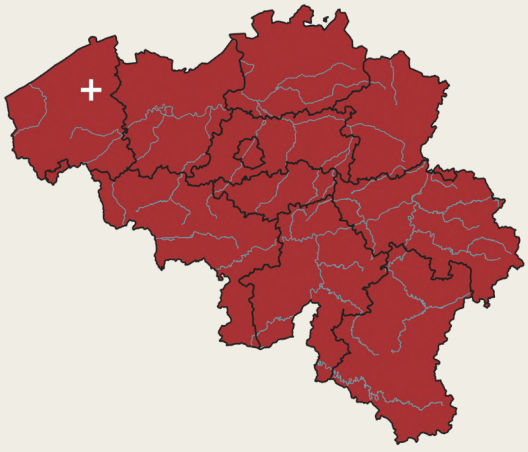


Fig 113. The invaded site is a pond with reshaped banks. Map: OpenStreetMap

Management actions

In spring 2018, the site was monitored for New Zealand Pigmyweed, and in June 2018, the first specimens were observed.

All the areas that were invaded by the plants were either excavated with a shovel or buried with sand obtained from previous bank reshaping work (Fig. 114). The harvested plant material and sediment were safely transported to a dry zone in the nature reserve and buried there (Fig. 115).

From June to October 2018, dozens of plants were managed through excavation or sand burial. Nevertheless, the New Zealand Pigmyweed was, then, rapidly observed both on the banks and in the water, impeding management actions.

In 2019, management actions were carried out until June, when the New Zealand Pigmyweed population was considered too extensive for further resources to be invested in management. Management actions were therefore cancelled in summer 2019.

Fig 114. For isolated individuals or limited invaded zones, excavation was implemented. The harvested material was transported to a dry area in the nature reserve. Photo: Bram D'hondt

Fig 115. Larger populations were buried with sand obtained from previous bank reshaping work. Photo: Bram D'hondt

Results and prospects

Despite the early detection and the resulting rapid response, the New Zealand Pigmyweed population could not be controlled. The colonisation of the site by the invasive plant might have been caused by waterfowl entering the nature reserve or by the machines used during previous bank reshaping work. Contamination of the site may have been important or repeated, leading to the rapid expansion of the species in a short amount of time. Moreover, it is likely that techniques such as the burial of larger infested zones are not effective enough. Since 2019, the site has no longer been subject to any management actions regarding the New Zealand Pigmyweed and the species now occupies its full niche, on the banks and in the pond (Fig. 116). The managers are now considering to periodically sod-cut parts of the banks to set back succession, allowing native flora to regenerate but also accepting New Zealand Pigmyweed as part of the pond flora.

Failure to control the New Zealand Pigmyweed population demonstrates the complexity to manage this invasive species. While terrestrial and benthic covers could have been placed to exclude sunlight, this method is not selective and has important impacts on vegetation.

Acknowledgments

All the information contained in this case study has been provided and compiled by Adrien Delforge and Bram D'hondt.

Fig 116. The site is no longer subject to management actions to control the New Zealand Pigmyweed and the species now occupies its full niche. Photo: Erwin Derous

Case study: *Erythranthe guttata*

Saint-Hubert

Situation before management

The invaded site is part of the Hatrival stream, located in the municipality of Saint-Hubert (Fig. 117). The invaded part of the stream is shallow and is under the responsibility of a private owner.

The monkeyflower was observed for the first time in 2010, and no management action was initiated. Nevertheless, in 2013, the important population size and the inconvenience caused by the presence of the plant, convinced the private owner to implement manual removal in 2014, and then, to seek the help from the Contrat de rivière Lesse in 2015. Before management in 2015, monkeyflower invaded the stream with a stand forming a 1km long strip (with a width of maximum 2m). The plant was also present on the banks.

Management objective

Due to the significant size of the invaded area and the accessibility of the site, systematic manual removal of the monkeyflower was implemented to control de population. Manual removal being laborious and time-consuming, operators benefited from the help of skilled volunteers who had been trained beforehand (Fig. 118).

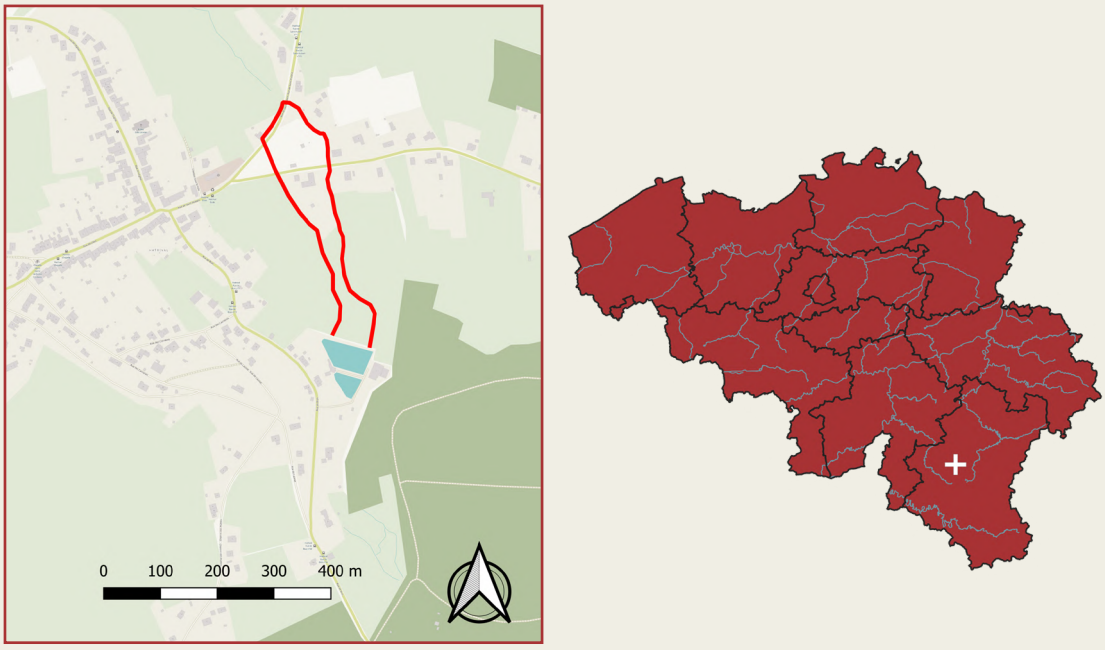


Fig 117. The invaded site is a 2m large stream located in Saint-Hubert. Map: OpenStreetMap

Management actions

The municipality of Saint-Hubert provided operators with tools in order to facilitate the manual removal. In addition to the management actions led by the Contrat de rivière Lesse, the private owner ensured regular management of the stream.

The first manual removal took place in 2015 and required 35 man-hours. The management of this population was made possible thanks to the help of interns. The harvested material was left on site, away from the stream and any wet areas.

From 2016 to 2019, several volunteers participated in the management as part of the «Orange Day», which allows employees from diverse organisations to use one day for voluntary purposes. This partnership brought together more than 100 volunteers during one annual manual removal conducted in July 2016 and 2017 and 2 others in July and August 2018 and 2019. Management efforts were fruitful as monkeyflower density was decreasing annually. Indeed, almost no plants were found during manual removal in 2019. Achieving population control seemed therefore possible.

Unfortunately, management actions that were planned for 2020 and 2021 had to be cancelled due to the COVID-19 pandemic (no "Orange day"), but also because of the major floods that strongly affected the Lesse basin.

In July 2022, management actions involving volunteers could start again. The monkeyflower invasion had returned to its initial state (Fig. 118).

Results and prospects

Although management actions were initiated by the Contrat de rivière in 2015, the monkeyflower still occurs in the Hatrival stream. Indeed, despite encouraging results in 2019, the absence of management actions in 2020 and 2021 enabled the population to return to its pre-management state. Moreover, the required manpower for the implementation of manual removal obliged operators to rely on volunteers who were not always sufficiently trained and qualified. As a result, despite the vigilance of the operators, fragments spread occurred after each manual removal. Manual removal should be conducted several times a year, if a good level of control is to be achieved. However, due to limited manpower, the Contrat de rivière can only conduct a restricted number of field visits.

In the future, the site will continue to be managed by the Contrat de rivière and volunteers, in addition to the actions conducted by the private owner.

Acknowledgments

All the information contained in this case study has been provided and compiled by Adrien Delforge and the Contrat de Rivière Lesse.

Fig 118. Despite management actions, the monkeyflower is still highly invasive in the Hatrival stream. Photo: CR Lesse

Case study: *Heracleum mantegazzianum* Vierset-Barse

Situation before management

The giant hogweed invaded a 1500m² wasteland adjacent to a woodland and located in the village of Vierset-Barse (Fig. 119). The wasteland belongs to a private owner but the road shoulder bordering the invaded site is owned by the municipality of Modave. The grove next to the wasteland is owned by another private person.

This giant hogweed population was observed for the first time in 2012. Before the first management action, around a hundred plants covering 500 m² were scattered over the road shoulder and the private wasteland (Fig. 120).

Giant hogweed management in the Walloon Region is part of the "Walloon action plan to tackle the giant hogweed" and benefits therefore from a coordinated management and support from the Public Services of Wallonia.

Management objective

Due to the limited population size and site accessibility, the Contrat de rivière Meuse Aval, the private owner and the municipality of Modave aimed for the eradication of the giant hogweed population. As knowledge of giant hogweed management is quite good, severing the tap root, a widely tested and preferred method in the Walloon Region, was implemented.

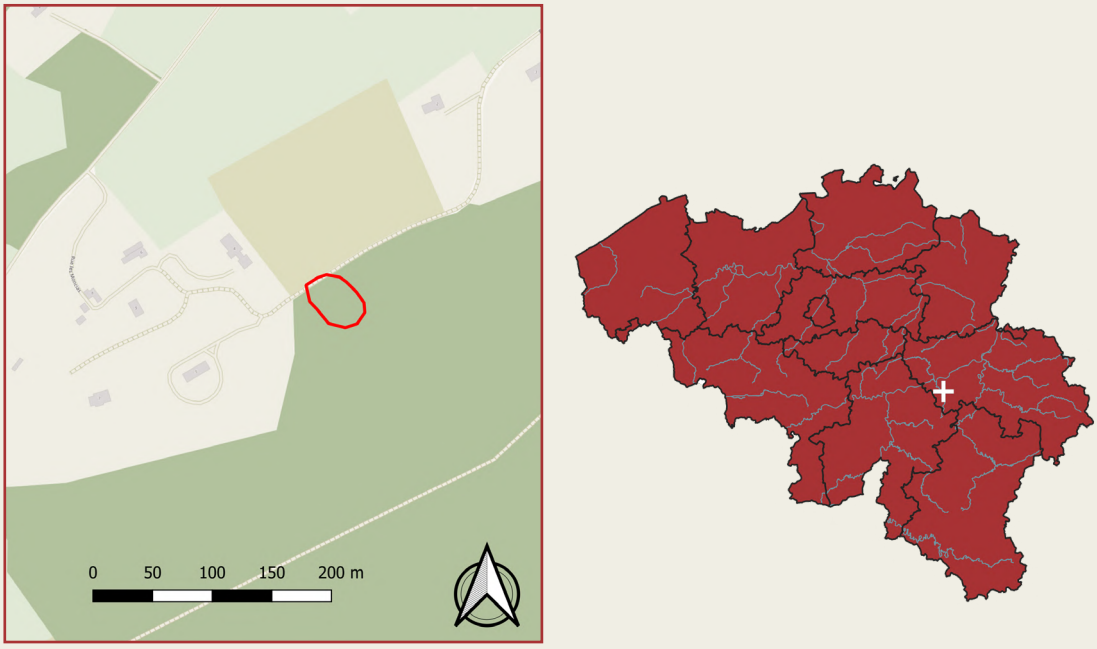


Fig 119. The invaded site is a private wasteland and road shoulder owned by the municipality. Map: OpenStreetMap

Management actions

In June 2014, the municipality of Modave and the Contrat de rivière Meuse Aval removed the 3 seedlings present on the road shoulder (Fig. 121). They also contacted the owner of the adjacent wasteland, who, then, decided to transform the wasteland into a pasture. Leveling the site was, therefore, planned the following year, after the management of the hundred plants present on site.

In May 2015, manual removal of more than a hundred giant hogweed present in the wasteland and the road shoulder was implemented by the Contrat de rivière Meuse Aval and the private owner. Moreover, to prevent seed set, 11 giant hogweeds were removed from the neighbouring grove to which the private owner had granted access. A second manual removal was organised in September, during which 5 plants were removed. The conversion of the wasteland into a pasture took place in September. Sheep grazing was planned by the private owner as a follow up measure to giant hogweed management.

Despite those plans, manual removal of giant hogweed was conducted by the Contrat de rivière and the municipality of Modave in spring 2016 and 2017. Indeed, the pasture was finally made available for horses, that were occasionally present. Nevertheless, the number of plants was significantly decreasing in the pasture. A few individuals could still be observed in the neighbouring grove, where monitoring and management were made difficult due to the density of the vegetation.

In May 2018, manual removal (tap root cutting) of around a hundred individuals was implemented by the Contrat de rivière. The majority of the plants was found in the grove (Fig. 122).

In June 2019, 7 plants were manually removed by the Contrat de rivière and the municipality of Modave in the area surrounding the site that was initially invaded.

In June 2020, 19 seedlings were manually removed from the grove by the municipality of Modave and the Contrat de rivière. No plant was, however, observed in the initial invaded site.

In July 2021 and 2022, the site was monitored by the Contrat de rivière. One giant hogweed was found and removed in 2021 while 2 others managed in 2022.

Fig 120. More than a hundred giant hogweeds were present on the site before management. Photo: CR Meuse Aval

Results and prospects

After several years of management, eradication is almost achieved. Although giant hogweed has not been observed in the pasture (previously the wasteland) since 2019, the invasive plant is still present in the neighbouring grove. Another agreement with the private owner enabled the implementation of management actions in order to prevent the population to develop once again. While it is challenging to detect seedlings in the grove, the annual decrease of giant hogweed number suggests that the total eradication of the population is achievable.

Those promising management results are the outcome of a rigorous surveillance, with the annual management preventing the rapid reestablishment of the giant hogweed. The site will be monitored by the Contrat de rivière Meuse Aval until the complete eradication of the population, i.e. until no giant hogweed is found during 7 years.

Acknowledgments

All the information contained in this case study has been provided and compiled by Adrien Delforge and the Contrat de Rivière Meuse Aval.

Fig 121. Although the majority of the population was found in the pasture, a few, less visible individuals were observed on the road shoulder. Photo: CR Meuse Aval

Fig 122. After several years of management, the giant hogweed is almost eradicated from the pasture. Photo: CR Meuse Aval

Case study: *Hydrocotyle ranuncoloides* Grez-Doiceau

Situation before management

Floating pennywort invaded a private pond which is connected to the Grande Marbaise, a shallow, non-navigable waterway of 1 to 2m large (Fig. 123). The stream flows to the Flemish Region, along the GrooteBroek nature reserve.

In order to preserve the nature reserve, mechanical and manual removal of floating pennywort found in the Flemish part, was conducted in 2014 by the province of Flemish Brabant and the Vlaamse Milieumaatschappij. To prevent recolonisation by the plant, the province of Walloon Brabant and the Contrat de rivière Dyle-Gette, which are responsible for waterways situated in the Walloon Region, conducted field research to determine the invasion hotspot from which propagation occurred. The invaded private pond was therefore identified, which led to the implementation of management actions.

In 2014, approximately 2,4km of watercourse (from the private pond to GrooteBroek) was invaded by the floating pennywort, obstructing the stream. Public water parts of the Grande Marbaise, located in the Walloon Region, were managed by the province of Walloon Brabant while private water parts (the pond and the canal connected to the Grande Marbaise), were managed by the Contrat de rivière. This case study only focuses on these 2 management projects.

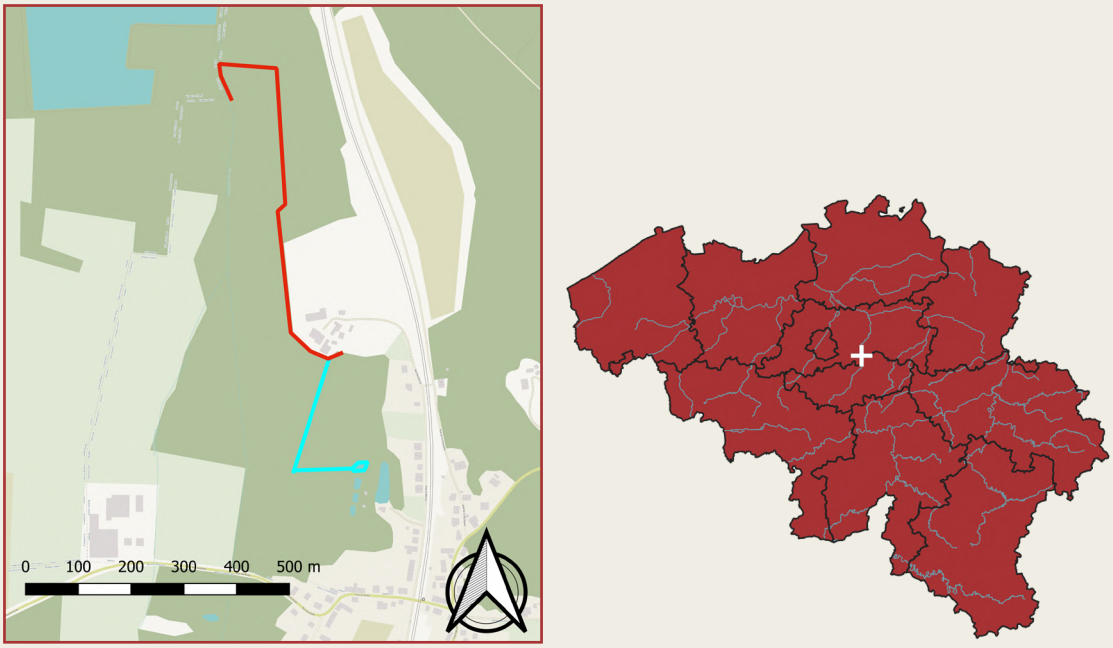


Fig 123. The invaded site is a private pond and canal as well as 750m of stream. The red line illustrates the part of the invaded site which was managed by the province of Walloon Brabant while the blue line highlights the invasion zone managed by the Contrat de rivière Dyle-Gette. Map: OpenStreetMap

Management objective

The identification of the invasion hotspot from which propagation occurred enabled the eradication of the population in the whole site, which was the goal of field managers after thorough discussions. The province of Walloon Brabant and Vlaamse Milieumaatschappij decided to adopt the same management process: the implementation of mechanical removal followed by manual removal. The Contrat de rivière Dyle-Gette performed a systematic manual removal of the invaded parts that were less accessible: the canal and the private pond.

Management actions

In July 2015, a containment net was placed by the province of Walloon Brabant to prevent fragment spread to the downstream part of the stream (Fig. 124). The banks were, then, mowed to facilitate the manual removal of the floating pennywort. The majority of the population invading the stream was mechanically removed with the help of excavators (Fig. 125). Mechanical removal was followed by manual removal of remaining plants and fragments. The private part was entirely managed by manual removal. The harvested plant material was first transported in flex containers to a storage area before being transferred to a refuse depot (Fig. 126). Manual removal was, in total, repeated 4 times (July, August, September and October). These operations were necessary to monitor the evolution of the population and to eliminate regrowth, for a total of more than 400 man-hours for the year 2015

In 2016, although the floating pennywort was still undeniably present, the quantity of plant material removed was much lower. Operators spent approximately 130 man-hours to eliminate regrowth.

In 2017, around 80 man-hours was necessary to remove the whole invasion from the stream, managed by the province of Walloon Brabant. The private part was monitored, and no plant was observed that year.

In 2018 and 2020, a few monitoring visits were organised and only a limited number of plants was observed and removed.

Fig 124. In order to prevent the spread of fragments, a containment net was placed in the stream. Photo: Province du Brabant Wallon

Fig 125. The largest population was mechanically managed in 2015. Photo: Province du Brabant Wallon

Results and prospects

The Contrat de rivière Dyle-Gette continues to monitor the whole site. The stream and the private pond are still free from floating pennywort. This successful eradication is the result of a strong cooperation between the different regions and stakeholders, working towards the conservation of biodiversity. Indeed, managing the invasion in the nature reserve of GroteBroek would have been futile if management actions were not implemented to tackle at the same time the source of the invasion. This interregional cooperation enabled the eradication of the floating pennywort on 2,4km invaded waterways.

Acknowledgments

All the information contained in this case study has been provided and compiled by Adrien Delforge, Jérémie Guyon and Marielle Brasseur.

Fig 126. The harvested plant material was stored in flex containers before being exported to a refuse depot. Photo: Province du Brabant Wallon

Case study: *Lagarosiphon major*

Durbuy

Situation before management

The invaded site is an artificial body of water which is owned by the municipality of Durbuy. This 3 000 m² and 1,5m deep site, is located in the city center, at the boundary of a Natura 2000 area (Fig. 127). Water jet and lighting systems are integrated to the site, and numerous pipes and cables are fixed to the bottom of the water body. In 2017, the totality of the pond surface was invaded by the curly waterweed.

Since the site is a tourist attraction and an important place of interest for the municipality, a water drawdown, foreseen to facilitate management actions, can only be implemented outside the tourist season (from the 15th of June to the 15th of October), in order to preserve the aesthetic value of the site (Fig. 128).

Management objectives

Operators from the SPW Agriculture, Natural resources and Environment, responsible for management, decided to aim for the eradication of the population by manual removal. Indeed, the lack of resources and management experience of the curly waterweed conducted operators to favour a popular method for the management of other invasive alien aquatic plant species. Involving divers for the placement of benthic covers was disregarded. Light deprivation using jute matting was therefore not considered.

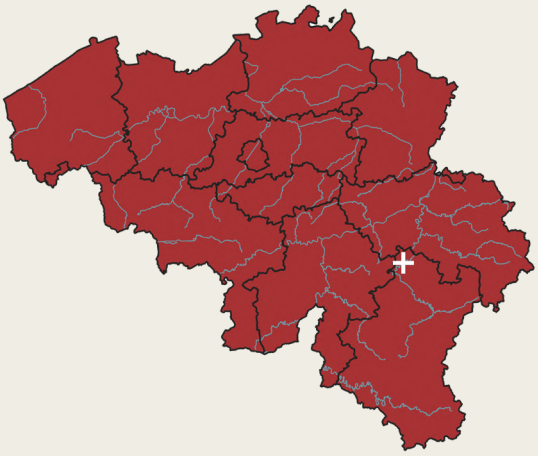


Fig 127. The invaded site is an artificial water body located in the town of Durbuy. Map: OpenStreetMap

Management actions

Water drawdown and repeated manual removal were conducted outside the tourist season, with the help of the municipality of Durbuy. Following the water drawdown, the deepest part of the water body was around 1m deep. After each management action, the harvested plant material was transported to an adequate refuse depot for green waste.

The first manual removal took place in October 2017, and was repeated a second time shortly after. Sediment disturbance caused by the first manual removal affected the clarity of the water. The second manual removal enabled to gather a maximum of plant material. Nevertheless, the presence of submerged obstacles like cables and pipes along with the important depth of some areas, increasedthe complexity of manual removal and, in some places, underground parts of the plants could not be entirely removed. Approximately 6 m³ of plant material was removed, for a total of 50 man-hours.

In 2018, manual removal was conducted a first time in June, before the tourist season, and a second time in October. Although curly waterweed was still present in areas that were less accessible, only 1 m³ of plant material was removed from these zones, for a total of 20 man-hours.

In 2019, manual removal was conducted after the tourist season (November) and a few plants were eliminated. Due to limited regrowth, eradication was considered achievable.

Nevertheless, in 2020 and 2021, COVID-19 pandemic-related lockdown had a serious impact on the organisation of management measures. Curly waterweed was therefore able to recolonise part of the water body. Due to the species' high dispersal abilities and the limited resources available, only partial manual removal was conducted. The curly waterweed invasion has now returned to its initial state (Fig. 129).

Fig 128. The site is located in the city center, where tourism is important. The aesthetic value of the site must therefore be preserved. Photo: SPW

Results and prospects

Despite promising and encouraging management results until 2019, the limited available resources and COVID-19-related constraints provided curly waterweed with the opportunity to recolonise the site. This highlights that a lack of rigorous management efforts can rapidly lead to a negative and undesired evolution of the managed population. Due to the species' high dispersal abilities through fragmentation, the presence of a water jet in the water body might also have had an impact on population dynamics.

It is essential to remove all the roots, even in deeper areas or in less accessible zones, if eradication by manual removal is to be achieved. The involvement of divers seems therefore crucial. Constraints related to the tourist season, to the important invasion size and to the aesthetic value of the site, could encourage operators to favour the placement of a benthic cover on parts or on the whole water body. Indeed, jute matting, which could be placed before the tourist season, can lead to the eradication of the species while conserving the aesthetic value of the site. Light deprivation using benthic jute matting appears to be adapted to this invasion situation. However, this requires the involvement of divers for the placement of the sheeting as well as monitoring efforts. The implementation of manual removal as a follow up measure might need to be conducted to remove any plant regrowth, especially near the obstacles.

Acknowledgments

All the information contained in this case study has been provided and compiled by Adrien Delforge and Pierre Joye.

Fig 129. The site is located in the city center, where tourism is important. The aesthetic value of the site must therefore be preserved. Photo: SPW

Case study: *Myriophyllum aquaticum*

Theux

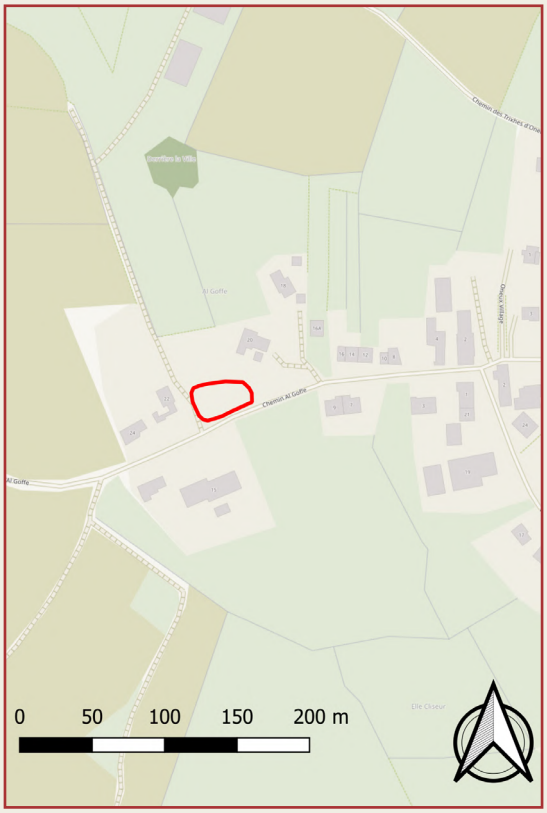
Situation before management

The area invaded by the parrot's feather is the third and last basin of a sewage lagoon located in Theux, the hamlet of Oneux (Fig. 130). The 500 m^2 and 1,5 m deep basin, owned by the municipality, is easily accessible. The siltation has developed to a considerable extent.

The parrot's feather population covered approximately 70% of the basin in 2017, right before the start of the first management action (Fig. 131).

Management objectives

After discussion with the municipality, it was decided by the SPW Agriculture, Natural resources and Environment to aim for the eradication of the parrot's feather population. Due to the surface area and the accessibility of the invaded basin, it was decided to conduct a manual removal.



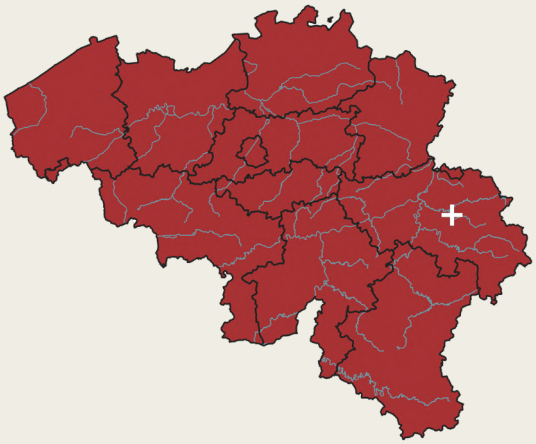


Fig 130. The invaded site is a basin of a sewage lagoon located in Theux. Map: OpenStreetMap

Management actions

As the invaded site is not connected to the hydrographic network and is, therefore, rather isolated, it was decided that the placement of physical barriers around the basins would be unnecessary.

The first management action took place in mid-October 2017. Although the depth of the water body increased the complexity of the operations, operators were able to remove 12 m3 of plant material for a total of 20 man-hours. The harvested material was stored in a container made available by the municipality of Theux, which was, then, responsible for green waste evacuation and treatment (Fig. 132).

In 2018, management results were already noticeable and only 2 m³ had to be removed in mid-October, for a total of 12 man-hours. However, as the depth of the water body still constrained operators, some underground parts of the plants could not be removed during manual removal.

In 2019, 4 monitoring visits were organised in May, July, September and October, and no parrot's feather was observed during those field visits. 2 species, the hornwort (Ceratophylum demersum) and common duckweed (Lemna minor), which display high competitive abilities, were able to colonise the water surface (Fig. 133).

Repeated manual removal, conducted in May 2020, June 2020, July 2020, August 2020, May 2021 and October 2021, was necessary to eliminate plant regrowth (a dozen plants). As the surface of the water body was still covered by the hornwort and the common duckweed, parrot's feather population was still under control, although eradication had not yet been achieved.

Fig 131. In 2017, the parrot's feather had invaded about 70% of the basin surface. Photo: SPW

Fig 132. 12 m³ of parrot's feather were manually removed in 2017 and stocked in a container made available by the municipality of Theux. Photo: SPW

Results and prospects

The first 2 years of management were sufficient to achieve a good level of control. The accessibility and the limited size of the invaded area along with a rigorous manual removal probably helped achieving good results. Nevertheless, the invasive weed was able to persist as some underground parts of the plants could not be removed during the operations. Additionally, the colonisation of the basin surface by the hornwort and common duckweed probably also negatively affected the development of the parrot's feather as well as the ecosystem functions of the water body. In order to prevent the eutrophication and the deterioration of the basin, introducing diverse species of plants that will filter the water and reduce nutrient excess should be considered.

Although the impact of the parrot's feather was reduced, the eradication objective has not been achieved yet. Monitoring the population is, therefore, still necessary. Moreover, the disruption of the ecosystem could help the parrot's feather to recolonise the basin. Special attention must be paid to active monitoring of the site, especially if ecosystem modifications are foreseen.

Acknowledgments

All the information contained in this case study has been provided and compiled by Adrien Delforge and Pierre Joye.

Fig 133. After 2 years of management, hornwort and common duckweed colonised the whole water surface, supplanting the parrot's feather. Photo: SPW

Glossary

Aftercare: all the maintenance techniques (e.g. manual removal) implemented after management in an attempt to prevent the managed invasive species from redeveloping and reestablishing

Alert list: a list of alien species that are not yet present in a certain area, or with a very limited distribution, and that pose a threat to biodiversity

Alien or exotic species: a species that is accidentally or intentionally introduced outside its natural range

Amphibious plant: a plant that can both develop in terrestrial and aquatic environments

Apomictic: related to apomixis; the means of seed production without fertilisation

Best management practice: a practice that has shown an acceptable level of effectiveness while being ethically and legally acceptable

Brackish water: water that has a salt content that is lower than seawater but higher than freshwater

Containment: all the measures implemented to prevent the dispersion of an invasive alien species (IAS) from one site to another

Control: a significant population reduction, in the medium term, of an invaded site

Core area: a known and controlled invaded area in which a species is not managed but its spread to other areas is actively prevented

Cultivar: a variety of plant cultivated and developed through selective breeding

Desiccation: the removal or extraction of water content which results in severe dryness

Dioecious: a plant in which male and female reproductive systems appear on separate individuals

Eradication: a total and permanent elimination of the targeted population

Evergreen: a plant which has a foliage that remains green throughout the year

Floating boom: a type of barrier intercepting and providing containment of all sorts of floatable objects such as plant fragments

Hypoxia: the state of a water system where levels of dissolved oxygen are low

Management: all the techniques implemented in an attempt to achieve the eradication or the control of IAS populations

Monospecific vegetation: composed of only one dominant species

Native or indigenous species: species naturally present in a specific geographical area (Belgium in this case)

Node: the point of a stem from where leaves originate

Outlet: a structure which allows water to flow out of the water body (e.g. pond)

Overwinter: to survive the winter

Perennial: a plant that can live for several years

Prevention: all the techniques implemented in an attempt to prevent the introduction, establishment and spread of IAS in an area

Revegetation: the process by which ecosystem restoration is facilitated through replanting vegetation in disturbed areas

Rhizome: an underground stem carrying adventitious roots and aerial stems. A rhizome accumulates nutrients and is also used for propagation

Rhizomatous: provided with a rhizome

Riparian plant: a plant that develops along banks and watercourse margins

Seedbank: the reserve of viable seeds that are stored in the soil

Stratification: the process of stimulating and promoting seed germination through exposure to varying temperatures

Submerged plant: a plant that has leaves and stems growing under the surface of the water. Flowers, if produced, may rise above the water surface.

Surveillance: the process by which a territory is scanned to detect populations of invasive alien species and report them

Tiller: a shoot that develops from the base of a plant and that develops its own adventitious roots

Tuber: a type of underground structure that is used to store nutrients in some plants

Turion: a type of bud that is produced by many aquatic plant species from which a new plant can develop

Zoochory: the dispersal of seeds, spores, fruits or fragments by animals

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