Lagarosiphon major. L. major *is an aquatic, submerged plant that can grow in dense mats up to 2–3 m thick. © Tim Adriaens, INBO.*

The management of curly waterweed (*Lagarosiphon major*)

Measures and associated costs

Scientific name(s)	*Lagarosiphon major* (Ridley) Moss
Common names (in English)	Curly waterweed
Authors	Andreas Hussner (Duisburg, Germany)
Reviewers	Jonathan R. Newman (Waterland Management Ltd, UK); Manuel A. Duenas, (CEH, Wallingford, UK)
Date of completion	04/07/2019
Citation	Hussner, A. 2019. Information on measures and related costs in relation to the species included on the Union list *Lagarosiphon major*. Technical note prepared by IUCN for the European Commission.

Table of contents

Summary of the measures 2

Prevention 3
- Ban on importing 3
- Control measures for mislabeled plant material 4

Secondary spread 6
- Public awareness campaigns 6

Early detection 9
- Citizen-science 9
- Surveying through eDNA 11
- Active surveillance using scuba divers 12

Rapid Eradication 13
- Physical control – Suction dredging 13
- Physical control – Hand weeding 14
- Physical control – Benthic barriers 16

Management 18
- Mowing and cutting 18
- Hydro-Venturi 20
- Biological control 22
- Herbicides 24

Bibliography 26

Appendix 29

Common names

BG	Голям лагаросифон
HR	Veliki lagarosifon (afrička vodena kuga)
CZ	Spirálovka větší
DA	Stor vandguirlande
NL	Verspreidbladige waterpest
EN	Curly waterweed
ET	Kähar näkikatk
FI	Afrikanvesihäntä
FR	Elodée crépue
DE	Wechselblatt-Wasserpest
EL	–
HU	Nagy fodros átokhínár
IE	Líobhógach Afracach
IT	Peste d'acqua arcuata
LV	Āfrikas elodeja
LT	Didysis vandrūnėlis
MT	–
PL	Lagarosyfon wielki
PT	Elódea-africana
RO	–
SK	Sifónovec machovitý
SL	Kodrasta vodna zel
ES	Elodea crispa
SV	Afrikansk vattenpest

Summary of the measures, emphasizing the most cost-effective options.

Lagarosiphon major is an evergreen submerged aquatic plant species, native to South America. The species has been introduced into Europe and is present in several European countries (Hussner, 2012), where it spreads exclusively via fragments, as no seed production is reported yet. *Lagarosiphon major* grows in stagnant and running waters, forming dense monospecific beds.

The unintentional introduction of aquatic species often occurs due to mislabelled or contaminated plant material in trade (Brunel, 2009; Champion *et al.*, 2010; Hussner *et al.*, 2014). As such, in order to prevent unintentional introductions of *L. major*, comprehensive controls of imported plant material should be implemented at places of entry and sites of sale of imported aquatic plants, so as to identify mislabelled or contaminated material. DNA barcoding tools can be used to support identification of *L. major* during inspections.

The spread of invasive alien aquatic plants into new water bodies often occurs through the transport of plant fragments attached to water sport equipment, such as boats and trailers (Johnstone *et al.*, 1985; Johnson *et al.*, 2001). This spread can be reduced by increasing public awareness of this problem via public campaigns and engagement activities and also through the implementation or improvement of biosecurity measures, which should also be incorporated into the actions recommended through public campaigns.

Early detection of new infestations can be achieved by intensive surveying (including through citizen-science and professional scuba divers) or by using novel tools like eDNA. Early detection of small infestations increases the likelihood of successful control measures to eradicate the species and, for small infestations, benthic barriers, suction dredging and hand weeding are potential control methods (Caffrey *et al.*, 2010, 2011; de Winton *et al.*, 2013). Larger infestations can be managed by a combination of mechanical and/or chemical control followed by hand weeding (Caffrey *et al.*, 2010, 2011).

Measures for preventing the species being introduced, intentionally and unintentionally.

This section assumes that the species is not currently present in a Member State, or part of a Member State's territory.

A ban on importing (pre-border measure), selling, breeding, growing, and cultivation, as required under Article 7 of the IAS Regulation, targeting intentional introduction of plants and propagules of *L. major.*

MEASURE DESCRIPTION

As the species is listed as an invasive alien species of Union concern, the following measures will automatically apply, in accordance with Article 7 of the EU IAS Regulation 1143/2014:

Invasive alien species of Union concern shall not be intentionally:

(a) brought into the territory of the Union, including transit under customs supervision;
(b) kept, including in contained holding;
(c) bred, including in contained holding;
(d) transported to, from or within the Union, except for the transportation of species to facilities in the context of eradication;
(e) placed on the market;
(f) used or exchanged;
(g) permitted to reproduce, grown or cultivated, including in contained holding; or
(h) released into the environment.

Also note that, in accordance with Article 15(1) – As of 2 January 2016, Member States should have in place fully functioning structures to carry out the official controls necessary to prevent the intentional introduction into the Union of invasive alien species of Union concern. Those official controls shall apply to the categories of goods falling within the Combined Nomenclature codes to which a reference is made in the Union list, pursuant to Article 4(5).]

Therefore measures for the prevention of intentional introductions do not need to be discussed further in this technical note

Control measures to check for mislabelled or contaminated plant material.

MEASURE DESCRIPTION

The major pathway of introduction of the species is intentional via aquatic plant trade (addressed in the section above). Nevertheless, the unintentional introduction of aquatic species also occurs due to mislabelled or contaminated plant material in trade (Brunel, 2009; Champion *et al.*, 2010; Hussner *et al.*, 2014). As *L. major* is primarily clonal, imported aquatic plant material needs to be inspected for vegetative diaspores and particularly fragments of *L. major* (and any other plant species from the list of invasive alien species of Union concern). However, the degree of contamination of the species within the import of aquatic plants is not known, nor is the degree of mislabelling.

For the contamination of plant material with diaspores and fragments, DNA barcoding tools can be used to support identification of *L. major* during inspections. In terms of mislabelled plant material, providing identification guidance to customs inspectors (for example see that produced by the GB NNSS[1]), and importers and sellers will help increase detection.

In addition to the un-intentional introduction via contaminated and mislabelled plants, the introduction into countries might also take place via propagules of *L. major* attached to for example boats and trailers (see section on secondary spread for more detailed information). *Lagarosiphon major* has a high resistance to desiccation (Heidbüchel *et al.*, 2019) and may survive even long-term overland transport.

SCALE OF APPLICATION

The measures to control imported plant material, in order to identify mislabelled or contaminated material, should be undertaken across the EU and installed at sites of entry (such as airports, ports), but also at sites of sale of imported aquatic plants (such as aquarium and plant shops), to identify any contamination of plants in trade with propagules of *L. major*.

EFFECTIVENESS OF MEASURE

Unknown.

The effectiveness of such control measures depends on the effort and resources applied. However, the success of import controls is hard to quantify, as no information about the level of contamination of imported plant material with the target species is available, and the number of mislabelled imported plant material is unknown. Furthermore, the success of these control measures depends on various parameters, such as knowledge of the species by inspectors and other responsible authorities.

A border control programme for aquatic weeds has been developed for New Zealand (Champion and Clayton, 2001), but no information about the success of this border control is available.

EFFORT REQUIRED

Control sites must be installed for the long-term to prevent any unintentional introduction of *L. major.*

RESOURCES REQUIRED

While inspection capacity already exists across the EU, additional control efforts usually entail additional costs; the costs per species will, however, be significantly reduced, if control measures are implemented for all aquatic plant species of Union concern at the same time.

The identification of a species from plant material and particularly from diaspores requires an excellent species knowledge of inspectors. DNA barcoding tools, which have been developed for other invasive alien aquatic plant (IAAPs) species of union concern, like *Hydrocotyle ranunculoides* (van de Wiel *et al.*, 2009), are a valuable tool to improve the reliability of the determination of diaspores and plants, but have not been developed for *L. major* yet. Resources are required for and should be invested into this.

SIDE EFFECTS

Environmental: Positive
Social: Neutral or mixed
Economic: Negative

The implementation of import control measures requires a good species knowledge and/or valuable tools (for example DNA barcoding), and will help to limit the import of other invasive alien aquatic plant species into the EU, especially of relatives of *L. major* from the family of Hydrocharitaceae.

Any restrictions of plant imports increase the costs for the import of plants, and can thus reduce the number of plants sold. However, the sale of native species can be supported and similar native plants can be sold as alternatives, as has been successfully initiated in Belgium as part of an agreement between representatives from the ornamental sector, public authorities and the scientific community (Halford *et al.*, 2014).

1 http://www.nonnativespecies.org/factsheet/factsheet.cfm?speciesId=1888

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

The establishment of voluntary agreements between the ornamental sector and authorities in Belgium (Halford *et al.*, 2014) indicates that the awareness about the problem of invasive aquatic plants is high, and thus control measures should be accepted by traders. Nevertheless, increased costs for the traders (due to restrictions of import) will most likely reduce the acceptability of any prevention measure.

ADDITIONAL COST INFORMATION

No data about the costs of implementation and maintenance of import controls are available for aquatic plants. Consequently, no information can be given about the cost-effectiveness of this measure. However, the intensive control of imported plant material will incur additional costs but, as mentioned above, it can be implemented as a general control of introduced plant material on plants prohibited from introduction and sale in accordance to EU Regulation 1143/2014.

The costs of inaction are hard to quantify, though as *L. major* is able to grow in a wide range of freshwater habitats throughout the EU, the costs of inaction (and subsequent eradication or control) will likely be higher than the costs of implementing these prevention measures (Hussner *et al.*, 2017).

LEVEL OF CONFIDENCE*

Unresolved.

Comprehensive import control must be considered as a valuable tool to stop the unintentional introduction of *L. major* and other invasive aquatic plant species. There is a consensus that the prevention of introduction of invasive alien aquatic plant species is cheaper than their later management and control (Hussner *et al.*, 2017). However, and although identification tools for whole plants, as well as for any part of a plant (for example DNA barcoding) exist for aquatic plants on the species level, no information about the implementation, ongoing costs, success and failures of these tools exist.

* See Appendix

Measures to prevent the species spreading once they have been introduced.

Public awareness campaigns.

MEASURE DESCRIPTION

It has been documented that the spread of invasive alien aquatic plants into new water bodies largely depends on the transport of plant fragments attached to water sport equipment, transported from one water body to another (Johnstone *et al.*, 1985; Johnson *et al.*, 2001). Aquatic plants produce fragments either by allofragmentation (fragmentation caused by disturbances) or auto fragmentation (self-induced fragmentation). The likelihood of successful spread increases with increasing number of fragments produced and transported into a new water body (Lockwood *et al.*, 2005).

In general, the number of fragments which can be found in a water body is species specific (Heidbüchel *et al.*, 2019). The number of fragments produced by *L. major* is relatively low, and was found to be much lower than in *Elodea canadensis* and *Egeria densa* (Redekop *et al.*, 2016). Moreover, the likelihood for regeneration of fragments is affected by their type, as fragments with apical tip show significantly higher regeneration rates than fragments without apical tip (Heidbüchel and Hussner, 2019).

The human-mediated un-intentional spread of *L. major* can occur via plant fragments attached to any water sport equipment, but boats and trailers are considered the major transport vectors for such fragments (Johnstone *et al.*, 1985). The survival time of the attached fragments depends on both weather conditions (the warmer and less humid, the shorter the survival period) and the clumping of fragments (single fragments have a shorter survival period than clumped patches of plant fragments). *Lagarosiphon major* fragments with apical tip keep viable even after >60 % water loss. Chlorophyll fluorescence was documented as a valuable tool for the determination of the viability of the fragments (Heidbüchel *et al.*, 2019).

To stop the spread of invasive alien aquatic plant species by fragments attached to boats and trailers, various preventive methods are reported. Overland dispersal of fragments via water sport equipment can be reduced by increasing public awareness of this problem via public campaigns like "Stop Aquatic Hitchhikers" initiated in the USA[2], Canada or New Zealand (author's observations), and the UK's "Check Clean Dry"[3] and "Be Plant Wise" campaigns. In general, the transport of viable fragments can also be reduced by undertaking several biosecurity measures (see below; Johnstone *et al.*, 1985; Barnes *et al.*, 2013; Anderson *et al.*, 2015; Cuthbert *et al.*, 2018; Hippolite and Kurapa, 2018; Crane *et al.*, 2019), which should be incorporated into the actions recommended through any public campaign:

(i) the creation of weed free haul-out areas to reduce the likelihood of fragments attaching to boats and trailers,
(ii) the collection of all visible plant fragments from boats and trailers, or killing the fragments by:
(iii) storing of boats and trailers prior to the release into new water bodies,
(iv) placing the boat into a wash station, a heated water system or exposing fragments to steam, and
(v) using aquatic disinfectants prior to the release of the trailered boats into a new water body.

SCALE OF APPLICATION

Public engagement activities are usually undertaken at a national level. In New Zealand, a public awareness campaign was brought to the public by informing various business organisations (for example outdoor, boat and fishing gear retailers and tourist attractions). Additionally, people were informed during local water related events, and even school classes were visited and both teachers and children were informed (Hippolite and Kurapa, 2018).

For biosecurity strategies, weed free haul-out areas are in use in several waters in for example the Bay of Plenty region, New Zealand (author's observation). Moreover, in this region, portable boat wash stations were tested for the in-field use at boat ramps (Hippolite and Kurapa, 2018). As alternatives to washing stations, heated water tanks (Anderson *et al.*, 2015), steam exposure (Crane *et al.*, 2019) or aquatic disinfectant (Cuthbert *et al.*, 2018) have been successfully

2 https://www.fws.gov/fisheries/ans/pdf_files/Stop_Aquatic_Hitchhikers_factsheet.pdf
3 www.nonnativespecies.org/checkcleandry/

tested in a laboratory experiment to kill fragments, but no information on field trials is available.

EFFECTIVENESS OF MEASURE

Effective.

Public campaigns have been initiated in several countries, but the efficiency of such measures is difficult to quantify. However, in the UK, the 'Check Clean Dry' campaign increased the numbers of general public following the recommended biosecurity procedures by 9% (and 14% in high risk user compliance; Burchnall, 2013). Moreover, a 40% reduction of biosecurity hazards were reported for anglers and canoeists who have heard of the 'Check Clean Dry' campaigns, compared to anglers and canoeists who have not heard about it (Anderson *et al.*, 2014).

In the Bay of Plenty Region in New Zealand, 75-86% of the users have freshwater weeds knowledge and were able to name any pest species, and 74-82 % follow biosecurity campaign measures when moving their boat from one freshwater to another (Hippolite and Kurapa, 2018). Nevertheless, the efficiency of public campaigns will most likely depend on the way and intensity by which the public has been informed. A combination of on-site information posters and press releases are recommended.

The success of direct biosecurity measures will depend on various parameters, for example the resistance of plants and seeds to desiccation and heating (Barnes *et al.*, 2013; Anderson *et al.*, 2015). However, considering the strong evidence for the importance of human-mediated overland dispersal of plant fragments via water sports equipment (Johnstone *et al.*, 1985), measures to stop this vector of unintended spread are considered to have a high impact. For *L. major*, some of these measures seem to be quite effective (see examples below).

EFFORT REQUIRED

For the sustainable success of public campaigns, they generally need to be applied in the long-term and must target all kinds of water users.

For bio security control, the exposure of *L. major* fragments to 45°C for 1 hour resulted in 100% mortality. The time required for drying to kill fragments depends on weather conditions and clumping of fragments (Heidbüchel *et al.*, 2019). Exposure to the aquatic disinfectant Virasure for 2 min at 1% concentration or 1 min at 4% showed optimised degradation of *L. major* fragments (Cuthbert *et al.*, 2018). Direct steam exposure, at a distance of 2-3 cm to the fragments, results in the die off of fragments (Crane *et al.*, 2019).

RESOURCES REQUIRED

The costs of generating a public awareness campaign are relatively low compared to the costs of managing established IAAPs. Even though public awareness campaigns were initiated in a number of countries, no data about the required resources are available.

The installation of net cages in lakes to create weed free areas requires scuba diving activity and ongoing maintenance, and fragments caught by the net cages must be removed and disposed of in an appropriate manner. For the installation of boat washing stations, heated water systems or a system for steam exposure, specific equipment and experienced workers are needed. Similarly, the use of aquatic disinfectant requires experienced workers.

SIDE EFFECTS

Environmental: Positive
Social: Neutral or mixed
Economic: Negative

The described methods provide a general barrier for the unwanted spread of invasive alien aquatic plants in general, which has positive environmental effects. Biosecurity measures can potentially impact the spread of native organisms, but such negative impacts on native plants have not been reported yet.

Although public campaigns generally have a positive social effect of raising awareness about other aquatic alien species, biosecurity measures affect the recreational human use of water bodies, creating a mixed social effect.

Biosecurity measures will also represent extra time and costs for boat owners.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed

While public campaigns are usually well accepted by stakeholders, the recommended active bio security measures (collecting fragments, washing, heating and disinfecting) will incur additional costs and take time, which might have a negative public perception, although this has not been investigated yet. The public campaign in itself can help to improve the understanding and acceptance of these measures.

ADDITIONAL COST INFORMATION

In general, no data about the costs of such public campaigns are available, but the costs will vary largely according to the number of in field information (for example information boards) needed. The costs for the measures to prevent species spread by killing the fragments depend on the number of boats that are transported overland and the number of lakes infested with the target species.

The costs of inaction are hard to quantify, but as *L. major* is able to grow in a wide range of freshwater habitats, the costs of inaction (and subsequent eradication or control) will be higher than the costs of implementing these measures (Hussner *et al.*, 2017).

LEVEL OF CONFIDENCE*

Established but incomplete.

Public campaigns to stop the unintentional, human mediated spread of *L. major* were implemented in for example New Zealand or the USA with good success (Hippolite and Kurapa, 2018). Moreover, for invasive submerged aquatic plant species which predominantly spread by fragments, like *L. major*, prevention of spread by implementing bio security measures to remove or kill fragments attached to boats and trailers is of high relevance. Boat washing stations have been, for example, successfully tested in the Bay of Plenty, New Zealand (Hippolite and Kurapa, 2018). In contrast, the use of for example aquatic disinfectants or hot steam exposure has only been tested under laboratory conditions (Cuthbert *et al.*, 2018; Crane *et al.*, 2019).

* See Appendix

Measures for early detection of the species and to run an effective surveillance system to detect efficiently new occurrences.

Surveying through citizen-science.

MEASURE DESCRIPTION

The detection of early infestations of invasive alien aquatic plant species is crucial for the later likelihood for rapid eradication of the target species (Genovesi *et al.*, 2010; Hussner *et al.*, 2017). If newly introduced invasive alien aquatic plant species are detected early, the eradication of these new populations is achievable prior to their establishment, which drastically reduces the costs of eradication measures (Hussner *et al.*, 2017).

Citizen-science programmes are a useful tool for surveying new incursions of invasive aquatic plants. They can show a high accuracy of data collected (80–95% accuracy; Delaney *et al.*, 2008) but, in the case of submerged aquatic weeds, specialised citizen scientists, such as recreational scuba divers with experience in macrophyte mapping, are usually required to undertake records. In lakes, scuba divers are required to identify early infestations of submerged plants, while in small to medium sized rivers submerged plants can usually be identified from the shore.

Citizen-science projects can be led by citizen scientists or, most commonly, by scientists in participation initiatives. For example, in Germany, the Federal Agency for Nature Conservation initiated a joint project with recreational divers, informing about invasive alien aquatic plant species and providing information brochures and identification keys (http://www.neobiota.info/Neophyten.php). Such engagement activities could also reach out to other recreational user groups.

A surveillance system to support early detection should also incorporate active monitoring of the species; see the sections below on use of scuba divers and environmental DNA.

SCALE OF APPLICATION

Citizen-science initiatives with recreational divers, and other key groups, would be undertaken at a national scale and drastically increase the number of water bodies that could be investigated, in relation to more traditional surveying methods.

EFFECTIVENESS OF MEASURE

Effective.

The efficiency of citizen-science projects depends on the species knowledge of the involved citizen scientists. In a citizen-science project dealing with the distribution and abundance of crabs in intertidal zones, species identification reached an accuracy between 80 and 95% (Delaney *et al.*, 2008). However, there is often concern about the quality of data provided by citizen scientists (Hochachka *et al.*, 2012) and the high phenotypic plasticity of submerged plants like *L. major* makes species identification difficult. Therefore, active engagement with and provision of identification materials to key groups (for example recreational divers) will be critical to guarantee or improve detection accuracy.

EFFORT REQUIRED

Early detection of invasive submerged aquatic plants requires comprehensive, repeated surveillance of the macrophyte communities.

RESOURCES REQUIRED

The development of a comprehensive and accurate citizen-science project requires a substantial coordination by a government or scientific body. The annual costs for running a citizen-science project are approximately between 80,000 – 170,000 EUR (Roy *et al.*, 2012 in Newman and Duenas, 2017).

Detailed species identification sheets and keys must be produced and provided to allow citizen scientists to identify the target species (for example Adriaens *et al.*, 2015). Data recording apps (incorporating verification of records) are also needed to enable citizen scientists to report geo located data records of new infestations of the target species.

Citizen-science data recording apps already exist for reporting occurrences of invasive alien species of Union concern at the EU level (the JRC EASIN Invasive Alien Species Europe smartphone App[4]) and within some EU Member States (for example see GB NNSS smartphone apps).

4 https://easin.jrc.ec.europa.eu/easin/CitizenScience/About

SIDE EFFECTS

Environmental: Positive
Social: Neutral or mixed
Economic: Negative

In general, citizen-science projects cause greater awareness of existing and future environmental problems, and increase the likelihood of additional IAS being reported.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

Informing the public and providing apps for non-scientists to submit records of species is usually very well accepted by stakeholders.

ADDITIONAL COST INFORMATION

It is widely accepted that, in general, the costs of inaction will be much higher than those of early detection measures, as the control and eradication of large infestations of IAAPs is much more time consuming and costly (Hussner *et al.*, 2017). The cost-effectiveness of early detection measures has not been studied in detail yet, but will differ between species and habitats.

LEVEL OF CONFIDENCE*

Established but incomplete.

Citizen-science projects have been reported to provide accurate observations of different species; however, its application to *L. major* and other submerged aquatic plants that require expertise to be confidently identified is not yet established.

* See Appendix

Surveying through eDNA.

MEASURE DESCRIPTION

A new valuable tool for early detection of organisms is the use of environmental DNA (eDNA) markers, allowing the detection of a target species in water bodies, when the eDNA concentration in the water reaches a detection threshold. The detection of a given species requires a species specific primer and after a positive eDNA record, an active survey programme is needed to locate the target species within the water body. Until yet, no eDNA studies dealing with *L. major* are available, and probably no primer has been developed for this species, but this method has been successfully tested with other Hydrocharitaceae species (Matsuhashi *et al.*, 2016).

SCALE OF APPLICATION

The use of eDNA allows for the fast analysis of waters from numerous water samples, drastically increasing the potential number of water bodies which can be investigated. For example, the detection of rare fish species, even in large >100 ha lakes, can be done within one day (Hussner *et al.*, unpublished).

EFFECTIVENESS OF MEASURE

Effective.

The use of eDNA is a relatively new tool and only few studies have analysed the efficiency of this method for identification of invasive aquatic plants (Scriver *et al.*, 2015; Matsuhashi *et al.*, 2016). In general, eDNA analysis requires the development of species specific primers (Scriver *et al.*, 2015). In a recent study (Scriver *et al.*, 2015), ten aquatic plant species were successfully detected from water samples. Matsuhashi *et al.*, (2016) tested the sensitivity of the eDNA method in the field and in an aquarium experiment using two Hydrocharitaceae, Hydrilla verticillata and *Egeria densa*. The authors document that both plants do not release constant amounts of eDNA, which makes the estimation of biomass difficult, but the method was found to be a valuable tool for the identification of the plant species within the water body. More studies are needed to evaluate the minimum biomass of submerged plants needed to get a high accuracy of the species detection.

EFFORT REQUIRED

In general, eDNA samples can be taken all year round, but no information exists on if sampling time affects the accuracy of the analysis for evergreen aquatic plant species. It is important to note that eDNA analysis provides only presence/absence data for the water body tested, the records are not geo located, and thus, after any positive result, additional macrophyte surveying is required to locate the species.

RESOURCES REQUIRED

eDNA studies require experienced scientists for both sampling and analysis. The costs of the analysis vary according to the number of different species which need to be identified from the sample, while the costs of sampling are the same. The sampling and analysing of water samples to identify the fish community in certain lakes cost ca. 2,000-3,000 EUR per lake (Hussner, unpublished).

SIDE EFFECTS

Environmental: Positive
Social: Neutral or mixed
Economic: Neutral or mixed

Overall, during eDNA studies other IAAPs can be identified, which reduces the total cost of monitoring per species.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

This measure should be acceptable to all stakeholder groups.

ADDITIONAL COST INFORMATION

There is no information available.

LEVEL OF CONFIDENCE*

Established but incomplete.

eDNA is a new powerful tool for species presence and absence detection, but more studies are needed to evaluate the minimum biomass of submerged plants needed to get a high accuracy of the species detection.

* See Appendix

Active surveillance using scuba divers.

MEASURE DESCRIPTION

Particularly for early detection of small infestations of submerged weeds like *L. major* in deeper waters, or for the confirmation of new occurrence records (for example via citizen-science or eDNA, see *surveillance* sections above), scuba diving seems to be the most appropriate method for in field identification. Within the EU, macrophyte surveying by scuba divers is widely used as part of regular monitoring programmes, in accordance to the Water Framework Directive (WFD), and could be used as part of an early detection programme.

The use of cable connected sub cameras allows a more rapid survey of macrophyte communities in a larger scale, but is less sensitive than surveys by scuba divers (van de Weyer *et al.*, 2007).

SCALE OF APPLICATION

Using scuba diving as an active survey measure is time consuming and allows detailed mapping of only small areas. Moreover, even zero-detection surveys do not definitely mean that the investigated water body is free of the target species, as finding of small infestations by scuba diving is generally difficult, particularly in turbid waters (Anderson, 2005). The macrophyte mapping in accordance to the WFD is usually limited to small areas (usually transects) in large lakes >50 ha.

EFFECTIVENESS OF MEASURE

Neutral.

Macrophyte mapping by professional scuba divers is commonly used in EU countries in accordance to the WFD. The presence of a target species within the studied transects is determined with high accuracy, but infestations outside the transects in the study area will not be detected.

EFFORT REQUIRED

Macrophyte mapping of evergreen species like *L. major* can be carried out throughout the year. In lakes with dominant native vegetation, when for example small *L. major* stands are embedded in dense beds of native macrophytes during the summer period, macrophyte mapping during winter time can help to identify small patches of this evergreen invasive alien aquatic plant species (author's observation).

RESOURCES REQUIRED

Macrophyte mapping by scuba divers requires specialised diving equipment and some experience in submerged macrophyte mapping, independently if the investigations are carried out by professional or citizen scientist divers.

However, by developing identification keys for the public and apps for mobiles (see *citizen-science* sections above), the cost of monitoring can be reduced and larger areas can be surveyed.

Even though the costs of mapping invasive aquatic plants are hard to quantify, it should be borne in mind that the surveillance of submerged plants in aquatic habitats is much more time-consuming and costly than mapping plants in terrestrial habitats.

SIDE EFFECTS

Environmental: Positive
Social: Neutral or mixed
Economic: Neutral or mixed

During macrophyte mapping by diving or using a sub-camera other IAAPs can be identified, which reduces the total cost of monitoring per species.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

This measure should be seen as acceptable by all stakeholder groups.

ADDITIONAL COST INFORMATION

There is no information available.

LEVEL OF CONFIDENCE*

Established but incomplete.

Repeated macrophyte mappings are carried out to map and evaluate the macrophyte community in accordance to the EU WFD in rivers and lakes >50 ha, and during these investigations infestations of invasive submerged plants are often found (van de Weyer *et al.*, 2007). However, the use of this method as an early detection mechanism has not been studied.

* See Appendix

Measures to achieve rapid eradication after an early detection of a new occurrence.

Physical control – Suction dredging.

MEASURE DESCRIPTION

For the rapid eradication of early infestations of invasive submerged aquatic plant species, physical control measures are the mostly used eradication measures. Suction dredging, hand weeding and shading of small areas by benthic barriers, for example jute matting, are documented as successful eradication measures for early infestations of submerged plants like *L. major*. These measures can be used alone or in combination, or as follow-ups of other eradication and management measures. Each of these measures is addressed in a separate rapid eradication section.

During suction dredging, the target plants, surrounding water and sediment are sucked up, and the plants are collected in a fine mesh bag on a floating barge (de Winton *et al.*, 2013). The level of control depends on the depth of sediment removed, as the whole root system must be removed for effective eradication. Due to the removal of the upper sediment, the rehabilitated sediment can be less suitable for fast and large reinfestations, which can provide effective control of *L. major* for up to three years (Wells *et al.*, 2000 in de Winton *et al.*, 2003). In combination with follow-up hand removal, submerged aquatic plants can be eradicated (de Winton *et al.*, 2013).

SCALE OF APPLICATION

Suction dredging is suitable for small areas (<0.1 ha) infested with the invasive submerged plant species (de Winton *et al.*, 2013), and is used in public amenity areas to reduce the risk of overland dispersal of aquatic weeds attached to water-sport equipment.

EFFECTIVENESS OF MEASURE

Effective.

Suction dredging results in effective control of *L. major* for up to three years (Wells *et al.*, 2000 in de Winton *et al.*, 2013) but, when used in combination with follow-up hand weeding, suction dredging has eradicated weeds from some sites in New Zealand lakes (de Winton *et al.*, 2013). In New Zealand, suction dredging is used to eradicate outlier colonies and new incursions of *L. major* (Wells and Clayton, 2005 in de Winton *et al.*, 2013), and it can have a small and short-term impact on extensive *L. major* infestations (Howard-Williams and Reid, 1989 in Clayton, 1996). Moreover, suction dredging is used to control aquatic weeds in public amenity areas, in order to reduce the risk of overland dispersal of aquatic plant fragments attached to water sport equipment, such as boats and trailers (de Winton *et al.*, 2013). In Texas, suction dredging successfully eradicated a submerged plant from a river section (Alexander *et al.*, 2008).

EFFORT REQUIRED

Suction dredging can be best carried out in good water clarity, if the sediment has a fine or muddy structure (de Winton *et al.*, 2013). Suction dredging is time consuming, as only small areas can be controlled within a certain amount of time. Nevertheless, the overall costs are still low to moderate, as no maintenance is required, but a monitoring should be carried out on an annual basis (de Winton *et al.*, 2013). In some cases, hand-weeding must follow suction dredging to eradicate the remaining individual plants.

RESOURCES REQUIRED

Suction dredging requires a large suction pump and skilled diving operators. While for small ponds and infestations close to the shore vehicular access is required, a barge must be used in larger systems (de Winton *et al.*, 2013). In dense weed beds, suction dredging requires 20 days per ha (de Winton *et al.*, 2013). In New Zealand, the costs of suction dredging were between 5,000 and 7,500 EUR per ha in Lake Wanaka and between 10,000 and 13,000 EUR in Rotorua Lakes (Wells *et al.*, 2000 in de Winton *et al.*, 2013).

SIDE EFFECTS

Environmental: Negative
Social: Negative
Economic: Neutral or mixed

Based on the experience of the diver, suction dredging can be highly species specific, consequently only having a minor impact on non-targeted plant species, although affecting the sediment-based biota (for example macroinvertebrates). While this measure is underway, invertebrates within the IAAPs and the upper sediment will be displaced, but direct effects on fish are unlikely as they can use avoidance behaviours to escape. The overall impact on the environment is low, and no impacts on public health are reported.

Suction dredging can, however, temporarily impact the recreational use of water bodies, disturbing activities such as diving, as it increases turbidity within the water column. However, the increase in turbidity is lower than for other management measures (for example Hydro Venturi) (de Winton *et al.*, 2013).

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

The acceptance of rapid eradication measures depends on the side effects of the measure and the knowledge about the potential ecological and environmental impact that large infestations of the target species might have. Suction dredging has an impact, although minor, on recreational activities performed in water bodies, so it might not be well accepted by some stakeholders.

ADDITIONAL COST INFORMATION

Rapid eradication measures have a high cost-effectiveness, as rapid eradication of early infestations is in general cheaper than later species management and control (Hussner *et al.*, 2017). The cost of inaction is hard to quantify but will be high, as *L. major* is suitable to grow in most water bodies within the EU.

LEVEL OF CONFIDENCE*

Well established.

Suction dredging is a well-established tool for the eradication of early infestations of submerged aquatic weeds.

Physical control – Hand weeding.

MEASURE DESCRIPTION

The removal of aquatic plants by hand is one of the most selective removal methods and can be used for small, localised infestations and for infestations within native plant communities that should not be negatively affected (de Winton *et al.*, 2013; Hussner *et al.*, 2016, 2017). During the removal, all plant parts, including their roots, should be removed to avoid any regrowth of the plants. Hand removal is suitable for small and limited incursions of submerged aquatic plant species (and is additionally used as a follow-up measure of other management measures at the larger scale). The removal by hand in shallow water is possible by wading, while in deeper water (>1.5m) snorkelling or scuba diving is required (Bellaud, 2009).

SCALE OF APPLICATION

Hand weeding can be successfully used for small scale eradications, and works best if the target species can be easily identified within native macrophyte communites (requiring sufficient water clarity) and is only present at low densities of <125 shoots per 0.1 ha (Bellaud, 2009), in small (<1m^2) monospecific plant patches. In Lough Corrib, Ireland, a number of small and isolated *L. major* stands were eradicated by hand weeding carried out by divers (Caffrey *et al.*, 2009).

In combination with manual raking and hand application of Hydro-Venturi (see *management* section below), approximately 45m^3 of *Myriophyllum aquaticum* were removed by hand from a small pond system (approximately 1 ha; Hussner, unpublished).

EFFECTIVENESS OF MEASURE

Effective.

Hand weeding is highly effective when carried out by skilled operators using appropriate equipment. Hand weeding has successfully eradicated small isolated plants and small patches of *L. major*, for example in Lake Wanaka and Lake Waikaremoana, New Zealand (de Winton *et al.*, 2013), and in Lough Corrib, Ireland (Caffrey *et al.*, 2009).

EFFORT REQUIRED

The majority of plants (> 90% of the biomass of the target species; Hussner *et al.*, 2016) can be removed during the first hand weeding operation. Plant regrowth usually occurs and requires follow-up treatments, until all plant material of the target species has been successfully removed (de Winton *et al.*, 2013; Hussner *et al.*, 2016). De Winton *et al.*, (2013) recommended monitoring for 3-5 years after removal of the last fragments before eradication of the species can be confirmed.

RESOURCES REQUIRED

Hand weeding requires waders and snorkel or diving equipment. As for all working activities in aquatic systems, human safety requires, among others, personal floatation devices and skills in working in aquatic systems (for example boat handling and diving; de Winton *et al.*, 2013).

De Winton *et al.*, (2013) estimated the costs of two hand weeding treatments to achieve weed eradication at about 12,000 EUR per ha. The costs of hand weeding in combination with raking and Hydro-Venturi, for the

* See Appendix

Lagarosiphon major *flowers on Salagou Lake in the commune of Clermont-l'Hérault, Hérault, France. © Christian Ferrer. CC BY-SA 4.0.*

eradication of 45 m^3 of *Myriophyllum aquaticum*, were ca. 18,000 EUR (Hussner, unpublished).

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

Hand weeding is one of the most species specific control measures, with minimal impact on native plants (Hussner *et al.*, 2016), as long as the hand weeding is carried out by skilled workers. During hand weeding and uprooting of plants, an increase in turbidity of the water might occur, but this has no sustained effect on the environment.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

The acceptance of rapid eradication measures depends on the side effects of the measure and the knowledge about the potential ecological and environmental impact that large infestations of the target species might have.

As hand weeding has no effect on economic activities, and only a very minor and temporary negative impact on the ecosystem, a high acceptance of this measure by stakeholders and the public is highly likely.

ADDITIONAL COST INFORMATION

Rapid eradication measures have a high cost-effectiveness, as rapid eradication of early infestations is in general cheaper than later species management and control (Hussner *et al.*, 2017). The cost of inaction is hard to quantify but will be high, as *L. major* is suitable to grow in most water bodies within the EU.

LEVEL OF CONFIDENCE*

Well established.

Hand weeding is well established as a tool for the eradication of early infestations of submerged aquatic weeds.

* See Appendix

Physical control – Benthic barriers.

MEASURE DESCRIPTION

Benthic barriers shade the sediment, hindering the plants to root in the sediment (de Winton *et al.*, 2013; Gettys *et al.*, 2014). Benthic barriers are used for the control of submerged aquatic plants (Boylen *et al.*, 1996; Caffrey *et al.*, 2010; Laitala *et al.*, 2012; Hoffmann *et al.*, 2013), but their use is limited to stagnant waters. While in the past plastic sheets were used, in recent years biodegradable jute, hessian or coconut mattings have been tested, with jute and coconut mats showing the best results (Caffrey *et al.*, 2010; Hofstra and Clayton, 2012). In contrast to plastic or polyethylene, loose woven biodegradable mats like jute mats allow the exchange of water and gas, allow some native plants to grow through the mats (Caffrey *et al.*, 2010; Hoffmann *et al.*, 2013) and allow native plant communities to regrow after the natural degradation of the material (Caffrey *et al.*, 2010; de Winton *et al.*, 2013).

Benthic barriers made of biodegradable material can be used in small ponds and lakes, when only small infestations (<0.4 ha; de Winton *et al.*, 2013) of the target species are present, and if only temporary installation of benthic barriers is required (de Winton *et al.*, 2013), while for long-term control treatments, long-lasting polypropylene mats are the best option (de Winton *et al.*, 2013).

It is important to note that high suspended sediment loading in the water column causes an accumulation of sediment on top of the benthic barriers, which provides a suitable substrate for new infestations of both native and invasive aquatic plants on the barriers (de Winton *et al.*, 2013; Hoffmann *et al.*, 2013).

SCALE OF APPLICATION

Benthic barriers have been used for infestations up to 5,000 m^2 (Caffrey *et al.*, 2010; de Winton *et al.*, 2013). In Lough Corrib, Ireland, a total area of 1,725 m^2 infested with *L. major* was covered with jute mats in 2008 (Caffrey *et al.*, 2009).

EFFECTIVENESS OF MEASURE

Effective.

Benthic barriers are effective in stagnant waters, and have been shown to cause decomposition of *L. major* in Lough Corrib, Ireland (Caffrey *et al.*, 2009, 2010).

EFFORT REQUIRED

In Lough Corrib, four months of shading by jute mattings resulted in the decomposition of *L. major* (Caffrey *et al.*, 2010).

RESOURCES REQUIRED

Most of the effort is required during the installation of the benthic barriers. Rolls of the benthic barrier (usually 5 m in width; Caffrey *et al.*, 2010) are used, and the material is placed onto the water surface from a boat-mounted dispenser. While plastic is difficult to sink and commonly floats up due to the gas production resulting from decaying plant material beneath it, biodegradable mattings made out of jute rapidly saturate with water and sink within minutes (Caffrey *et al.*, 2010), not floating up due to the loose-woven structure which allows gas exchange (Caffrey *et al.*, 2010). The installation of benthic barriers requires scuba divers to put the barriers in place and to anchor the barriers within the sediment by using weights (rock or sand bags, or a layer of gravel or sand) or pins (Caffrey *et al.*, 2009, 2010; de Winton *et al.*, 2013; Gettys *et al.*, 2014). A reduction of the biomass may be necessary prior to the installation of the barriers, if submerged plants have already built up large stands which do not allow the barriers to be put in place. While plastic or polyethylene barriers must be removed from the habitat after the control measures, biodegradable mats can stay in place. The costs for benthic barriers are ca. 20,000 EUR per ha (one treatment, de Winton *et al.*, 2013).

SIDE EFFECTS

Environmental: Negative

Social: Neutral or mixed

Economic: Neutral or mixed

Benthic barriers, particularly those made of plastic or polyethylene, affect all organisms beneath the barrier, including algae and submerged plants, as well as macroinvertebrates and benthic fish. However, if loose-woven biodegradable material like jute is used, native plants (for example charophytes) can grow through the barriers, resulting in a rapid recovery of native plant communities (Caffrey *et al.*, 2010).

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

The acceptance of rapid eradication measures depends on side effects of the measure and the knowledge about the potential ecological and environmental impact that large infestations of the target species might have.

Benthic barriers do not have a negative impact on economic activities and provide a rapid control solution in sites where high conflicts of interest occur due to the nuisance growth of submerged aquatic weeds such as *L. major* (for example in harbours). Consequently, there should be high acceptability of this measure.

ADDITIONAL COST INFORMATION

Rapid eradication measures have a high cost-effectiveness, as rapid eradication of early infestations is in general cheaper than later species management and control (Hussner *et al.*, 2017). The cost of inaction is hard to quantify but will be high, as *L. major* is suitable to grow in most water bodies within the EU.

LEVEL OF CONFIDENCE*

Established but incomplete.

Benthic barriers are established tools for the eradication of early infestations of submerged aquatic weeds.

* See Appendix

Mowing and cutting.

MEASURE DESCRIPTION

Mowing and cutting is the most common method to manage large infestations of submerged aquatic weeds in Europe (Hussner *et al.*, 2017). Cutting and mowing boats are used either with or without subsequent harvest of the cut biomass (Gettys *et al.*, 2014; Hussner *et al.*, 2017; Kuiper *et al.*, 2017).

While the cutting depth of mowing boats is often limited to a maximum of 2 m (although some cutter boats in the USA can cut up to 5 m in depth; Podraza *et al.*, 2008; Caffrey *et al.*, 2009; de Winton and Clayton, 2016; Hussner *et al.*, 2017), V-blades can be pulled along the lake bed and rip plants from the substrate, resulting in an uprooting of plants and causing greater damage than cutting in the upper parts of the plants (Caffrey *et al.*, 2011).

The efficiency of the cutting can be influenced by the morphology of *L. major* during the measure application (Caffrey *et al.*, 2009). In Lough Corrib, Ireland, two different morphologies of *L. major* were found, with a "collapsed" form between May and October and an "erect" form between October and March, being the latter form more easy to cut and harvest (Caffrey *et al.*, 2009).

SCALE OF APPLICATION

Mowing and cutting is mostly used as a control measure for infestations of submerged weeds in large scales, like it has been done for *Elodea nuttallii* in large lakes and reservoirs in Germany (Podraza *et al.*, 2008; Zehnsdorf *et al.*, 2015). In Ireland, about 29.2 ha of *L. major* infestations were cut and about 4,700 tons of cut plant material was subsequently harvested (Caffrey *et al.*, 2009).

EFFECTIVENESS OF MEASURE

Neutral.

Depending on the objective of the control programme, mowing and cutting of *L. major* can be effective. The biomass of submerged aquatic weeds like *L. major* can be reduced by mowing, however eradication is highly unlikely (except in control programmes where various methods are combined) (Podraza *et al.*, 2008; de Winton *et al.*, 2013; Hussner *et al.*, 2017). For example, long-term mowing activities (> 10 years) did not significantly decrease the biomass of submerged *Elodea nuttallii* in reservoirs, but repeated mowing during the summer period allowed the recreational use of the water body (Podraza *et al.*, 2008).

Research trials documented that cutting with V-blades at the root level significantly reduce the regrowth of *L. major* to less than 10% after seven months, and noted that most regrowth came from fragments that drifted into the cut sites (Clayton and Franklyn, 2005 in Caffrey *et al.*, 2011; Caffrey and Acevedo, 2008; Caffrey *et al.*, 2011). One year after cutting using V-blades, the coverage of *L. major* was reduced by 75% (Caffrey *et al.*, 2011), when compared to prior to the cutting.

In general, after cutting, most submerged weeds usually grow back to the water surface within a few weeks (depending on climatic conditions and cutting depth), but repeated mowing can reduce the reserves of the plants within the roots and rhizomes (Podraza *et al.*, 2008; de Winton *et al.*, 2017; Hussner *et al.*, 2017). Moreover, cutting is often used prior to the use of other control measures, like herbicide application, and it increases the success of the latter (de Winton *et al.*, 2013).

EFFORT REQUIRED

All weed cutting and mowing measures must be repeated up to several times within a year to produce a significant reduction in biomass of the target species. Cutting by using V-blades is reported to be more effective than mowing, allowing longer intervals between treatments.

RESOURCES REQUIRED

For mowing and cutting, boats and harvesters are required, as well as skilled operators. De Winton *et al.*, (2013) noted costs of 2,000-4,000 NZD (ca. 1,175–2,350 EUR) per ha for mowing and harvesting the plant material, with costs varying with the distance to the dump site to deposit the harvested material. The costs for mowing and harvesting submerged *Elodea nuttallii* were about 2,500 EUR per day for 0.5 ha (Podraza, 2017).

SIDE EFFECTS

Environmental: Negative
Social: Neutral or mixed
Economic: Neutral or mixed

Mechanical harvesting is commonly considered as having no impact on the environment, but fish and macroinvertebrates might be entrapped and killed within the harvested biomass (de Winton and Clayton, 2016). Furthermore, mowing and

Lagarosiphon major. L. major *prefers lakes, reservoirs, and slow moving rivers with silty or sandy bottoms. © Tim Adriaens, INBO.*

cutting are not species specific, and thus native plants localised within the treated area will be affected as well (Hussner *et al.*, 2017). Moreover, it must be considered that mowing and cutting produce large amounts of plant fragments, which can lead to an even faster spread of the target species (Anderson, 1998). The turbidity of the water column might also increase due to the uprooting of plants and the V-blade pulled along the sediment surface. Harvesting large amounts of biomass reduces the nutrient pool of aquatic systems (Kuiper *et al.*, 2017), but this is the case for all management methods which remove biomass.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

The public perception of mowing and cutting is positive, as this is usually carried out when large weed beds prohibit the recreational use of water bodies.

ADDITIONAL COST INFORMATION

Mowing and cutting have not been documented as providing long-term effects in eradicating a submerged aquatic weed. While mowing in water depth up to 2 m does not lead to a substantial decrease in the biomass of the target species, V-blades which are pulled behind a boat across the sediment surface can significantly decrease the abundance of the target species within the treated area (Caffrey *et al.*, 2011). Thus, the cost-effectiveness for mowing must be considered low, while the cost-effectiveness for cutting along the sediment using V-blades shows a higher efficiency.

However, the cost of inaction is high, as canopy forming submerged weeds like *L. major* can hinder the recreational use of water bodies, which might result in decreasing values of lakefront properties, as it has been documented for lakes infested with *Myriophyllum heterophyllum* (Halstead *et al.*, 2003).

LEVEL OF CONFIDENCE*

Established but incomplete.

There are several studies documenting the effects of mowing and cutting with V-blades on *L. major* infestations, but meta-analyses are lacking.

* See Appendix

Hydro-Venturi.

MEASURE DESCRIPTION

The hydro-venturi (water jet) system pumps water into the upper sediment and washes the rooted plants out, which then float up and can be harvested. As whole plants are uprooted, there is less regrowth and less fragments are produced in comparison to other mechanical management measures, like mowing and cutting (van Valkenburg, 2011; Dorenbosch and Bergsma, 2014; Hussner *et al.*, 2017). This system has not yet been applied to *L. major*, but is expected to be suitable, based on its use on other invasive alien aquatic plants.

The hydro-venturi works best in soft sediments (van Valkenburg, 2011; Hussner, unpublished) and has so far only been used in up to 1.5 m of water depth (van Valkenburg, 2011; Podraza, 2017), although its use in deeper water is possible. It is not species specific, but skilled operators can limit the impact on other aquatic plants.

SCALE OF APPLICATION

The hydro-venturi was used for the control of *Cabomba caroliniana* and *Myriophyllum heterophyllum* in a shallow lake in the Netherlands (van Valkenburg, 2011). In combination with hand weeding, the application of hydro-venturi was used to eradicate approximately 45 m^3 of *Myriophyllum aquaticum* in two connected ponds (total area about 1 ha), which resulted in > 99% reduction of the biomass of the target species, and only approximately 15 l of plants were found during the first post-treatment, three months after the management measures (Hussner, unpublished).

EFFECTIVENESS OF MEASURE

Effective.

While not yet used on *L. major*, it is expected that this system would be as effective to reduce (control) the species impacts, as it has been shown to for other invasive alien aquatic plants. It was successfully used for the reduction of biomass and abundance of evergreen *Cabomba caroliniana* and *Myriophyllum heterophyllum* in shallow water systems in the Netherlands (van Valkenburg, 2011) and Germany (Hussner, unpublished). A hand application of the hydro-venturi system was successfully tested to reduce the biomass of submerged *Myriophyllum heterophyllum* in shallow waters with a maximum depth of approximately 50 cm: > 99% of biomass reduction was achieved after a single treatment, controlled one year after the treatment (Hussner, unpublished). In reservoirs of the River Ruhr, Germany, hydro-venturi control of *Elodea nuttallii* was not successful (Podraza, 2017), but no reasons for this failure of the control measures with hydro-venturi are noted.

The efficiency of the control by using hydro-venturi depends on the sediment structure and water depth, as the water jet must be pumped into the upper sediment layer for successful uprooting of the plants.

EFFORT REQUIRED

The effort required for successful and sustainable control depends on the habitat conditions of the invaded area (water depth, sediment type). The use of a hand application is more time consuming than the use of boat attached hydro-venturi systems, but it is more species specific (depending on the skills and experience of the operator) and more efficient, although it can only be used in shallow waters (<1 m) (Hussner, unpublished). A single treatment with hand application, in combination with hand weeding, resulted in a >99% biomass reduction of the target species and only very few regrowth was found (Hussner, unpublished).

RESOURCES REQUIRED

The operation of the hydro-venturi system requires 1-2 skilled operators, and the subsequent harvest of the uprooted plant material requires additional workers. The cost of the hydro-venturi system operated by boat is ca.1.35-2.05 Euro/m^2 (depending on sediment structure and other variables), while the cost for management using hand application is ca. 5 Euro/m^2 (Hussner, unpublished).

SIDE EFFECTS

Environmental: Negative
Social: Neutral or mixed
Economic: Neutral or mixed

The hydro-venturi washes the rooted plants out of the sediment, and thus an increase of the water turbidity during the control measures will occur. Any organisms within the sediment are dislocated by the water jet, and macroinvertebrates and fish might be trapped within the harvested plant material (like for all management measures which harvest plant material out of the water). Hydro-venturi is not species specific, and thus effects on other plant species seem likely, although this negative impact can be reduced if the hydro-venturi is carried out by skilled operators. In comparison to mowing and cutting, hydro-venturi produces less fragments, reducing the risk for subsequent spread of the species being controlled.

ACCEPTABILITY TO STAKEHOLDERS

As for all other management methods, the control of invasive aquatic plants by hydro-venturi has a high level of acceptability by stakeholders and the public, particularly in areas where the nuisance growth of aquatic weeds like *L. major* prohibits the recreational use of the water. Despite the disturbance of aquatic fauna, such as macroinvertebrates, and other non-target plant species, no negative effects on native animals are reported.

ADDITIONAL COST INFORMATION

As for all management methods, the cost of inaction is usually high and will result in spreading of the target species, reducing the likelihood of future eradication and increasing management costs. The cost of inaction is also high, as canopy forming submerged weeds like *L. major* can hinder the recreational use of water bodies, which might result in decreasing values of lakefront properties, as it has been documented for lakes infested with *Myriophyllum heterophyllum* (Halstead *et al.*, 2003).

LEVEL OF CONFIDENCE*

Unresolved.

Hydro-venturi has been successfully used to control some aquatic weed species in shallow waters, but the control of *Elodea nuttallii* in the reservoirs of the River Ruhr was not successful. More research is needed to improve the success and applicability of this system. In addition, hydro-venturi has not been tested for the control of *L. major* so far (althoughit seems reasonable that it will be a valuable tool for the control of the species).

* See Appendix

Biological control.

MEASURE DESCRIPTION

Biological control agents can be used to reduce the growth or reproductive capacity of a target species (Cuda *et al.*, 2008). There are various types of biocontrol, including generalist herbivores, the inundative and the classical and augmentative biocontrol (Hussner *et al.*, 2017).

Generalist herbivores can be either native or non-native species which have a broad host range. The species are introduced with the aim to control the target plants. For the control of submerged aquatic weeds like *L. major*, grass carp (*Ctenopharyngodon idella*) is considered as a potential generalist control agent (Chapman and Coffey, 1971) and particularly a sterile triploid form is widely used (Venter and Schoonbee, 1991); however, grass carp is itself an invasive alien species in Europe. Grass carp have been stocked in a number of European lakes to control other submerged weeds like *Elodea nuttallii*. This often resulted in a decrease of all submerged plant species in the water body, as grass carp are not species specific (Dibble and Kovalenko, 2009; Hussner *et al.*, 2017).

It should be borne in mind that the release of macro-organisms as biological control agents is currently not regulated at EU level. Nevertheless, national/regional laws are to be respected. Before any release of an alien species as a biological control agent, an appropriate risk assessment should be made.

For classical biological control, the potential biological control agent is collected within the native range and introduced into the invasive range of the target species (van Driesche *et al.*, 2010). Host specificity tests are required prior to the release of the control agent to ensure that host shift will not occur. While for floating and emergent aquatic plants several successful examples of classical biological control are documented, there are no examples of successful classical biological control of submerged weeds (Hussner *et al.*, 2017).

Several phytophagous insects (including for example Bagous sp., *Nymphulinae* sp., *Polypedilum* n.sp.) have been documented feeding on *L. major*, some of which have a high potential as biocontrol agents of the species (Baars *et al.*, 2010; Earle *et al.*, 2013). The most studied species for classical biological control of *L. major* is *Hydrellia lagarosiphon*, a leaf mining fly (Mangan and Baars, 2013; Martin *et al.*, 2013; Mangan *et al.*, 2019), but even for this species studies about the success to control *L. major* under field conditions are lacking.

The inundative control of aquatic weeds using mycoherbicides is a new technique which was tested successfully in mesocosm experiments, but under field conditions no success in the control of submerged aquatic weeds is reported so far (Shearer, 1994, 1996; Hofstra *et al.*, 2004; Hussner *et al.*, 2017). There is no information on the use of mycoherbicides to control *L. major*.

SCALE OF APPLICATION

No biological control agents have been released so far for the control of *L. major*.

EFFECTIVENESS OF MEASURE

Unknown.

There is no information about the use and success of generalist, classical, or inundative biological control agents to control *L. major* in the field. However, grass carp has proven to be a successful control agent for other submerged aquatic weeds (de Winton *et al.*, 2013), showing their potential effectiveness in controlling *L. major*.

EFFORT REQUIRED

For control using generalist herbivores, grass carp must be stocked in appropriate quantities (Dibble and Kovalenko, 2009) for several years to prevent any regrowth from vegetative means in the sediment.

For *L. major*, no classical or inundative biocontrol control agents have been tested under field conditions so far. However, in general, host specificity testing would take about 3 years prior to the potential release of a control agent (Newman and Duenas, 2017).

RESOURCES REQUIRED

The cost of the use of grass carp depends on the stocking densities needed. High costs will be incurred for the successful removal of grass carp after the control of the target species, to allow for the restoration of native plant communities (Hussner *et al.*, 2017).

The testing of inundative and classical biological control agents requires experienced scientists and also involves high costs.

SIDE EFFECTS

Environmental: Negative
Social: Negative
Economic: Neutral or mixed

The side effects are indicated only for the use of grass carps, which are proven successful control agents for submerged aquatic weeds (de Winton *et al.*, 2013). However, they are themselves an invasive alien species in Europe and consume all kind of aquatic plants, so impacts on native plants are likely to be high. The disappearance of aquatic vegetation may affect water birds, which use aquatic plants and associated macroinvertebrates as food. The disappearance of submerged aquatic plants can also cause a shift to a phytoplankton-dominated state in the ecosystem, with increased turbidity, which makes water bodies less attractive for recreational activities and tourism.

The use of classical biological and inundative control agents has not been tested in the field so far for *L. major*, but Newman and Duenas (2017) noted that there should be no side effects on native plant species, if the classical biological control programme is well-managed.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

The potential negative effects caused by grass carps may reduce the acceptability of this measure by stakeholders, as turbid waters are less attractive for recreational activities and tourism in general.

For potential inundative and classical biological control agents for *L. major*, there is a large knowledge gap about the impacts that these control agents might cause, and consequently their acceptability is hard to quantify.

ADDITIONAL COST OF INFORMATION

The cost-effectiveness is often considered high for grass carp use, if only the costs of stocking are considered (about 1,000 NZD (ca. 587 EUR) per ha; Clayton, 1996). However, the follow-up costs make stocking of grass carp an expensive management strategy. The costs can be reduced in water bodies where water-level drawdown can be used to remove the grass carp after treatment.

No data about the costs of classical and inundative biological control are available, but both methods require comprehensive testing prior to their use, incurring high costs. The costs for the testing phase are ca. 300,000 EUR (Newman and Duenas, 2017), and its cost-effectiveness has been estimated to be from 2.5:1 to 15:1, and even up to 4000:1 (McConnachie *et al.*, 2003 and Culliney, 2005 in Newman and Duenas, 2017).

As for all control strategies, the costs of inaction will be high, as *L. major* is able to grow in most water bodies within the EU member states.

LEVEL OF CONFIDENCE*

Inconclusive.

Generalist herbivores such as grass carps are widely used to control submerged weeds, in general, and have been suggested for the control of *L. major* (Chapman and Coffey, 1971), but information on their use and success is lacking.

Potential classical inundative and biological control agents (like *Hydrellia lagarosiphon*) have been identified for *L. major*, but there are no data from field tests available.

* See Appendix

Herbicides.

MEASURE DESCRIPTION

Herbicides, in general terms, are used to control aquatic plants in ponds and lakes, channels and irrigation systems (de Winton *et al.*, 2013; Gettys *et al.*, 2014; Hussner *et al.*, 2017). Herbicide treatment may significantly reduce the biomass of submerged weeds like *L. major* and can result in the eradication of a target species (de Winton *et al.*, 2013; Champion and Wells, 2014; Hussner *et al.*, 2017). While herbicides are usually not species specific, the chosen concentration, exposure time, species specific uptake rates of a given herbicide and the application method used can cause a level of selectivity (Getsinger *et al.*, 1997, 2008, 2014; Carvalho *et al.*, 2007; Netherland, 2014).

EU/national/local legislation on the use of plant protection products and biocides needs to be respected when applying this measure. According to Regulation (EC) No 1107/2009 concerning plant protection products, none of the active substances mentioned below are approved for use in the EU, although national authorisations might be possible. It is important to also comply with Regulation (EU) No 528/2012 on the use of biocidal products.

SCALE OF APPLICATION

Herbicides are commonly used for the largescale control of submerged aquatic weeds (Clayton, 1996). In Lake Rotorua, New Zealand, herbicide treatment was used to treat >100 ha of invasive aquatic weeds (Clayton, 1996). In Lough Corrib (Ireland), only parts of the lakes and a harbour were treated with the herbicide dichlobenil (Caffrey *et al.*, 2009).

EFFECTIVENESS OF MEASURE

Neutral.

For *L. major*, some herbicides have been tested, with varying levels of control achieved (Clayton, 1996; Hofstra and Clayton, 2001; Caffrey *et al.*, 2009; Hussner *et al.*, 2017). Endothal and diquat, which are registered for use in New Zealand,have been tested to control *L. major* in the country (de Winton and Clayton, 2016) and successful treatments have caused a substantial reduction in the species biomass (Clayton, 1996; de Winton and Clayton, 2016).

In Lough Corrib, Ireland, the application of dichlobenil granules did not result in a remarkable reduction of *L. major* coverage (Caffrey and Avecedo, 2008), which was probably a result of the granules being trapped in the vegetation. Consequently, they did not reach the lake bed, which is the site of activity for dichlobenil (Caffrey, 1993a,b in Caffrey and Acevedo, 2008). However, in suitable habitats, a 100% eradication of *L. major* is normally achieved (Caffrey *et al.*, 2011).

EFFORT REQUIRED

The frequency and amount of herbicide needed for successful control depends on the herbicide and its formula used (Hofstra and Clayton, 2001; Hussner *et al.*, 2017). In Lough Corrib, a single treatment with dichlobenil resulted in total weed kill in suitable habitats (Caffrey *et al.*, 2011).

RESOURCES REQUIRED

Besides the herbicide, a boat and experienced workers are needed for the surface application of herbicides like dichlobenil. In water bodies with a high biomass of the target species, aerial application is possible (de Winton *et al.*, 2013).

The full cost (herbicide, operator and equipment) of herbicide treatment with gel-formulated diquat in Lake Rotorua, New Zealand, was less than 350 EUR (500 NZD) per ha (Clayton, 1996).

SIDE EFFECTS

Environmental: Negative

Social: Negative

Economic: Neutral or mixed

In Lake Rotorua, diquat application enhanced the maintenance of native charophytes, which are resistant to this herbicide (Clayton, 1996). However, the effects of herbicides on other submerged aquatic plants depend on the sensitivity of the species to the herbicides, with varying effects at a species level. Besides the effects on other submerged plants, macroinvertebrates and fish can also be affected. Caffrey (1993a,b) described only minor negative effects of dichlobenil on water quality, non-target aquatic plants, macroinvertebrates and fish.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

The chemical control of submerged aquatic weeds by using herbicides can be relatively cheap (Clayton, 1996), which might increase the acceptability of stakeholders, while the potential negative impact on other submerged plants,

Lagarosiphon major *can grow to depths of 6.6 m © Tim Adriaens, INBO.*

fauna and water quality could cause less acceptability. Until now, only dichlobenil was used for the control of *L. major* in Ireland (Caffrey *et al.*, 2009).

ADDITIONAL COST INFORMATION

While no specific information about the costs in the EU is available, the general low cost of aquatic weed control with herbicides (Clayton, 1996) makes its cost-effectiveness high. However, if the used herbicide negatively affects native plant communities, their restoration will have additional costs.

LEVEL OF CONFIDENCE*

Unresolved.

The results from field trials with dichlobenil in Lough Corrib (Ireland) had varying results in the control of *L. major* (Caffrey *et al.*, 2009, 2011).

* See Appendix

Bibliography

Adriaens, T., Sutton-Croft, M., Owen, K., and Schneider, K., (2015). Trying to engage the crowd in recording invasive alien species in Europe: experiences from two smartphone applications in northwest Europe. *Management of Biological Invasions*, 6,215–225.

Alexander, M.L., Doyle, R.D., and Power, P. (2008). Suction dredge removal of an invasive macrophyte from a spring-fed river in Central Texas, USA. *Journal of Aquatic Plant Management,* 46, 184–185.

Anderson, L.W. J. (1998). Dissipation and movement of Sonar and Komeen following typical applications for control of *Egeria densa* in the Sacramento–San Joaquin Delta and Production and viability of *E. densa* fragments following mechanical harvesting (1997/1998). Davis, CA U.S. Department of Agriculture–Agricultural Research Service, Environmental Impact Report for California Department of Boating and Waterways, 79pp.

Anderson, L.W. J. (2005). California's reaction to *Caulerpa taxifolia*: A Model for Invasive Species Rapid Response. *Biological Invasions*, 7, 1003-1016.

Anderson, L.G., Dunn, A.M., Rosewarne, P.J., and Stebbing, P.D. (2015). Invaders in hot water: a simple decontamination method to prevent the accidental spread of aquatic invasive non-native species. *Biological Invasions*, 17, 2287–2297.

Anderson, L.G., White, P.C., Stebbing, P.D., Stentiford, G.D., and Dunn, A.M. (2014). Biosecurity and vector behaviour: Evaluating the potential threat posed by anglers and canoeists as pathways for the spread of invasive non-native species and pathogens. *PLOS ONE,* 9(4), e92788.

Baars, J.R., Coetzee, J.A., Martin, G., Hill, M.P., and Caffrey, J.M. (2010). Natural enemies from South Africa for biological control of *Lagarosiphon major* (Ridl.) Moss ex Wager (Hydrocharitaceae) in Europe. *Hydrobiologia*, 656, 149-158.

Barnes, M.A., Jerde, C.L., Keller, D., Chadderton, W.L., Howeth, J.G., and Lodge, D.M. (2013). Viability of aquatic plant fragments following desiccation. *Invasive Plant Science and Management*,6, 320-325.

Bellaud, M.D. (2009). Cultural and physical control of aquatic weeds. Chapter 6. In: Gettys LA, Haller WT, Bellaud M (Eds). Biology and control of aquatic plants, a best management practices handbook. Aquatic Ecosystem Restoration Foundation, Georgia, USA.

Boylen, C.W., Eichler, L.W., and Sutherland, J.W. (1996). Physical control of Eurasian watermilfoil in an oligotrophic lake. *Hydrobiologia,* 340, 213–218.

Brunel, S. (2009). Pathway analysis: aquatic plants imported in 10 EPPO countries. *EPPO Bulletin,* 39, 201–213.

Burchnall, W. (2013). Wetland Biosecurity Officer project report. The Broads Authority. http://www.broads-authority.gov.uk/__data/assets/pdf_file/0020/405344/Biosecurity_officer__6_month_update.pdf.

Caffrey, J.M. (1993a). Aquatic weed management practices using dichlobenil: an Irish experience. *Polskie Archiwum Hydrobiologii,* 40, 255-26.

Caffrey, J.M. (1993b). Plant management as an integral part of Ireland's aquatic resources. *Hydroecologie Applique*, 5, 77-96.

Caffrey, J.M., and Acevedo, S. (2008). *Lagarosiphon major* in Lough Corrib – Management options. In: C Moriary, R Rossell, and P Gargan (eds.). Fish stocks and their environment, 85-97. Westport, Institute of Fisheries Management.

Caffrey, J.M., Evers, S., and Moran, H. (2009). Research and control programme for *Lagarosiphon major* in Lough Corrib 2008. Dublin Central Fisheries Board.

Caffrey, J.M., Millane, M., Evers, S.L., and Moran, H. (2011). Management of *Lagarosiphon major* (Ridley) Moss in Lough Corrib – a review. *Biology and Environment: Proceedings of the Royal Irish Academy*, 111, 205-212.

Caffrey, J.M., Millane, M., Evers, S., Moran, H., and Butler, M. (2010). A novel approach to aquatic weed control and habitat restoration using biodegradable jute matting. *Aquatic Invasions*, 5, 123-129.

Carvalho, R.F.de, Bromilow, R.H., and Greenwood, R. (2007). Uptake of pesticides from water by curly waterweed *Lagarosiphon major* and lesser duckweed *Lemna minor. Pest Management Science*, 63, 789-797.

Champion, P.D., and Clayton, J. S.(2001). Border Control for Potential Aquatic Weeds. Stage 2. Weed Risk Assessment. Science for Conservation 165. Department of Conservation, Wellington, New Zealand, 30pp.

Champion, P.D., Clayton, J.S., and Hofstra, D.E. (2010). Nipping aquatic plant invasion in the bud: weed risk assessment and the trade. *Hydrobiologia*, 656, 167–172.

Champion, P., and Wells, R. (2014). Proactive management of aquatic weeds to protect the nationally important Northland dune lakes. In: Nineteenth Australasian Weeds Conference, New Zealand. www.caws.org.au/awc/2014/awc201411391.

Chapman, V.J., and Coffey, B.J. (1971). Experiments with grass carp in controlling exotic macrophytes in New Zealand. *Hydrobiologia*, 12, 313-323.

Clayton, J.S. (1996). Aquatic weeds and their control in New Zealand lakes. *Journal of Lake and Reservoir Management,* 12, 477-486.

Clayton, J.S., and Franklyn, G. (2005). Assessment of the December 2004 *Lagarosiphon major* control in Lake Wanaka. Internal Report, National Institute of Water and Atmospheric Research, New Zealand.

Crane, K., Cuthbert, R.N., Dick, J.T.A., Kregting, L., MacIsaac, H.J., and Coughlan, N.E. (2019). Full steam ahead: direct steam exposure to inhibit spread of invasive aquatic macrophytes. *Biological Invasions*, 21, 1311-1321.

Cuda, J.P., Charudattan, R., Grodowitz, M.J., Newman, R.M., Shearer, J.F., Tamayo, M.L., and Villegas, B. (2008). Recent advances in biological control of submersed aquatic weeds. *Journal of Aquatic Plant Management*, 46, 15–32.

Culliney, T.W. (2005). Benefits of Classical Biological Control for managing invasive plants. *Critical Reviews in Plant Sciences*, 24, 131-150.

Cuthbert, R.N., Coughlan, N.E., Crane, K., Caffrey, J.M., and MacIsaac, H.J. (2018). A dip or dab: assessing the efficacy of Virasure Aquatic disinfectant to reduce secondary spread of the invasive curly waterweed *Lagarosiphon major. Management of Biological Invasions*, 9, 259-265.

Delaney, D.G., Sperling, C.D, Adams, C.S., and Leung, B. (2008). Marine invasive species: validation of citizen-science and implications for national monitoring networks. *Biological Invasions*, 10, 117-128.

de Winton, M., and Clayton, J.S. (2016). Ten year management plan for *Lagarosiphon major* at Lake Dunstan: 2016-2025. NIWA Client report No. HAM2016-040, 41pp.

de Winton, M., Jones, H., Edwards, T., Özkundakci, D., Wells, R., McBride, C., Rowe, D., Hamilton, D., Clayton, J., Champion, P., and Hofstra, D. (2013). Review of best management practices for aquatic vegetation control in storm water ponds, wetlands, and lakes. Prepared by NIWA and the University of Waikato for Auckland Council. Auckland Council technical report, TR2013/026.

Dibble, E.D., and Kovalenko, K. (2009). Ecological impact of grass carp: a review of the available data. *Journal of Aquatic Plant Management*,47, 1–15.

Dorenbosch, M., and Bergsma, J.H. (2014). Bestrijding van waterwaaier in Hardinxveld met hydro-venturi. Evaluatie Onderzoek En Beknopte Literatuur Vergelijking.Bureau Waardenburg, Culemborg.

Earle, W., Mangan, R., O'Brien, M., and Baars, J.R. (2013). Biology of *Polypedilum* n.sp. (Diptera: Chironomidae), a promising candidate agent for the biological control of the aquatic weed *Lagarosiphon major*

(Hydrocharitaceae) in Ireland. *Biocontrol Science and Technology*, 23, 1267-1283.

Genovesi, P., Scalera, R., Brunel, S., Roy, D., and Solarz, W. (2010). Towards an early warning and information system for invasive alien species (IAS) threatening biodiversity in Europe. EEA Technical report No 5/2010, EEA, Copenhagen, 47pp.

Getsinger, K.D., Turner, FOR EXAMPLE, Madsen, J.D., and Netherland, M. (1997). Restoring native plant vegetation in a Eurasian watermilfoil dominated community using the herbicide triclopyr. *Regulated River,* 13, 357–375.

Getsinger, K.D., Netherland, M.D., Grue, C.E., and Koschnick, T.J. (2008). Improvements in the use of aquatic herbicides and establishment of future research directions. *Journal of Aquatic Plant Management*, 46, 32–41.

Getsinger, K.D., Dibble, E., Rodgers, J.H., and Spencer, D. (2014). Benefits of Controlling Nuisance Aquatic Plants and Algae in the United States. CAST Commentary, QTA2014-1, 12pp.

Gettys, L., Haller, W., and Petty, D. (Eds.) (2014). Biology and Control of Aquatic Plants. A Best Management Practices Handbook: Third Edition. Aquatic Ecosystem Restoration Foundation, USA, 252pp.

Halford, M., Heemers, L., van Wesemael, D., Mathys, C., Wallens, S., Branquart, E., Vanderhoeven, S.,*et al*., (2014). The voluntary Code of conduct on invasive alien plants in Belgium: results and lessons learned from the AlterIAS LIFE+ project. *EPPO Bulletin*, 44, 1-11.

Halstead, J.M, Michaud, J., Hallas-Burt, S., and Gibbs, J.P. (2003) Hedonic analysis of effects of a non-native invader (*Myriophyllum heterophyllum*) on a New Hampshire (USA) lakefront properties. *Environmental Management*, 32, 391-398.

Heidbüchel, P., and Hussner, A. (2019). Fragment type and water depth determine the regeneration and colonization success of submerged aquatic plants. *Aquatic Sciences*, 81, 6.

Heidbüchel, P., Jahns, P.,and Hussner, A. (2019). Chlorophyll fluorometry sheds light on the role of desiccation resistance for vegetative overland dispersal of aquatic plants. *Freshwater Biology*, 64(8),1401-1415.

Hippolite, J., and Te Kurapa, T.W.M. (2018). Aquatic Pest Report 2018. Bay of Plenty Regional Council, Environmental Publication 2018/02, Whakatane, New Zealand.

Hochachka, W.M., Fink, D., Hutchinson, R.A., Sheldon, D., Wong, W.K., and Kelling, S. (2012). Data intensive science applied to broad-scale citizen-science. *Trends in Ecology and Evolution*, 27, 130-137.

Hoffmann, M., Gonzalez, A.B., Raeder, U., and Melzer, A. (2013). Experimental weed control of *Najas marina* ssp. intermedia and *Elodea nuttallii* in lakes using biodegradable jute matting. *Journal of Limnology*, 72, 485-493.

Hofstra, D.E., and Clayton, J.S. (2012). Assessment of benthic barrier products for submerged aquatic weed control. *Journal of Aquatic Plant Management*, 50, 101-105.

Hofstra, D., Shearer, J., Edwards, T., Clayton, J.,and Gemmill, C. (2004). *Mycoleptodiscus terrestris*: A comparison between isolates from the United States and New Zealand. In: Aquatic Plant Management Society Conference, July 2004.

Howard-Williams, C., and Reid, V. (1989). Aquatic weed survey of Lake Whakamarino following dredging. DSIR unpublished report to Electrocorp.

Hussner, A. (2012). Alien aquatic plants in European countries. *Weed Research*, 52, 397-406.

Hussner, A., Nehring, S., and Hilt, S. (2014). From first reports to successful control: a plea for improved management of alien aquatic plant species in Germany. *Hydrobiologia*, 737, 321–331.

Hussner, A., Stiers, I., Verhofstad, M.J.J.M., Bakker, E.S., Grutters, B.M.C., Haury, J., van Valkenburg J.L.C.H., Brundu, G., Newman, J., Clayton, J.S., Anderson, L.W.J., and Hofstra, D. (2017). Management and control methods of invasive alien aquatic plants: a review. *Aquatic Botany*, 136, 113-137.

Hussner, A., Windhaus, M., and Starfinger, U. (2016). From weed biology to successful control: an example of successful management of *Ludwigia grandiflora* in Germany. *Weed Research*, 56, 434-441.

Johnson, L.E., Ricciardi, A., and Carlton, J.T. (2001). Overland dispersal of aquatic invasive species: a risk assessment of transient recreational boating. *Ecological Applications*,11, 1789-1799.

Johnstone, I.M., Coffey, B.T., and Howard-Williams, C. (1985). The role of recreational boat traffic in interlake dispersal of macrophytes: a New Zealand case study. *Journal of Environmental Management*, 20, 263-279.

Kuiper, J.J., Verhofstad, M.J.J.M., Louwers, E.L.M., Bakker, E.S., Brederveld, R.J., van Gerven, L.P.A., Janssen, A.B.G., de Klein, J.J.M., and Mooij, W.M. (2017). Mowing submerged macrophytes in shallow lakes with alternative stable states: battling the good guys? *Environmental Management*, 59, 619-634.

Laitala, K.L., Prather, T.S., Thill, D., Kennedy, B., and Caudill, C. (2012). Efficacy of benthic barriers as a control measure for Eurasian Watermilfoil (*Myriophyllum spicatum*). *Invasive Plant Science and Management*, 5: 170–177.

Lockwood, J.L., Cassey, P., and Blackburn, T. (2005). The role of propagule pressure in explaining species invasions. *Trends in Ecology and Evolution*, 20, 223-228.

Mangan, R., and Baars, J.R. (2013). Use of life table statistics and degree day values to predict the colonisation success of *Hydrellia lagarosiphon* Deeming (Diptera: Ephydridae), a leaf mining fly of *Lagarosiphon major* (Ridley) Moss (Hydrocharitaceae), in Ireland and the rest of Europe. *Biological Control*, 64, 143-151.

Mangan, R., Carolan, J.C., and Baars, J.R. (2019). Molecular characterization of *Hydrellia lagarosiphon*, a leaf mining biological control agent for *Lagarosiphon major*, reveals weak variance across large geographic areas in South Africa. *Biological Control*, 132, 8-15.

Martin, G.D., Coetzee, J.A., and Baars, J.R. (2013). *Hydrellia lagarosiphon* Deeming (Diptera: Ephydridae), a potential biological control agent for the submerged aquatic weed, *Lagarosiphon major* (Ridl.) Moss ex Wager (Hydrocharitaceae). *African Entomology*, 21, 151-160.

Matsuhashi, S., Doi, S., Fujiwara, A., Watanabe, S., and Minamoto, T. (2016). Evaluation of the Environmental DNA Method for Estimating Distribution and Biomass of Submerged Aquatic Plants. *PLoS One*,11(6), e0156217.

McConnachie, A.J., de Wit, M.P., Hill, M.P., and Byrne, M.J. (2003). Economic evaluation of the successful biological control of *Azolla filiculoides* in South Africa. *Biological Control*, 28, 25-32.

Netherland, M.D. (2014). Chemical control of aquatic weeds. In: Gettys, L., Haller,W., Petty, D. (Eds.), Biological Control of Aquatic Plants. A Best Management Practices Handbook, third edition. Aquatic Ecosystem Restoration Foundation, USA, 71–88.

Newman, J., and Duenas, M.A. (2017). Information on measures and related costs in relation to species included on the Union list: *Alternanthera philoxeroides*. Technical note prepared by IUCN for the European Commission.

Podraza, P. (2017). Aquatische Makrophyten als Herausforderung für das Management von Flussstauseen am Beispiel der Ruhrstauseen. Oral presentation, AquaMak Conference, Leipzig, 30 March 2017.

Podraza, P., Brinkmann, T., Evers, P., von Felde, D., Frost, U., Klopp, R., and Knotte, H. (2008). Untersuchungen zur Massenentwicklung von Wasserpflanzen inden Ruhrstauseen und Gegenmaßnahmen. Abschlussbericht des F and E-Vorhabens im Auftrag des Ministeriums für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz des Landes NRW (MUNLV), 364 S.

Redekop, P., Hofstra, D., and Hussner, A. (2016). *Elodea canadensis* shows a higher dispersal capacity via fragmentation than *Egeria densa* and *Lagarosiphon major. Aquatic Botany*, 130, 45-49.

Roy, H.E., Pocock, M.J.O., Preston, C.D., Roy, D.B., Savage, J., Tweddle, J.C., and Robinson, L.D. (2012). Understanding citizen-science and environmental monitoring. Final report on behalf of UK-EOF. NERC Centre for Ecology and Hydrology and Natural History Museum.

Scriver, M., Marinich, A., Wilson, C., and Freeland, J. (2015). Development of species-specific environmental DNA (eDNA) markers for invasive aquatic plants. *Aquatic Botany*, 122, 27-31.

Shearer, J. (1994). Field test of first commercial formulation of *Mycoleptodiscus terrestris* (Gerd.) Ostazeski as a biocontrol for Eurasian Watermilfoil. Miscellaneous. Paper A-94-4. US Army Waterways Experiment Station, Vicksbury, MS.

Shearer, J. (1996). Field and laboratory studies of the fungus *Mycoleptodiscus terrestris* as a potential agent for management of the submerged aquatic macrophyte, *Hydrilla verticillate*. Technical report A-96-3. US Army Waterways Experiment Station, Vicksbury, MS.

van de Weyer, K., Nienhaus, I., Tigges, P., Hussner, A., and Hamann, U. (2007): Eine einfache und kosteneffiziente Methode zur flächenhaften Erfassung von submersen Pflanzenbeständen in Seen. *Wasser und Abfall*, 9, 20-22.

van de Wiel, C.C., van der Schoot, J., van Valkenburg, J.L.H.C., Duistermaat, H., and Smulders, M.J. (2009). DNA barcoding discriminates the noxious invasive plant species, floating pennywort (*Hydrocotyle ranunculoides* L.f.), from non-invasive relatives. *Molecular Ecology Resources*, 9, 1086-1091.

van Driesche, R.G., Carruthers, R.I., Center, T., Hoddle, M.S., Hough-Goldstein, J., Morin, L., Smith, L.,*et al*., (2010). Classical biological control for the protection of natural ecosystems. *Biological Control*, 54, 2-33.

van Valkenburg, J.L.H.C. (2011). *Cabomba caroliniana* and *Myriophyllum heterophyllum* a Nightmare Combination. Robson Meeting February 2011. www.robsonmeeting.org/valkenburg.pdf.

Venter, A.J.A., and Schoonbee, H.J. (1991). The use of triploid grass carp, *Ctenopharyngodon idella* (Val.), in the control of submerged aquatic weed in the Florida Lake, Roodepoort, Transvaal. *Water SA*, 17, 321-326.

Wells, R.D.S., and Clayton, J.S. (2005). Mechanical and chemical control of aquatic weeds: costs and benefits. Chapter 208. In: Pimentel, D. (Ed). Encyclopaedia of Pest Management. CRC Press 2002. http://www.crcnetbase.com/doi/abs/10.1201/NOE0824706326.ch208.

Wells, R., Clayton, J., Schwarz, A.M., Hawes, I., and Davies-Colley, R. (2000). Mighty River Power aquatic weeds: issues and options. NIWA Client Report MRP00502, prepared for Mighty River Power Ltd: 55.

Zehnsdorf, A., Hussner, A., Eismann, F., Rönicke, H., and Melzer, A. (2015). Management options of invasive *Elodea nuttallii* and *Elodea canadensis*. *Limnologica*, 51, 110–117.

Appendix

Level of confidence provides an overall assessment of the confidence that can be applied to the information provided for the measure.

- **Well established:** comprehensive meta-analysis or other synthesis or multiple independent studies that agree. *Note:* a meta-analysis is a statistical method for combining results from different studies which aims to identify patterns among study results, sources of disagreement among those results, or other relationships that may come to light in the context of multiple studies.
- **Established but incomplete:** general agreement although only a limited number of studies exist but no comprehensive synthesis and/or the studies that exist imprecisely address the question.
- **Unresolved:** multiple independent studies exist but conclusions do not agree.
- **Inconclusive:** limited evidence, recognising major knowledge gaps

Your feedback is important. Any comments that could help improve this document can be sent to ENV-IAS@ec.europa.eu

This technical note has been drafted by a team of experts under the supervision of IUCN within the framework of the contract No 07.0202/2016/739524/SER/ENV.D.2 "Technical and Scientific support in relation to the Implementation of Regulation 1143/2014 on Invasive Alien Species". The information and views set out in this note do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this note. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.