Hydrocotyle ranunculoides © *Tim Adriaens, INBO.*

The management of floating pennywort (*Hydrocotyle ranunculoides*)

Measures and associated costs

Scientific name(s)	*Hydrocotyle ranunculoides* L.f.
Common names (in English)	Floating pennywort
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Common names

BG	Лютичевидно хидрокотиле
HR	Žabnjački ljepušak
CZ	Pupečník pryskyřníkovitý
DA	Flydende vandnavle
NL	Grote waternavel
EN	Floating pennywort
ET	Tulik-vesipaunikas
FI	Sumasammakonputki
FR	Hydrocotyle fausse-renoncule
DE	Großer Wassernabel
EL	–
HU	Hévízi gázló
IE	Lus pingine snámhach
IT	Soldinella reniforme
LV	–
LT	Vėdryninė raistenė
MT	–
PL	Wąkrotka jaskrowata
PT	–
RO	–
SK	Pupkovník iskerníkovitý
SL	Plavajoči popnjak
ES	Redondita de agua
SV	Flytspikblad

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

Hydrocotyle ranunculoides L.f. (Araliaceae) is a perennial sediment rooted, floating or emerged leaved aquatic plant species native to the Americas (Mathias, 1936). The species has been introduced into several European countries (EPPO, 2006; Hussner, 2012) and is managed in some of these countries (such as the Netherlands and the UK). It is able to grow in a wide range of aquatic habitats, including ditches, canals, irrigation channels, ponds and lakes (Plant Protection Service *et al.*, 2011). *Hydrocotyle ranunculoides* spreads easily via plant fragments, and even small fragments regenerate, as long as one node is present (Hussner, 2009). Seed production is reported for Europe, but nothing is known about the viability of the seeds and their germination in the field.

Unintentional introduction of aquatic weeds into the EU might occur due to the mislabelling or contamination of imported plants (Brunel, 2009), so prevention of unintentional introductions of *H. ranunculoides* can be done through the implementation of control programmes at borders and specialised shops to identify mislabelled and/or contaminated plants. Prevention of secondary spread of the species, which is mostly transported between unconnected water bodies through the movement of fragments and seeds attached to water sport equipment, can be done through public awareness campaigns and biosecurity measures targeted at water users. Surveillance measures to support the detection of new invasions should be implemented through surveying programmes using citizen science and remote sensing.

Early detection and rapid eradication is crucial for a fast eradication of the species. Early detection can be achieved through intensive surveying, including citizen science, and remote sensing; rapid eradication of new invasions can be achieved through hand weeding. Due to the easy fragmentation and high regeneration capacity of the species, management is difficult, and care should be taken to prevent species spread via fragments during the management activities (Pot, 2002; Newman and Duenas, 2010). As such, for established populations, a detailed management plan is needed and, although herbicides and biological control can be used, mechanical control followed by hand weeding is considered the best practice to manage large infestations (Newman and Duenas, 2010). As similarly to other emerged growing aquatic invasive plants (like *Myriophyllum aquaticum* and *Ludwigia grandiflora*), *H. ranunculoides* performs best under high nutrients (Hussner, 2009), nutrient reduction in water bodies will also help to limit their growth. Consequently, in an integrated management plan, nutrient reduction should be considered as an additional management tool and, even though it will not eradicate the species, it will reduce its growth and spread.

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 *H. ranunculoides.*

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 programmes to identify mislabelled and/or contaminated plants.

MEASURE DESCRIPTION

Aquatic weeds like *H. ranunculoides* enter the EU via intentional and unintentional human mediated introductions. As mentioned above, the intentional introductions are regulated, but the unintentional introduction of aquatic weeds into the EU might occur due to the mislabelling or contamination of imported plants (Brunel, 2009). In a study undertaken in German shops, no *H. ranunculoides* was found for sale, but some relatives were found in trade (Hussner *et al.*, 2014) and thus it seems reasonable that *H. ranunculoides* can be imported as a mislabelled plant. Consequently, a comprehensive control programme is needed to both identify mislabelled plants of *H. ranunculoides* (and of other aquatic weeds of Union concern) and to check for imported plants potentially contaminated with this species.

For the genus *Hydrocotyle*, a DNA barcoding tool has been developed, which allows the determination of the species by using plant parts (van de Wiel *et al.*, 2009).

SCALE OF APPLICATION

Import controls must be installed at the sites of entry into different EU countries (such as airports; Brunel, 2009) and additional controls in specialised shops (for example aquarium and garden plant shops) are required.

EFFECTIVENESS OF MEASURE

Unknown.

Import control measures can be highly effective, depending on the experience and species knowledge of inspectors and other responsible authorities. But nevertheless, 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. A border control programme for aquatic weeds has been developed for New Zealand (Champion and Clayton, 2000, 2001), but no information about the success of this border control is available.

EFFORT REQUIRED

Any import control programme must be installed as a long-term measure to prevent any un-intentional import of a target species.

RESOURCES REQUIRED

Control programmes to identify the species will probably require training of workers. The identification of plants using identification keys requires excellent species knowledge, particularly in the case of *H. ranunculoides* and its several congeners within the genus *Hydrocotyle* (Hussner and van de Weyer, 2004) which have been found in trade (Hussner *et al.*, 2014).

A DNA barcoding tool has been developed for the genus *Hydrocotyle* and can be used as a valuable tool to improve the accuracy of the determination of whole plants and plant parts (van de Wiel *et al.*, 2009). Once again, in this case, all import control authorities will require experienced workers and appropriate scientific equipment, which can be costly. Integrating a system for the simultaneous control of all invasive aquatic plant species of Union concern will considerably reduce the costs per species.

SIDE EFFECTS

Environmental: Positive
Social: Neutral or mixed
Economic: Negative

Any import control measures will increase the likelihood for the detection of unwanted organisms imported and will thus generally reduce the number of other prohibited species (according to the EU regulation 1143/2014) imported for sale into the EU.

Nevertheless, any control measures will cause additional costs for the plant import industry in general, which might increase the prices of plants in sale, and thus reduce the number of plants sold. In order to reduce these negative effects, the sale of native plants can be supported and sold as alternatives. Similar approaches have been undertaken in for example Belgium, where agreements between representatives from the ornamental sector, the scientific community and public authorities were made in order to decrease the number of invasive plants sold (Halford *et al.*, 2014).

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Any restrictions of imports and additional control efforts cause additional costs, which are not well perceived. However, as indicated by the voluntary agreements between traders and public authorities mentioned above (Halford *et al.*, 2014), awareness about the impact of invasive aquatic weeds among traders is high, and thus the acceptability of import controls will be high.

ADDITIONAL COST INFORMATION

No data on the costs of implementation and running of import controls are available, even from already established border control programmes in for example New Zealand (Champion and Clayton, 2000, 2001). Consequently, the cost-effectiveness of this measure is hard to quantify. Nevertheless, in general, the costs of inaction must be considered much higher than the costs of import control measures, as *H. ranunculoides* is able to grow in a wide range of freshwater habitats throughout the EU (Hussner *et al.*, 2017). In fact, 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).

LEVEL OF CONFIDENCE*

Established but incomplete.

Comprehensive import control must be considered as a valuable tool to stop the unintentional introduction of *H. ranunculoides* and other invasive aquatic plant species (such as *Lagarosiphon major*). Although identification tools for whole plants, as well as for any part of a plant (for example DNA barcoding) exist on a species level for the genus *Hydrocotyle*, no information about the costs and effectiveness of this measure exists.

* See Appendix

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

Public awareness campaigns.

MEASURE DESCRIPTION

Aquatic weeds spread within and between water bodies. For the spread of *H. ranunculoides*, both seeds and vegetative propagules might play a role. Seed production was found within the EU (author's observation) and, even though studies about the viability of the seeds are lacking, it seems likely that the seeds are vital and can act as dispersal units. Fragments of *H. ranunculoides* are highly regenerative, and even small fragments (approx. 1 cm in length with a single node) showed high regeneration capacities (Hussner, 2009). Consequently, the likelihood for spread via fragments and seeds is generally high.

Aquatic plants produce fragments either by allofragmentation (fragmentation caused by disturbances) or auto fragmentation (self-induced fragmentation). The number and size of fragments determine the likelihood for successful spread of the species (Lockwood *et al.*, 2005). The number of fragments produced by a species was found to be species specific (Heidbüchel *et al.*, 2016; Redekop *et al.*, 2016) and, compared to other aquatic weeds, very low for *H. ranunculoides* (Heidbüchel *et al.*, 2016), which reduces the capacity of the species to spread via auto fragments within a water body.

It is reported that invasive aquatic species spread within water bodies and between unconnected water bodies. While spread within a water body is caused by water movement which causes the dispersal of seeds and plant fragments, spread between unconnected water bodies depends on the transport of seeds or plant fragments by a vector. Overland transport of fragments most likely occurs due to the movement of fragments attached to water sport equipment (for example boats and trailers), whereas for seeds waterfowls can act as additional vectors (Garcia-Alvarez *et al.*, 2015).

As a side note, the likelihood for spread of *H. ranunculoides* via water movement within a water body can be reduced by floating barriers, which have been reported as control measures to limit the spread of floating plants (Lancar and Krake, 2002). Additionally, woven plastic cloths of less than 1 mm were installed as control measures to limit the spread via seeds in irrigation channels (Lancar and Krake, 2002).

While the spread of *H. ranunculoides* between water bodies by seeds via waterfowls can hardly be controlled, the spread via fragments attached to water sport equipment can be limited through the implementation of public campaigns that raise awareness on aquatic invasive species, and on the adequate use of biosecurity procedures (usually coupled with the implementation of increased biosecurity measures; see section below). Public campaigns like "Protect your waters"[1], "Stop Aquatic Hitchhikers"[2], "Check, Clean, Dry"[3] or "Be wise"[4] have been used to inform and raise awareness of the public about the spread of invasive species in New Zealand, the USA and the UK.

SCALE OF APPLICATION

Public campaigns can be implemented at a national level, and particularly people with activities closely linked to water bodies (for example outdoor activities like boating, fishing, diving, etc.) should be informed. Information can be brought to the public during local water related events, but school class visits can also be used to inform about invasive aquatic species and their spread (Hippolite and Kurapa, 2018). Information posters/placards installed on-site at infested water bodies and press releases are additional valuable tools to increase awareness about invasive aquatic species.

EFFECTIVENESS OF MEASURE

Effective.

In general, the efficiency of public campaigns is hard to quantify, but it has been reported that public campaigns generally increase public awareness and knowledge about existing biosecurity items and procedures. The percentage of the general public who follows the guidelines for biosecurity procedures increases (by about 9% in general and 14% in high risk users; Burchnall, 2013), and the

1 http://www.env.gov.bc.ca/fw/fish/regulations/docs/1011/fa_AquaticHitchhikers.pdf
2 https://www.fws.gov/fisheries/ans/pdf_files/Stop_Aquatic_Hitchhikers_factsheet.pdf
3 http://www.nonnativespecies.org/checkcleandry/
4 www.nonnativespecies.org/checkcleandry/ and www.nonnativespecies.org/beplantwise/

number of biosecurity hazards decreases by 40%, if people are informed by public campaigns (Anderson *et al.*, 2015). Public campaigns resulted in increased knowledge of invasive species when 75-86% of users have aquatic weeds knowledge, and 74-82% follow the guidelines provided by the “Check, Clean, Dry” campaign when moving their boat between water bodies (Hippolite and Kurapa, 2018). Nevertheless, the success of public campaigns depends on several factors, including for example the frequency at which the public has been informed and how the information was conveyed. A combination of on-site information placards in the field and press releases might result in a high level of success.

EFFORT REQUIRED

For sustainable success, campaigns must be applied in the long-term and must target all kinds of water users to get long-lasting and remarkable effects.

RESOURCES REQUIRED

The costs of public awareness campaigns generally depend on the effort undertaken. Public awareness campaigns were initiated in a number of countries, but data about their costs, resources and staff required are not available.

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Neutral or mixed

Public awareness campaigns generally increase the knowledge and awareness of environmental issues by the public and might help detect additional invasive aquatic species.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

Public awareness campaigns are generally well accepted by stakeholders.

ADDITIONAL COST INFORMATION

No data about the overall costs of public campaigns are available, but they depend on the number of in field information (such as placards) installed and the amount of time spent for informing the public during events and visits of school classes.

The cost-effectiveness of public campaigns is high. Public campaigns are not species specific and will reduce the overall likelihood for the spread of unwanted organisms.

Costs of inaction are hard to quantify, but *H. ranunculoides* has the capacity to grow in and impact a variety of aquatic habitats throughout Europe (Newman and Dawson, 1999; Baas, 2001; Pot, 2002; Hussner and Lösch, 2007; Hussner, 2009). Consequently, the overall costs of inaction will be higher than the costs of the described measures (Hussner *et al.*, 2017).

LEVEL OF CONFIDENCE*

Established but incomplete.

Public campaigns to stop unintentional, human mediated spread of aquatic weeds have been implemented in for example New Zealand or the USA with success, but more data on campaigns effectiveness and costs are needed.

* See Appendix

Improved biosecurity measures at water recreation areas.

MEASURE DESCRIPTION

As mentioned in the section above, the spread of invasive aquatic species between unconnected water bodies depends on the transport of seeds or plant fragments by a vector and is most likely related to overland transport of fragments or seeds attached to water sport equipment (such as boats and trailers).

As preventive biosecurity measures, different strategies can be used, like (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 (Johnstone *et al.*, 1985; Barnes *et al.*, 2013; Anderson *et al.*, 2015; Cuthbert *et al.*, 2018; Hippolite and Kurapa, 2018; Crane *et al.*, 2019).

For example, in lakes in the Bay of Plenty region (New Zealand), weed free haul-out areas were created by installing nets (author's observation), and portable boat wash stations were tested at boat ramps (Hippolite and Kurapa, 2018). Other new technologies (steam exposure, aquatic disinfectants or hot water tanks) have been tested (Anderson *et al.*, 2015; Cuthbert *et al.*, 2018; Coughlan *et al.*, 2018; Crane *et al.*, 2019), but not used as direct control measures in the field yet.

It must be taken into account that all measures dealing with the killing of plants have been successfully tested for vegetative plant fragments, but seeds will be most likely less affected by such measures.

SCALE OF APPLICATION

Control measures to stop overland dispersal of aquatic plants via water sport equipment must be installed at every lake infested with the target species.

EFFECTIVENESS OF MEASURE

Effective.

The determination of the success of biosecurity measures to kill plant fragments to prevent overland dispersal of aquatic weeds is difficult. The success of these measures relies on various parameters and plant attributes, such as the resistance of vegetative plant fragments and seeds to heat

Hydrocotyle ranunculoides *in a pond on Anglesey © Velela. Public domain.*

and desiccation (Barnes *et al.*, 2013; Anderson *et al.*, 2015; Heidbüchel *et al.*, 2019). However, considering the major role of human-mediated overland dispersal on the spread of aquatic species (Johnstone *et al.*, 1985), such measures will have a high impact on halting this type of spread.

EFFORT REQUIRED

The measures that have been tested required only a moderate workload under experimental conditions (Coughlan *et al.*, 2018; Cuthbert *et al.*, 2018; Crane *et al.*, 2019), but these measures have not been tested under field conditions yet.

RESOURCES REQUIRED

Any direct biosecurity control measure requires experienced workers and specific equipment. From the direct control measures mentioned above, only net cages and boat washing stations are currently in use (Hippolite and Kurapa, 2018), while the other techniques (hot steam, aquatic disinfectants) have only been tested in experimental conditions. However, no data about the costs of these measures are available.

SIDE EFFECTS

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

Direct biosecurity control measures can potentially affect the spread of native organisms as well. However, detailed studies dealing with the potential negative impact of these measures on native plants have not been reported yet.

The recreational human use of water bodies will be affected, and these measures will represent extra time and costs for boat owners.

ACCEPTABILITY TO STAKEHOLDERS

The described active control measures (collecting fragments, washing, heating and disinfecting) will cause additional costs and take time, therefore probably facing some opposition by water users. Public awareness campaigns can help to improve the understanding and acceptance of these measures by the general public.

ADDITIONAL COST INFORMATION

The costs of biosecurity control measures depend on the number of activities undertaken, as every measure will require different time and effort on a specific lake site. Direct control measures are not species specific and will reduce the overall likelihood for the spread of unwanted organisms.

Costs of inaction are hard to quantify, but *H. ranunculoides* has the capacity to grow in and impact a variety of aquatic habitats throughout Europe (Newman and Dawson, 1999; Baas, 2001; Pot, 2002; Hussner and Lösch, 2007; Hussner, 2009). Consequently, the overall costs of inaction will be higher than the costs of the described measures (Hussner *et al.*, 2017).

LEVEL OF CONFIDENCE*

Established but incomplete.

The implementation of biosecurity measures to limit the spread of *H. ranunculoides* by seeds and fragments attached to water sport equipment is of high relevance. Boat washing stations, for example, were successfully tested in the Bay of Plenty, New Zealand (Hippolite and Kurapa, 2018), while the use of for example aquatic disinfectants or hot steam exposure were only 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.

Citizen Science.

MEASURE DESCRIPTION

The detection of early infestations of aquatic weeds like *H. ranunculoides* is a key component of successful rapid eradication measures (Genovesi *et al.*, 2010; Hussner *et al.*, 2017). If the target species is found in early infestations, eradication is achievable prior to its establishment, which drastically reduces the costs of the eradication measures (Hussner *et al.*, 2017).

In contrast to submerged aquatic weeds, for which the detection often requires specific equipment (such as diving equipment or sub-cameras), free floating and rooted emerged or floating leaved species like *H. ranunculoides* can be relatively easily found. Even though the identification of plants within the genus *Hydrocotyle* seems relatively difficult and detailed identification keys are required (Hussner and van de Weyer, 2004), citizen scientists can provide valuable support for early detection measures of *H. ranunculoides*. Such citizen science programmes are used to identify early infestations and to monitor the spread of species. The accuracy of the species identification relies on the training and experience of the citizen scientist and the information provided (Delaney *et al.*, 2008; Gallo and Waitt, 2011). Moreover, it seems reasonable that the accuracy of the citizen science data will also depend on the species itself, as the difficulty to identify a certain species will vary between genus and species. For *Hydrocotyle*, due to the high number of species within this genus, the correct identification of *H. ranunculoides* will be more difficult than for species with for example only one species in the genus. Consequently, citizen science programmes require a comprehensive training of the citizen scientists and a scientific or other coordinating body (Gallo and Waitt, 2011; Roy *et al.*, 2012). Additionally, comprehensive determination keys and apps for mobile devices are developed and provided to the public, increasing the ability of citizen scientists to identify species and report GPS-supported data about the exact location of infestations (Adriaens *et al.*, 2015), supporting rapid eradication (Hussner *et al.*, 2017).

In general, citizen science programmes can show a high accuracy (80-95%) of data collected (Delaney *et al.*, 2008), depending on training of citizen scientists and difficulties in the determination of the species.

SCALE OF APPLICATION

Citizen science projects can be implemented at every level (local, regional or national). Nevertheless, to assure the quality of the data, guidance and support by scientists and the responsible authorities are mandatory (Roy *et al.*, 2012).

EFFECTIVENESS OF MEASURE

Effective.

Citizen science projects can be highly effective, depending on the training, knowledge and experience of citizen scientists (Gallo and Waitt, 2011). In Florida, a long-term citizen science project collected data from 1100 lakes and other additional water bodies (Hoyer *et al.*, 2014).

Species identification by citizen scientists can reach accuracies between 80-95% (Delaney *et al.*, 2008), and the collected data can be used by scientists for further planning of management measures. However, in the case of *H. ranunculoides*, species identification can be difficult and thus well-developed determination keys/apps are required as tools for the citizen scientists.

EFFORT REQUIRED

Every surveying project must be implemented in the long-term to achieve long-term documentation about the introduction and spread of aquatic weeds.

RESOURCES REQUIRED

Citizen science projects require comprehensive training and identification keys/apps to achieve a high accuracy of the data (Delaney *et al.*, 2008; Gallo and Waitt, 2011; Hoyer *et al.*, 2014). The projects should be coordinated by scientists, and trained and committed staff are needed to supervise and work along with the citizen scientists (Hoyer *et al.*, 2014). Moreover, qualified workers are required to provide direction and ensure the consistency of the collected data (Hoyer *et al.*, 2014). The annual costs for running a citizen science project in the UK were estimated between 80,000 and 170,000 EUR (Roy *et al.*, 2012 in Newman and Duenas, 2017).

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Neutral or mixed

Citizen science projects allow for the identification of more than one target species at the same time, increasing their cost-effectiveness. Moreover, citizen science projects increase the awareness about current and future environmental problems, such as the impact of invasive species.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

Surveying through citizen science will not cause remarkable impact on the human use of water bodies, consequently having a high stakeholder acceptance.

ADDITIONAL COST INFORMATION

In general, the cost-effectiveness of the described early detection measure will be high, as *H. ranunculoides* is able to grow in a wide range of aquatic habitats within the EU and control of early infestations is generally cheaper than control of large infestations.

LEVEL OF CONFIDENCE*

Established but incomplete.

Citizen science is documented as a valuable tool for the early detection of invasive species. However, no specific examples of this early detection measure is available for *H. ranunculoides*.

Surveying through remote sensing.

MEASURE DESCRIPTION

Early detection of floating (such as *Eichhornia crassipes*), rooted floating or emerged leaved (such as *Ludwigia* spp. and *Hydrocotyle* spp.) and submerged aquatic plant species can be achieved through various methods of remote sensing (Hestir *et al.*, 2008; Khanna *et al.*, 2011, 2018; Brundu *et al.*, 2012). Orthophotos (aerial photos) and satellite images (for example Google Earth ™) can be used to identify early infestations (Brundu *et al.*, 2012) and to document the spread of a species (Wersal and Madsen, unknown; Khanna *et al.*, 2018). An integrated approach using different types of hyperspectral methods with data from hyperspectral imagery with 125 bands (400-2400 nm) and several indices in a decision tree format mapped a close relative of *H. ranunculoides*, *Hydrocotyle umbellata*, with an accuracy of 87% (Khanna *et al.*, 2011). Short-wave infrared, Red Edge Index, near-infrared reflectance, LSU fractions and SAM rule values provided the most important input to create the decision tree (Khanna *et al.*, 2011). However, no information is available about the accuracy of the separation between species within the genus *Hydrocotyle*.

The identification of areas and habitats which are highly likely to be infested by *H. ranunculoides* would help to increase the efficiency of remote sensing for the identification of infestations. Information on species biology (such as Pot, 2002; Hussner and Lösch, 2007; Hussner, 2009; Hussner and Meyer, 2009; Gantes *et al.*, 2001) and habitat characteristics can be used for the identification of such priority areas.

SCALE OF APPLICATION

Remote sensing can be used for small and large water bodies, like river systems and river deltas (Khanna *et al.*, 2011; Ta *et al.*, 2017).

EFFECTIVENESS OF MEASURE

Effective.

Remote sensing is documented as a valuable tool for the identification of aquatic weeds, and high detection accuracies are reported (Khanna *et al.*, 2011; Ta *et al.*, 2017). The accuracy of the data obtained differs between species, with for example 88% accuracy reported for *Eichhornia crassipes*, 87% for *Hydrocotyle umbellata* and 71% for *Ludwigia* spp. in a study within the Sacramento-San Joaquin River Delta in California, USA (Khanna *et al.*, 2011).

EFFORT REQUIRED

Every surveying project must be implemented in the long-term to achieve long-term documentation about the introduction and spread of aquatic weeds.

RESOURCES REQUIRED

Remote sensing requires repeated flight lines for data acquisition, a comprehensive data analysis by trained workers and adequate hardware and software (Khanna *et al.*, 2011).

* See Appendix

SIDE EFFECTS

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

Remote sensing allows for the identification of more than one target species at the same time, which can assist in the early detection of other aquatic invasive species.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

Remote sensing will not cause any impact on the human use of water bodies, consequently having a high stakeholder acceptance.

ADDITIONAL COST INFORMATION

In general, the cost-effectiveness of this measure will be high, as it allows for the detection of more than one target species at the same time and as control of early infestations is generally cheaper than control of large infestations of *H. ranunculoides*.

LEVEL OF CONFIDENCE*

Established but incomplete.

Remote sensing is documented as a valuable tool for the early detection of invasive species. However, no specific examples of this early detection measure is available for *H. ranunculoides*.

* See Appendix

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

Hand weeding.

MEASURE DESCRIPTION

For the rapid eradication of early infestations of *H. ranunculoides*, hand weeding is reported as a successful control measure. Hand weeding is one of the most selective removal methods and can be used for small infestations, even within native plant communities which must be protected (de Winton *et al.*, 2013; Hussner *et al.*, 2016, 2017).

During removal, all plant parts of *H. ranunculoides*, including their roots, should be harvested to avoid any regrowth of the plants, which is documented as highly regenerative from fragments (Hussner, 2009). Consequently, even though hand weeding produces less fragments than mechanical control measures, the use of nets is required to reduce the risk of dispersal of produced fragments. In the case of *H. ranunculoides*, removal by hand is, at most sites, possible by wading, as the species usually grows in shallow water or waterlogged sediments, for example in ditches (Hussner and Meyer, 2009; Newman and Duenas, 2010).

Hand weeding of *H. ranunculoides* should be carried out prior to the ripening of seeds, even though no reports of seed germination in the field are available.

SCALE OF APPLICATION

Hand weeding of *H. ranunculoides* is particularly relevant for small and early infestations, especially during the first year of invasion and particularly in spring; management becomes more difficult if it starts two or more years after the introduction of the species (Pot, 2002; Plant Protection Service and Centre of Ecology and Hydrology, 2011), as it is time consuming.

It is considered an appropriate tool for low density stands and small patches (< $1m^2$; Bellaud, 2009). However, hand weeding can be used at any size of stands of *H. ranunculoides*, depending on the resources and time available (GB NNSS, 2018). In combination with manual raking and Hydro-Venturi, approx. $45m^3$ of a species with similar rooted-floating and emerged leaved growth form (*Myriophyllum aquaticum*) was removed by hand from a small pond system (approx. 1 ha; author's observation).

EFFECTIVENESS OF MEASURE

Effective.

Hand weeding is considered a successful eradication measure for small infestations of *H. ranunculoides* in spring (Plant Protection Service and Centre of Ecology and Hydrology, 2011). Repeated hand weeding seems necessary in most sites, as the plant is highly regenerative, and it seems hardly possible to eradicate all plant parts within the first-hand weeding session.

EFFORT REQUIRED

Hand weeding is time consuming, and it must be repeated, unless no regrowth from remaining fragments occurs. This might vary between sites, depending on for example sediment, habitat structure and experience of the workers.

RESOURCES REQUIRED

Hand weeding is time consuming and requires a high human work load, thus having high costs, although no specific equipment is needed. Volunteers can be used for undertaking hand weeding measures, in order to reduce costs (GB NNSS, 2018). However, workers must be trained in the identification of *H. ranunculoides*.

De Winton *et al.*, (2013) estimated that the costs of two hand weeding treatments to achieve eradication of aquatic vegetation would be 20,000 NZD per ha (about 12,000 EUR per ha), but no specific data about the costs of hand weeding *H. ranunculoides* are available.

SIDE EFFECTS

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

Hand weeding is a selective tool to eradicate small infestations of *H. ranunculoides*, and the impact on native plants and animals will be very low.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

Hand weeding hardly causes any impact on the environment and on economic activities, and will thus have a high acceptance by stakeholders.

ADDITIONAL COST INFORMATION

The cost-effectiveness of hand weeding is considered low, as it is very time consuming.

The cost of inaction must be generally considered high, as *H. ranunculoides* can grow in a wide range of aquatic habitats within the EU and the costs for the eradication of early infestations are much lower than the costs of later management of the species.

LEVEL OF CONFIDENCE*

Established but incomplete.

The efficiency of hand weeding to control *H. ranunculoides* in small scales is reported from several studies (such as Plant Protection Service and Centre for Ecology and Hydrology, 2011; GB NNSS, 2018), but a comprehensive synthesis is lacking.

* See Appendix

Mechanical control.

MEASURE DESCRIPTION

In general, integrated management approaches combining two or more management methods are considered the most successful in achieving total eradication of emerged growing aquatic weeds like *H. ranunculoides* (Delbart *et al.*, 2013). Detailed management plans based on the species biology and habitat characteristics (Hussner *et al.*, 2016), and an adapted management approach (learning from experience; GHD, 2015) help to increase the success of integrated management approaches.

Mechanical control using excavators or weed boats is a widely used tool to manage large infestations of *H. ranunculoides* (Pot, 2002; Newman and Duenas, 2010; Plant Protection Service and Centre for Ecology and Hydrology, 2011). Excavators are usually equipped with cutter buckets and weed boats use rakes to remove the plants, which usually produces a large number of plant fragments during the management treatments (Pot, 2002; Newman and Duenas, 2010); thus, the use of fences or nets are recommended to avoid dispersal of these fragments (Newman and Duenas, 2010; Plant Protection Service and Centre for Ecology and Hydrology, 2011; GB NNSS, 2018). It is noted that the success of mechanical control actions may vary between the time of the year, and mechanical management in autumn is reported to cause a higher level of control than during summer, as regrowth is less vigorous in autumn (Plant Protection Service *et al.*, 2011).

It is reported that mechanical control can only reduce the impact of the species for a certain period of time, until regrowth takes place, and thus follow-up intensive hand weeding is recommended (Newman and Duenas, 2010; Plant Protection Service and Centre for Ecology and Hydrology, 2011; Ackermann *et al.*, unknown).

SCALE OF APPLICATION

Mechanical control using excavators and weed boats is used in the large scale. In the Netherlands, weed boats were used to manage 20 km of a brook, which was almost completely covered by *H. ranunculoides* (Pot, 2002). However, as not all fragments were removed and no fences or nets were installed downstream the control sites, the species was even able to spread into new sites.

EFFECTIVENESS OF MEASURE

Effective.

Mechanical control is effective, if combined with other control techniques, like hand weeding. Mechanical control measures alone can be used for the short-term reduction of *H. ranunculoides* (Plant Protection Service *et al.*, 2011), but measures to prevent the spread of produced fragments are mandatory. Floating barriers can be installed to limit the spread of fragments, particularly fragments produced during the management activities (Lancar and Krake, 2002).

For example, in Australia, attempts to control *H. ranunculoides* with a cutting boat in the Canning River failed to cause a long-term reduction of the species, and actions were stopped by the time the growth rates of the plants exceeded the removal rate (Ruiz-Avila and Klemm, 1996). In this case, mechanical control was not followed by hand weeding.

In the upper reaches of the Rivers Chelmer and Cam, UK, mechanical plant removal combined with hand weeding of the remaining plants resulted in the eradication of *H. ranunculoides* in the controlled sites (Plant Protection Service *et al.*, 2011).

Mechanical harvest with a digger, followed by intense hand weeding (once per month during the growing season), prevented the recolonization of *H. ranunculoides* in the Gillingham Marshes, UK (Kelly, 2006).

EFFORT REQUIRED

The effort required depends on the management strategy adopted. For a short-term reduction in the biomass and coverage of *H. ranunculoides*, mechanical control must be carried out at least once per year (Plant Protection Service *et al.*, 2011). For long term eradication, a single treatment with mechanical control measures followed by ongoing hand weeding is required (Kelly, 2006).

RESOURCES REQUIRED

For excavation and cutting, diggers, boats and harvesters are required, as well as skilled operators. The removal of *H. ranunculoides* by cutting with mowing boats, and subsequent collection and removal of the floating plant material with a dragline, cost over 200,000 EUR for a 20 km brook in the Netherlands (Pot, 2002). However, the costs of hand weeding, which is required after mechanical control to achieve a sustainable control or eradication are high, but no data on these are available. Nevertheless, the engagement of volunteers can help reduce the costs of the time-consuming hand weeding (GB NNSS, 2018).

SIDE EFFECTS

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

Mechanical control measures like mowing and cutting are not species specific, and thus negative effects on native plants are highly likely (Hussner *et al.*, 2017). The turbidity of the water column might increase, for example, due to excavation of plants and sediment. Fish and macroinvertebrates located within the plant mats might be entrapped during the control measures and be killed within the harvested biomass (de Winton and Clayton, 2016). Like for all aquatic plants, harvesting large amounts of biomass reduces the nutrient pool of the aquatic system.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

Even though the mechanical control of H. raunculoides by using excavators and weed boats causes serious impacts on the whole ecosystem (including native plants and animals), stakeholder perception of this measure will be positive, as these control measures are usually carried out when large weed beds prohibit the recreational use of water bodies.

ADDITIONAL COST INFORMATION

The cost-effectiveness of mechanical control options depends on the management strategy used and will be higher for integrated approaches combining mechanical control with subsequent hand weeding, than for the solely use of mechanical control. Nevertheless, the cost of inaction will be high, as *H. ranunculoides* is able to grow in and impact a wide range of aquatic habitats within the EU.

LEVEL OF CONFIDENCE*

Established but incomplete.

There are several studies reporting the mechanical control of *H. ranunculoides* by digging and cutting, but a comprehensive synthesis is still lacking.

* See Appendix

Biological control.

MEASURE DESCRIPTION

Biological control agents are used to reduce the growth or reproductive capacity of a target species (Cuda *et al.*, 2008). The term biological control covers 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 (Hussner *et al.*, 2017).

For classical biological control, a comprehensive research for potential control agents and subsequent collection of the species within the native range of the target species is required (van Driesche *et al.*, 2010). Subsequently, host specificity tests are carried out prior to the release of the control agent in the invasive range of the target species. There are some successful examples of classical biological control of floating and emergent aquatic plants (Hussner *et al.*, 2017), but for *H. ranunculoides* no control agents have been released so far, even though several potential agents have been identified (Cordo *et al.*, 1982; Cabrera Walsh *et al.*, 2013; Cabrera Walsh and Maestro, 2017). At the moment, the weevil *Listronatus elongatus* is considered as the species with the highest potential as a future classical biological control agent for *H. ranunculoides* (Cordo *et al.*, 1982; Cabrera Walsh and Meastro, 2017).

The inundative control of aquatic weeds using mycoherbicides is a new technique, which was tested for the control of submerged aquatic weeds (Shearer, 1994, 1996; Hofstra *et al.*, 2004; Hussner *et al.*, 2017). Harms *et al.*, (2012) found eight fungal species during a study on natural enemies of *H. ranunculoides* in southern USA, but the authors considered none of these as host specific to *H. ranunculoides*.

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 the release of any alien species as a biological control agent, an appropriate risk assessment should be made.

SCALE OF APPLICATION

No biological control agents have been released so far for the control of *H. ranunculoides*.

The floating marsh pennywort is widespread in both tropical and temperate parts of the world. © Dick Culbert. CC BY 2.0.

EFFECTIVENESS OF MEASURE

Unknown.

No generalist, classical or inundative biological control agents have been released into the field to control *H. ranunculoides* yet.

EFFORT REQUIRED

In general, the implementation of a biological control programme requires comprehensive research about potential control agents and subsequently intensive host specificity testing, which would take about 3 years prior to the potential release as a control agent (Newman and Duenas, 2017).

RESOURCES REQUIRED

The search for and the host specificity testing of inundative and classical biological control agents for *H. ranunculoides* is costly and requires experienced scientists. Both methods require comprehensive testing prior to use, inflicting costs of about 300,000 EUR (Newman and Duenas, 2017).

SIDE EFFECTS

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

Classical biological control should not have meaningful side effects, as the control agents selected will be species specific. However, if generalist herbivores, which have a broad host range, are used, some non-target species might be affected. Negative effects of biological control programmes on native plants and animals can be minimised if the biological control programme is well-managed (Newman and Duenas, 2017).

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

Although no biological control agents have been released for the control of *H. ranunculoides*, in general the acceptability of this measure will be high, especially if side effects can be ruled out.

ADDITIONAL COST INFORMATION

The cost-effectiveness of biological control of aquatic plants ranges from 2.5:1 to 15:1, and even up to 4000:1 (McConnachie *et al.*, 2003; Culliney, 2005 in Newman and Duenas, 2017).

As for all control strategies, the costs of inaction will be high, as *H. ranunculoides* is able to grow in and impact most water bodies within the EU member countries.

LEVEL OF CONFIDENCE*

Unknown.

Even though potential classical biological control agents are identified (Cabrera Walsh *et al.*, 2013; Cabrera Walsh and Maestro, 2017), no biological control agents have been released for the control of *H. ranunculoides* yet.

* See Appendix

Herbicides.

MEASURE DESCRIPTION

Herbicides, in general terms, are used to control aquatic plants in almost all types of aquatic habitats (de Winton *et al.*, 2013; Gettys *et al.*, 2014; Hussner *et al.*, 2017). Herbicide treatment can cause a reduction in the biomass of aquatic weeds and may cause the eradication of the target species (de Winton *et al.*, 2013; Champion and Wells, 2014; Hussner *et al.*, 2017). Most herbicides are not species specific, but the used concentration, exposure time and application method can cause a level of selectivity (Getsinger *et al.*, 1997, 2008, 2014; Netherland, 2014).

For *H. ranunculoides*, glyphosate and 2,4-D were used during chemical control experiments in the UK (Newman and Dawson, 1999), and glyphosate is the only herbicide authorised for regular use on emergent aquatic weeds like *H. ranunculoides* in Europe (Hussner *et al.*, 2017). The application of glyphosate might follow a mechanical removal of the species, for better access of herbicide application (Ruiz-Avila and Klemm, 1996; Newman and Duenas, 2010).

As regrowth might occur within 6-8 weeks after the herbicide treatment from such as dormant nodes of *H. ranunculoides*, continuous monitoring and follow-up treatments are required (Plant Protection Service and Centre for Ecology and Hydrology, 2011).

For the use of herbicides, EU/national/local legislation on the use of plant protection products and biocides needs to be respected.

SCALE OF APPLICATION

Herbicides are widely used for the large-scale control of aquatic weeds (Clayton, 1996). For example, herbicides have been used to control large infestations (> 100 ha) of submerged weeds (Clayton, 1996). Glyphosate is used for the control of both large and small (approximately 1 m^2) infestations of *H. ranunculoides* (Plant Protection Service and Centre for Ecology and Hydrology, 2011).

EFFECTIVENESS OF MEASURE

Effective.

While glyphosate was considered ineffective after the first control attempts in the UK (Newman and Dawson, 1998), two adjuvants which improve its efficiency are available (Plant Protection Service and Centre for Ecology and Hydrology, 2011; GB NNSS, 2018). In the early season (until mid-August), TopFilm (which sticks to the leaves, absorbs the herbicide and slowly releases it) showed good levels of control, while after August, Codacide Oil, which dissolves the waxy leaf cuticle and causes rapid absorption of the herbicide by the plants, is used as adjuvant (Plant Protection Service and Centre for Ecology and Hydrology, 2011).

Herbicide treatment alone does not cause the eradication of *H. ranunculoides* (Newman and Dawson, 2010) and therefore follow-up treatments using different measures (for example hand weeding) are necessary for any eradication chemical control programme of this species (Newman and Duenas, 2010; Plant Protection Service *et al.*, 2011).

EFFORT REQUIRED

The frequency and amount of herbicides needed for successful control depends on the herbicide used, its formula and the seasonal time of application (Hofstra and Clayton, 2001; Newman and Duenas, 2010; Hussner *et al.*, 2017). Any herbicide control of *H. ranunculoides* requires a follow-up herbicide, mechanical or hand weeding treatment, 2-4 weeks after the first herbicide treatment (Newman and Duenas, 2010; Plant Protection Service *et al.*, 2011).

RESOURCES REQUIRED

The application of herbicides for the control of *H. ranunculoides* requires boats and access to the water bodies, as well as skilled operators, but there are no data available about the costs of herbicide control of *H. ranunculoides*.

For submerged weeds, the full costs (herbicide, operator and equipment) of herbicide treatment with gel-formulated diquat was less than 350 EUR (500 NZD) per ha, when treating >100 ha in New Zealand's Lake Rotorua (Clayton, 1996).

It must be taken into consideration that herbicides might negatively affect native plant communities, and their restoration will involve additional costs.

SIDE EFFECTS

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

Herbicides are not species specific and the use of herbicides will affect both native plants and animals. Nevertheless, adjustments in the used concentration, exposure time and application method can cause a level of selectivity (Getsinger *et al.*, 1997, 2008, 2014; Netherland, 2014). In general, the effects of an herbicide on other submerged aquatic plants than the target weeds depend on the sensitivity of the species to the used herbicide, with varying effects on a species level. After the herbicide treatment, native plants

Hydrocotyle ranunculoides © *Tim Adriaens, INBO.*

can recolonise sites formerly covered with aquatic weeds, as it has occurred for native Charophytes in Lake Rotorua, which were resistant to the used herbicide (Clayton, 1996).

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 impacts on other submerged plants and fauna causes less acceptability. In Australia, there were strong community concerns about the use of glyphosate to control large infestations of *H. ranunculoides*, and thus an extensive process of public information and education through the media became essential (Ruiz-Avila and Klemm, 1996).

ADDITIONAL COST INFORMATION

Herbicide use for the control of aquatic weeds can provide a good cost-effectiveness, if no further control measures are required.

The cost of inaction will be high, as *H. ranunculoides* is able to grow in and impact a wide range of aquatic habitats throughout the EU.

LEVEL OF CONFIDENCE*

Established but incomplete.

Glyphosate has been used in several sites to control *H. ranunculoides*, but no syntheses about the results is available.

* See Appendix

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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

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