Pistia stratiotes is an aquatic plant, stoloniferous, floating on lakes, streams, and stagnant water ponds and in lime-rich water.
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The management of water lettuce (*Pistia stratiotes*)

Measures and associated costs

Scientific name(s)	*Pistia stratiotes* L.
Common names (in English)	Water lettuce
Author(s)	Andreas Hussner (Heinrich Heine University, Germany)
Reviewer(s)	Martin Hill (Rhodes University, South Africa)
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Summary of the measures, emphasizing the most cost-effective options.

Pistia stratiotes L. is a free floating aquatic plant species. While the native range of the species is uncertain, either South America or pantropical (Renner and Zhang, 2004; Neuenschwander *et al.*, 2009; Brundu *et al.*, 2012), the species has been introduced into Europe and subsequently spread into 14 European countries (EPPO, 2016). Climate modelling demonstrated the potential future distribution of *P. stratiotes* in southern Europe, where the species has already been reported as invasive (Brundu, 2012; EPPO, 2016) and under control through manual removal (Brundu *et al.*, 2012; EPPO, 2016). Additionally, *P. stratiotes* has established in naturally thermally heated waters in Germany, Russia and Slovenia (Sajna *et al.*, 2007; Hussner *et al.*, 2014a). The floating plants are sensitive to frost, and emerged floating leaves die when exposed to freezing air temperatures, but the small flat winter forms can persist air frost however they will die when enclosed in ice (Hussner *et al.*, 2014a). Viable seed production has been documented and the seeds are viable even after exposure to freezing temperatures (Hussner *et al.*, 2014a). *P. stratiotes* spreads easily via daughter plants with the water flow (Heidbüchel *et al.*, 2016) and dispersal by seeds via waterbirds seems likely (Green, 2016).

P. stratiotes forms dense monospecific mats, which block sunlight and prevent wind-induced mixing of the water column (Neuenschwander *et al.*, 2009; EPPO, 2016). Reduced light availabilities reduced growth of submerged plants (Hussner, 2014) and anoxic conditions with serious effects for invertebrates and fish have been documented (Dray and Center, 2002).

P. stratiotes is frequently imported and traded within shops in Europe (Brunel, 2009; Hussner *et al.*, 2014b) and a trading ban would limit the number of intended and unintended introductions.

The eradication of *P. stratiotes* can be achieved with hand weeding at early infestations, for larger infestations mechanical, biological and chemical options are available to control *P. stratiotes* (Hussner *et al.*, 2017). If a persistent seed bank occurs, the eradication measures require follow-up treatments for a sustainable control of *P. stratiotes*.

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 *P. stratiotes*.

MEASURE DESCRIPTION

The ornamental trade is the major pathway for the introduction of invasive alien aquatic plants (IAAPs) into continents and countries (Kay and Hoyle, 2001; Maki and Galatowitch, 2004; Cohen *et al.*, 2007; Martin and Coetzee, 2011). Prevention of further introductions of a species is cheaper and easier to achieve than the management of invasive alien aquatic plant species. Trading bans and codes of conduct are valuable tools to stop the future introduction of invasive alien aquatic plant species (Verbrugge *et al.*, 2014; Hussner *et al.*, 2017). *P. stratiotes* is frequently imported (Brunel, 2009) and sold in shops (Hussner *et al.*, 2014b) in European countries, and every single plant poses a potential risk for secondary intended or unintended releases into freshwater habitats from aquarium and garden pond cultures of *P. stratiotes*. However, accidental escapes from cultivated *P. stratiotes* populations (for waste water treatments and experiments) may occur, and thus measures to prevent this unintended spread must be taken (Brundu *et al.*, 2012).

EFFECTIVENESS OF MEASURE

Pistia stratiotes is banned from sale in New Zealand (Champion *et al.*, 2014), South Africa (www.environment.gov.za), and Florida and California (USDA, 2015). Within Europe, the species is prohibited in Portugal (http://www.silvaplus.com/fotos/editor2/LegislacaoPT/Floresta/dec_lei_565_99.pdf) and Spain (http://www.boe.es/boe/dias/2013/08/03/pdfs/BOE-A-2013-8565.pdf). In the Netherlands, additional information about the invasion risk should be provided on the plant labels as part of a code of conduct (Verbugge *et al.*, 2014). In Belgium, *P. stratiotes* was included within an awareness campaign, where native plants were recommended as alternatives for invasive plants (Halford *et al.*, 2014).

The identification of *P. stratiotes* is, in comparison to most submerged invasive alien aquatic plants, relatively easy, but still species identification knowledge of the responsible authorities controlling the import of plants is required (Hussner *et al.*, 2017). This will increase the success of trading bans and codes of conduct, but the success is still hard to quantify and depends on various parameters, e.g. on correct labelling of plant material and contamination by seeds (Hussner *et al.*, 2014; 2017).

EFFORT REQUIRED

Prevention measures such as trading bans and codes of conduct must be applied in the long-term to achieve a sustainable prohibition of import of the target species. Species knowledge by responsible authorities, plant labelling and the current distribution of the target species within the region determine the success of the prevention measures. Illegitimate names, spelling mistakes and mislabelling make it difficult to identify the target species (Brunel, 2009; Hussner *et al.*, 2014b).

RESOURCES REQUIRED

The implementation of trading bans require a good species knowledge and identification skills on the part of the responsible authorities. DNA barcoding tools, which were developed to simplify species identification in genus containing several native and/or alien species (e.g. for *Hydrocotyle*; van de Wiel *et al.*, 2009), have not been developed for *P. stratiotes* yet but seems to be not necessary considering the relatively ease of identification, and keys available. In contrast, the detection of viable seeds of *P. stratiotes* is far more complex.

Even though there is no information available about the costs and the equipment required to implement trading bans, it is widely accepted that prevention is cheaper than management of a given species (Hussner *et al.*, 2017).

SIDE EFFECTS

The implementation of a trading ban would generally increase the control measures in place to hinder the introduction of IAAPs. Thus it seems highly likely, that the control measures will lead to the identification of other invasive alien aquatic plant species in trade, especially of other species with the same free floating growth form, such as *Eichhornia crassipes* and *Salvinia molesta*.

ACCEPTABILITY TO STAKEHOLDERS

There will be some direct impact on the economy, as *P. stratiotes* is frequently traded (Brunel, 2009; Hussner *et al.*, 2014b). Additional costs may occur for the required improved labelling of plants in the trade.

ADDITIONAL COST INFORMATION

No data on the costs of the implementation and action of trading bans and codes of conducts are available. *P. stratiotes* is frequently imported, and Brunel (2009) reported > 3,600 plants imported into the EU at selected international airports. Additionally, further production of *P. stratiotes* within the EU will occur, as in commercial online shops *P. stratiotes* is frequently offered for sale (for example in about 50 % of online shops included in a German study; Hussner *et al.*, 2014b). The prices for *P. stratiotes* plants depend on the plant size and are between 1–5 Euros per plant. Moreover, even established populations within the EU can act as sources for plants for online trading like in the case of the established population of *P. stratiotes* of the River Erft (Germany). The number of private sellers offering *P. stratiotes* for sale is much higher in cities along the river than for other regions within Germany, indicating that floating *P. stratiotes* plants, which are easy to sample, are frequently collected from the River Erft for ornamental purposes (Hussner, pers. obs.).

Summarizing, the economic loss to traders can be considered as significant . Even though the trading ban will lead to ongoing costs, it is a widely accepted fact, that trading bans and codes of conduct provide a high level of efficiency in preventing IAS introductions at a relatively low cost in comparison to the management costs to control of *P. stratiotes* infestations. In Florida, the control of floating *P. stratiotes* on public waterways costs > 1 Million USD per year (Center, 1994). In the case of *P. stratiotes*, the cost of inaction must be considered as high , as the species is still limited within Europe, but once introduced it spreads rapidly via daughter plants and viable seeds (Hussner *et al.*, 2014a; Sajna *et al.*, 2007).

LEVEL OF CONFIDENCE[1]

Moderate.

Pistia stratiotes is banned from sale in some European countries. Its currently limited distribution will increase the success of trading bans on the future introduction and spread of the species.

1 See Appendix

Public awareness raising campaigns, supported by physical barriers, to reduce unintentional movement of seeds of the species.

MEASURE DESCRIPTION

In general, the spread of IAAPs into new water bodies is largely based on the human-mediated dispersal of plant fragments via water sport equipment (Johnstone *et al.*, 1985; Johnson *et al.*, 2001), but in the case of *P. stratiotes* also a spread by seeds via water sport equipment and waterbirds seems likely (Hussner *et al.*, 2014a; Garcia-Alvarez *et al.*, 2015; EPPO, 2016). In addition, *P. stratiotes* produces high numbers of viable seeds, and the contamination of sediments by seeds must be considered as an additional pathway of introduction and spread (when seeds contaminate the sediment attached to plants which were introduced, and when contaminated sediment is transported during e.g. lake / pond cleaning activities).

The spread within river and lake systems is largely based on the movement of plants by the water flow (Heidbüchel *et al.*, 2016). *P. stratiotes* produces daughter plants which were first connected to the mother plants via stolons (Neuenschwander *et al.*, 2009), but get disconnected from the mother plants and subsequently start spreading into new areas. The number of drifting *P. stratiotes* plants was reported as high in the River Erft (Germany), where *P. stratiotes* became established (Hussner *et al.*, 2014a; Heidbüchel *et al.*, 2016), and a high number of plants were spreading with the water flow into connected rivers (i.e. River Rhine; Heidbüchel *et al.*, 2016). The transport of seeds via the water flow seems highly likely, but has not yet been studied.

In general, the number of plants and seeds produced and dispersed, determine the spread potential of the species (Lockwood *et al.*, 2005). Thus, any measures to limit or stop the transport or movement of such propagules, especially into freshwater systems that are not hydrologically connected, will reduce the spread of *P. stratiotes*.

The spread of floating plants via water flow can be limited by using floating barriers (Lancar and Krake, 2002), which do not hinder the water flow but restrain the drift of floating plants. For seeds, screens made out of woven plastic cloth of less than 1mm were used in irrigation channels (Lancar and Krake, 2002).

The overland dispersal of seeds and plants via watersport equipment, or movement of contaminated sediment, can be reduced by informing the public using public campaigns like the "Stop Aquatic Hitchhikers" campaign, which were initiated in the US (https://www.fws.gov/fisheries/ans/pdf_files/Stop_Aquatic_Hitchhikers_factsheet.pdf), Canada or New Zealand (http://www.env.gov.bc.ca/fw/fish/regulations/docs/1011/fa_AquaticHitchhikers.pdf; https://www.fws.gov/fisheries/ans/pdf_files/Stop_Aquatic_Hitchhikers_factsheet.pdf; authors observations), and the UKs "Check Clean Dry" and "Be Plant Wise" campaigns (www.nonnativespecies.org/checkcleandry/ and www.nonnativespecies.org/beplantwise/).

The transport of plants and seeds via water sport equipment can be reduced by (i) creating weed free haul-out areas for boats; (ii) manually collecting all visible plants and seeds from water sport equipment (particularly boats and trailers), (iii) drying plants attached to the boat by storing the boat on dry land for a certain amount of time, and (iv) placing the boat into a heated water system that kills plants (Johnstone *et al.*, 1985; Barnes *et al.*, 2013; Anderson *et al.*, 2015). However, while the killing of *P. stratiotes* plants is possible by drying and heating, seeds are more resistant and thus such measures will most likely not have any effect on seed viability.

The potential spread of *P. stratiotes* by seeds via water birds is hard to stop. The management of existing *P. stratiotes* populations should be carried out in early summer to prevent the ripening of the seeds, which will limit the likelihood of spread by seeds via water birds (and water movement).

EFFECTIVENESS OF MEASURE

Public campaigns (e.g. "Stop Aquatic Hitchhikers" and "Clean, Drain, Dry") have been initiated in several countries, but the efficiency of measures taken against human-mediated overland dispersal is difficult to quantify. According to Burchnall (2013) in the Broads, UK, the Check Clean Dry (CCD) campaign led to a 9% increase in the numbers of general public following the recommended biosecurity procedures, and 14% increase in high risk user compliance. In addition, a study on anglers and canoeists in the UK found that those who had heard of the CCD campaign exhibited biosecurity hazard scores that were 40% lower than those who had not (Anderson *et al.*, 2014).

Considering the strong evidence for the importance of human-mediated spread of plants and seeds via water sports equipment (Johnstone *et al.* 1985), measures to stop this vector of unintended spread is considered to have a high impact. However, success depends on various parameters, e.g. the resistance of plants and seeds to desiccation and heating (Barnes *et al.*, 2013; Anderson *et al.*, 2015).

Floating barriers and screens to prevent the spread of *P. stratiotes* plants and seeds via water movement might be an efficient way of limiting the dispersal of *P. stratiotes* within water systems, but data on the efficiency are lacking (Lancar and Krake, 2002).

EFFORT REQUIRED

Measures to stop the dispersal of IAAPs must be applied over the long-term to guarantee significant and sustainable success. These measures require a comprehensive public awareness campaign and the installation of infrastructure, such as hot water ponds to kill plants (Anderson *et al.*, 2015) or floating barriers and screens, to prevent the dispersal via water movement (Lancar and Krake, 2002). In New Zealand, nets were installed to create weed free haul-out areas in lakes infested with weeds, reducing the likelihood of plants becoming attached to boats and trailers (author's observations).

RESOURCES REQUIRED

The costs of generating a public awareness campaign are relatively low compared to the costs of managing established IAAPs, the costs of running the UK Check Clean Dry campaign is currently around £50,000/year (Booy, O. GB Non-native Species Secretariat, pers. comm.). The installation of net cages in lakes to create weed free areas requires scuba diving activity. The installation of floating barriers and screens requires experienced workers. Any installation of net cages and floating barriers also requires ongoing maintenance, and collected plants and seeds must be removed and disposed of in an appropriate manner.

SIDE EFFECTS

The described measures provide a barrier to the dispersal of unwanted organisms in general, and not purely a single species. This could also have a negative impact on the dispersal of native organisms, but such negative impacts on native plants have not yet been reported.

ACCEPTABILITY TO STAKEHOLDERS

The suggested measures have an impact on recreational water sport activities, but this impact is low in comparison to the high impact of the damage caused by *P. stratiotes*. Consequently, the measures might have a high public perception, even though this has not been analysed. The measures to kill plant and seeds attached to boats and trailers (heating; clean, drain, dry) also impact on animals attached to the boat (e.g. *Dreissena* species, zebra and quagga mussel), and thus also help to control the spread of alien fauna (Johnson *et al.*, 2001).

ADDITIONAL COST INFORMATION

No data on the costs of the public awareness campaigns and in field measures are available. In comparison to management costs, the costs of mounting a public awareness campaign must be considered to be low, resulting in a good level of cost-effectiveness. Consequently, the cost of inaction is much greater than the cost of implementing prevention methods (Hussner *et al.*, 2017). However, due to the limited distribution of *P. stratiotes* in Europe, the cost of implementing these prevention methods at such a limited scale (such as the installation of net cages and floating barriers) are low.

The costs of inaction are difficult to determine, but *P. stratiotes* causes significant impact.

LEVEL OF CONFIDENCE[1]

Moderate.

Public awareness campaigns to hinder the human mediated spread of invasive aquatic plants have been implemented in New Zealand or the US with good success (Hussner *et al.*, 2017). Similar campaigns should be implemented in the EU as a tool to stop the spread of species. For *P. stratiotes* the prevention of spread is important, as the species has still a limited distribution in Europe and thus the likelihood of stopping the spread is high.

1 See Appendix

Measures for early detection of the species and to run an effective surveillance system for an early detection of a new occurrence.

Remote sensing.

MEASURE DESCRIPTION

The early detection of invasive alien aquatic plant species is a key factor in the successful eradication. Thus programmes centred on early detection and rapid eradication are crucial for effective management resulting in successful eradication (Genovesi *et al.*, 2010; Hussner *et al.*, 2017). Early detection and rapid eradication is a proactive approach, focussed on the successful management of alien species prior to them becoming damaging. After the early detection of an IAAP like *P. stratiotes*, well-coordinated rapid management measurements are required, which must take into account the IAAP's biology (Hussner *et al.* 2014a) and habitat requirements to achieve the eradication of the target species (Hussner *et al.*, 2016; Hussner *et al.*, 2017).

Early detection of floating plants like *P. stratiotes* can be achieved through various methods of remote sensing. Brundu *et al.* (2012) used orthophotos (aerial photos) and satellite images (Google Earth™) to identify early infestations, and historical presence, of *P. stratiotes* in Southern Europe. Wersal and Madsen (unknown) calculated the spread rate of *P. stratiotes* using aerial imagery. Hyperspectral remote sensing was successfully used to identify both emergent, floating and submerged aquatic weeds (Hestir *et al.*, 2008), and for *P. stratiotes* an accuracy of > 80 % was recorded (Everitt *et al.*, 2003).

EFFECTIVENESS OF MEASURE

Both remote sensing and citizen-scientist programmes (see Early Detection table below) allow the surveillance of large areas with relatively low costs and both methods seem to be high efficient for the early detection of *P. stratiotes*.

EFFORT REQUIRED

Remote sensing requires accurate aerial images (Hestir *et al.*, 2008) and experienced scientists for analysis.

RESOURCES REQUIRED

Remote sensing requires accurate aerial images and experienced scientists for analysis. The cost for remote sensing is low compared to in field detection as large areas can be investigated in a short period of time.

SIDE EFFECTS

During monitoring via remote sensing and citizen-science programmes, other IAAPs can be identified, which reduces the total cost of IAAPs monitoring. Both citizen-science programmes and remote sensing allows identification of early infestations of *P. stratiotes*. Small infestations identified at an early stage of encroachment are easier to eradicate and thus intervention at this stage will have a less negative impact on the ecosystem than control measures taken on an established infestation.

ACCEPTABILITY TO STAKEHOLDERS

Early detection and rapid eradication will have less impact on ecosystems and economic and recreational activities than other management efforts, which are carried out to control large IAAPs infestations (Hussner *et al.*, 2017).

ADDITIONAL COST INFORMATION

There is no information available on the overall costs of remote sensing programmes for *P. stratiotes*. However, the costs of inaction will be much higher, 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 and rapid eradication actions on aquatic plants has not been studied in detail yet and will differ between species, infested habitats and the management methods required for the eradication of the species.

LEVEL OF CONFIDENCE[1]

Moderate.

Early detection and rapid eradication is considered as a highly cost efficient control method. *P. stratiotes* has still a limited distribution within the EU, and early detection is the key to stop the future spread of the species

1 See Appendix

Citizen-science.

MEASURE DESCRIPTION

Citizen-science programmes have been used to survey for and monitor several species, but the accuracy of the species identification depends on the experience of the citizen-scientist and the information they are provided (Delaney *et al.* 2008). Moreover, the species itself will influence the accuracy as difficulties in determination will vary between the species. In the case of *P. stratiotes*, a high accuracy can be expected, as the free floating species is relatively easy to determine, compared to most submerged aquatic plants. Nevertheless, citizen-science programmes require a coordinating scientific or government body (Roy *et al.*, 2012).

Determination keys and apps have been developed and provided to the public, enabling people to identify and report sites of infestations of IAAPs. This information can be used to facilitate rapid eradication, and can furthermore be used for the mapping of IAAPs in larger invaded areas (Hussner *et al.*, 2017).

EFFECTIVENESS OF MEASURE

Early detection and rapid eradication have been documented as successful methods in the eradication of new infestations of invasive species (Anderson, 2005). However, the identification of early infestations of *P. stratiotes* seems to be relatively easy in comparison to e.g. most submerged IAAPs and a high accuracy can be expected from citizen-science programmes.

Both citizen scientist programmes and remote sensing (see *Early Detection* section above) allow the surveillance of large areas with relatively low costs and both methods seem to be high efficient for the early detection of *P. stratiotes*.

Pistia stratiotes *is propagated by seeds or more rapidly by stolons.*
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EFFORT REQUIRED

Remote sensing and citizen-science programmes can be used for the large-scale surveillance of water bodies. Citizen-science programmes require guidance and support by coordinating scientists and or the appropriate authority and a system that assures the quality of the data (Roy *et al.*, 2012).

RESOURCES REQUIRED

Citizen-science programmes require a coordinating scientific or government body, and the annual costs were estimated at €40.000–85.000 per year (Roy *et al.*, 2012).

SIDE EFFECTS

During monitoring via remote sensing and citizen-science programmes, other IAAPs can be identified, which reduces the total cost of IAAPs monitoring. Both citizen-science programmes and remote sensing allows identification of early infestations of *P. stratiotes*. Small infestations identified at an early stage of encroachment are easier to eradicate and thus intervention at this stage will have a less negative impact on the ecosystem than control measures taken on an established infestation.

ACCEPTABILITY TO STAKEHOLDERS

Early detection and rapid eradication will have less impact on ecosystems and economic and recreational activities than other management efforts, which are carried out to control large IAAPs infestations (Hussner *et al.*, 2017). Informing the public and providing apps for citizen-scientists will increase the success and acceptance of early detection and rapid eradication methods compared to comprehensive control measures.

ADDITIONAL COST INFORMATION

There is no information available on the overall costs of citizen-science programmes for *P. stratiotes*. However, the costs of inaction will be much higher, 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 and rapid eradication actions on aquatic plants has not been studied in detail yet and will differ between species, infested habitats and the management methods required for the eradication of the species.

LEVEL OF CONFIDENCE[1]

Moderate.

Early detection and rapid eradication is considered as a highly cost efficient control method. *P. stratiotes* has still a limited distribution within the EU, and early detection is the key to stop the future spread of the species

1 See Appendix

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

Mechanical harvesters.

MEASURE DESCRIPTION

Mechanical harvesting is commonly used in Europe for the control of free floating plants like *P. stratiotes* (Laranjaira and Nadais, 2008; Gettys *et al.*, 2014; Hussner *et al.*, 2017). The harvesters store the harvested plant mass within a storage conveyor, which must be cleared out regularly at the shore, where the biomass must be transferred onto a truck and disposed of in an appropriate manner away from the any other water body (Laranjeira and Nadais, 2008). The harvester can be used for large and dense infestations of floating plants like *P. stratiotes*. The species should be removed before flowering and seeding (State of Queensland Department of Agriculture and Fisheries, 2016).

The manual harvesting of IAAPs is one of the most species-specific control methods available, provided the weed grows in monocultures (Hussner *et al.*, 2017), but is limited to small infestations, as *P. stratiotes* forms dense stands with biomass accumulation of up to 100 tons per ha (Gettys *et al.*, 2014).

EFFECTIVENESS OF MEASURE

Harvesters have been used for the successful eradication of large infestations of free floating Eichhornia crassipes in Portugal (Laranjeira and Nadais, 2008). However, follow-up measures are needed if regrowth from seeds or remaining plants occur, even though small regrowth can be removed by hand-weeding. Plants should be removed prior to seeding to prevent the regrowth of plants from seeds (Hussner *et al.*, 2014a; State of Queensland Department of Agriculture and Fisheries, 2016).

EFFORT REQUIRED

The time and effort required for the eradication of a *P. stratiotes* infestation depends on the size of the harvester, the time for transporting the harvested biomass to the shore, the density of the target species population and the presence of navigable waters (Gettys *et al.*, 2014).

Plant regrowth will most likely occur and thus the weed eradication will require follow-up management measures, until the last plant has been successfully removed (de Winton *et al.*, 2013; Hussner *et al.*, 2016). If a persistent seed bank in the sediment exists, the follow-up management must last for several years until no regrowth from seeds occur. De Winton *et al.* (2013) recommended monitoring for 3–5 years after the removal of the last fragments before the eradication of the species can be confirmed.

The total eradication of *P. stratiotes* by mechanical harvesters is often achieved in combination with hand-weeding, which is used to collect the remaining small plant patches and single plants.

RESOURCES REQUIRED

For mechanical harvesting, a harvester, a transporter to store the harvested plant material and transport it to the shore, a conveyor to elevate the harvested biomass to a truck and a suitable disposal site is required (Gettys *et al.*, 2014). The cost for the management of free floating plants with a harvester depends on the population size, the time for transporting, disposal costs and the accessibility of the water (Gettys *et al.*, 2014; Laranjeira and Nadais, 2008).

For all activities from boats personal floatation devices, skills in boat handling are mandatory for the safety of the operator (de Winton *et al.*, 2013).

SIDE EFFECTS

Mechanical harvesters are not species specific and all plants are removed (Gettys *et al.*, 2014). This might include other invasive aquatic plant species as well as native species. Thus this method might not be suitable in conservation areas.

ACCEPTABILITY TO STAKEHOLDERS

Mechanical harvesting can clean large areas within a short period of time, which will lead to a high acceptance from stakeholders and the public.

The removal of the biomass from the water body and correct disposal at a suitable landfill site is essential to prevent the unsightly and odorous build-up of rotting plant material.

ADDITIONAL COST INFORMATION

The costs for mechanical harvesting of *P. stratiotes* are hard to determine and depend on various parameters (see above). Inaction will lead to the spread of the target species, increasing the management costs and reducing the likelihood of future eradication.

LEVEL OF CONFIDENCE[1]

High.

Mechanical harvesting and hand weeding has been used for the successful control and eradication of infestations of free floating IAAPs, including *P. stratiotes*.

1 See Appendix

Hand weeding.

MEASURE DESCRIPTION

In contrast to mechanical removal (above section), hand weeding is used for the control of early and small infestations of IAAPs and for the selective removal of a target species within mixed plant communities (de Winton *et al.* 2013; Hussner *et al.*, 2016). Hand-weeding is also used, when mechanical control methods are not an option, e.g. in waters with no accessibility by large harvesters (Hussner *et al.*, 2017). Furthermore, hand-weeding can be used in integrated control programmes, e.g. as a follow-up to larger control measures, to eradicate remaining patches of the target species (Gettys *et al.*, 2014; Hussner *et al.*, 2017). The manual harvesting of IAAPs is one of the most species-specific control methods available, provided the weed grows in monocultures (Hussner *et al.*, 2017), but is limited to small infestations, as *P. stratiotes* forms dense stands with biomass accumulation of up to 100 tons per ha (Gettys *et al.*, 2014).

Hand-weeding of *P. stratiotes* can be carried out by wading in shallow water or collecting the plants by hand or small nets from a boat. The success of hand-weeding depends on the plant species and the skills and techniques of the operator (de Winton *et al.*, 2013). *P. stratiotes* should be removed before flowering and seeding (State of Queensland Department of Agriculture and Fisheries, 2016).

EFFECTIVENESS OF MEASURE

Hand-weeding is highly effective for small infestations, when carried out by skilled operators. Manual harvesting is limited to small infestations due to the high biomass accumulation of *P. stratiotes* (Gettys *et al.*, 2014). Plants should be removed prior to seeding to prevent the regrowth of plants from seeds (Hussner *et al.*, 2014a; State of Queensland Department of Agriculture and Fisheries, 2016). Hand-weeding can be used after mechanical harvesting to achieve the total eradication of the target species.

The leaves are approximately 13cm long and 17cm wide.
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EFFORT REQUIRED

In small infestations when hand-weeding is appropriate, the majority of plants can be removed with the first hand-weeding operation. Plant regrowth will most likely occur and thus the weed eradication will require follow-up management measures, until the last plant has been successfully removed (de Winton *et al.*, 2013; Hussner *et al.*, 2016). If a persistent seed bank in the sediment exists, the follow-up management must last for several years until no regrowth from seeds occur. De Winton *et al.* (2013) recommended monitoring for 3–5 years after the removal of the last fragments before the eradication of the species can be confirmed.

RESOURCES REQUIRED

Waders, nets and boats are required. For all activities from boats personal floatation devices, skills in boat handling are mandatory for the safety of the operator (de Winton *et al.*, 2013). De Winton *et al.* (2013) estimated the costs of hand-weeding for two hand-weeding treatments to achieve weed eradication of about NZD 20,000 per ha (ca. 12,000 EUR). The costs for follow-up treatments can be reduced by using volunteers who are able to identify plant regrowth and eliminate these plants.

SIDE EFFECTS

Hand-weeding is a species-specific control measure with minimal negative effects on native plants, if the management is carried out by skilled operators.

ACCEPTABILITY TO STAKEHOLDERS

As hand-weeding has only a minor negative impact on an ecosystem, a high acceptance of hand-weeding measures from stakeholders and the public are highly likely. No impacts of hand-weeding on animal welfare have been reported.

The removal of the biomass from the water body and correct disposal at a suitable landfill site is essential to prevent the unsightly and odorous build up of rotting plant material.

ADDITIONAL COST INFORMATION

Hand-weeding has a relatively high costs per area, but the cost-effectiveness is high when eradication of *P. stratiotes* is achieved. Successful eradication of a small infestation of another free floating species (*Eichhornia crassipes*) was reached by hand-weeding and collecting by small hand nets in Eastern Germany (K. Schneider, pers. comm.). Inaction will lead to the spread of the target species, increasing the management costs and reducing the likelihood of future eradication.

LEVEL OF CONFIDENCE[1]

High.

Mechanical harvesting and hand weeding has been used for the successful control and eradication of infestations of free floating IAAPs, including *P. stratiotes*.

1 See Appendix

Measures for the species' management.

Mechanical harvesters.

MEASURE DESCRIPTION

Mechanical harvesting is commonly used in Europe for the control of free floating plants like *P. stratiotes* (Laranjaira and Nadais, 2008; Gettys *et al.*, 2014; Hussner *et al.*, 2017). The harvesters store the harvested plant mass within a storage conveyor, which must be cleared out regularly at the shore, where the biomass must be transferred onto a truck and disposed of in an appropriate manner away from the any other water body (Laranjeira and Nadais, 2008). The harvester can be used for large and dense infestations of floating plants like *P. stratiotes*. The species should be removed before flowering and seeding (State of Queensland Department of Agriculture and Fisheries, 2016).

The manual harvesting of IAAPs is one of the most species-specific control methods available, provided the weed grows in monocultures (Hussner *et al.*, 2017), but is limited to small infestations, as *P. stratiotes* forms dense stands with biomass accumulation of up to 100 tons per ha (Gettys *et al.*, 2014).

Large mats can block light, shade native submerged plants, and alter immersed plant communities by crushing them. © Jean-Marc Dufour-Dror

EFFECTIVENESS OF MEASURE

Harvesters have been used for the successful eradication of large infestations of free floating *Eichhornia crassipes* in Portugal (Laranjeira and Nadais, 2008). However, follow-up measures are needed if regrowth from seeds or remaining plants occur, even though small regrowth can be removed by hand-weeding.

Plants should be removed prior to seeding to prevent the regrowth of plants from seeds (Hussner *et al.*, 2014a; State of Queensland Department of Agriculture and Fisheries, 2016).

EFFORT REQUIRED

The time and effort required for the eradication of a *P. stratiotes* infestation depends on the size of the harvester, the time for transporting the harvested biomass to the shore, the density of the target species population and the presence of navigable waters (Gettys *et al.*, 2014).

Plant regrowth will most likely occur and thus the weed eradication will require follow-up management measures, until the last plant has been successfully removed (de Winton *et al.*, 2013; Hussner *et al.*, 2016). If a persistent seed bank in the sediment exists, the follow-up management must last for several years until no regrowth from seeds occur. De Winton *et al.* (2013) recommended monitoring for 3–5 years after the removal of the last fragments before the eradication of the species can be confirmed.

RESOURCES REQUIRED

For mechanical harvesting, a harvester, a transporter to store the harvested plant material and transport it to the shore, a conveyor to elevate the harvested biomass to a truck and a suitable disposal site is required (Gettys *et al.*, 2014). The cost for the management of free floating plants with a harvester depends on the population size, the time for transporting, disposal costs and the accessibility of the water (Gettys *et al.*, 2014; Laranjeira and Nadais, 2008).

For all activities from boats personal floatation devices, skills in boat handling are mandatory for the safety of the operator (de Winton *et al.*, 2013).

SIDE EFFECTS

Mechanical harvesters are not species specific and all plants are removed (Gettys *et al.*, 2014). This might include other invasive aquatic plant species as well as native species. Thus this method might not be suitable in conservation areas.

ACCEPTABILITY TO STAKEHOLDERS

Mechanical harvesting can clean large areas within a short period of time, which will lead to a high acceptance from stakeholders and the public.

The removal of the biomass from the water body and correct disposal at a suitable landfill site is essential to prevent the unsightly and odorous build-up of rotting plant material.

ADDITIONAL COST INFORMATION

The costs for mechanical harvesting of *P. stratiotes* are hard to determine and depend on various parameters (see above). The monthly costs for the mechanical control of free floating Eichhornia crassipes in a 529 ha freshwater lagoon in Portugal were about 5000–8000 EUR, additionally to the costs for the acquisition of the harvester and associated material (Laranjeiro and Nadais, 2008).

Inaction will lead to the spread of the target species, increasing the management costs and reducing the likelihood of future eradication.

LEVEL OF CONFIDENCE[1]

High.

Mechanical harvesting and hand weeding has been used for the successful control of infestations of free floating IAAPs, including *P. stratiotes*.

1 See Appendix

Biological control.

MEASURE DESCRIPTION

There are 46 phytophagous insects that were reported feeding on *P. stratiotes*, 11 of which were assumed as monophagous (Neuenschwander *et al.*, 2009). Out of these, *Neohydronomus affinis* was chosen as biocontrol agent, which is successfully used in Africa, Australia and the US (Cilliers, 1991; Dray and Center, 2002; Coetzee *et al.*, 2011).

The biological control of *P. stratiotes* using the host specific weevil, *Neohydronomus affinis* has been highly successful in most parts of the world where it has brought the weed under control (Cilliers, 1991; Dray and Center, 2002; Neuenschwander *et al.*, 2009, Coetzee *et al.*, 2011).

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.

EFFECTIVENESS OF MEASURE

The effects of *N. affinis* on *P. stratiotes* is influenced by climatic conditions and habitat types (Coetzee *et al.*, 2011). *N. affinis* reduced *P. stratiotes* in subtropical South Africa, but did not cause the eradication of the species (Coetzee *et al.*, 2011; Moore and Hill, 2012). In contrast, the effects of *N. affinis* on *P. stratiotes* in Florida are less impressive due to climate incompatibility (Gettys *et al.*, 2014).

EFFORT REQUIRED

The control agent must be collected from *P. stratiotes* and needs be tested for host specify prior to its release (van Driesche *et al.*, 2002). The agent needs to be implemented correctly and new infestations of the weed should be inoculated with the weevil.

RESOURCES REQUIRED

Biological control of *P. stratiotes* using *N. affinis* has been implemented in 20 countries around the world since the 1980s (Winston *et al.*, 2014) and thus much of the fundamental research has already been undertaken and is published which lowers the cost of implementing this technology.

SIDE EFFECTS

Positive side effects of biological control include a return of the invaded system to a functional ecological state, enhancing floral and faunal biodiversity. There are no documented non-target impacts due to the rigorous host-specificity requirements of biological control.

ACCEPTABILITY TO STAKEHOLDERS

Using biological control agents might have a high acceptability, as non-target effects on native plants will not occur. The fast release of nutrients from decomposing plants into the water column can increase the nutrients in the water column which might lead to a phytoplankton bloom.

ADDITIONAL COST INFORMATION

The cost-effectiveness is considered as high for classical biological control. Established populations of the control agent lead to sustainable control of the target species, but this method will not result in eradication of the weed, but should reduce surface area covered by 80–90% (Coetzee *et al.*, 2011; Moore and Hill, 2012).

LEVEL OF CONFIDENCE[1]

High.

The classical biological control of *P. stratiotes* with *N. affinis* is widely used, particularly in Africa, but the success of the control is influenced by climatic and habitat conditions.

1 See Appendix

Herbicides.

MEASURE DESCRIPTION

Herbicides, in general terms, can be used to control aquatic plants in various types of water bodies, including lakes, channels, irrigation systems, and ponds (de Winton *et al.*, 2013; Gettys *et al.*, 2014; Hussner *et al.*, 2017). Herbicides are usually not species specific, but selectivity can be achieved by choosing between different types of application method, the right concentration and the exposure time (Getsinger *et al.*, 1997; 2008; 2014; Netherland, 2004).

Herbicide treatment significantly reduces the biomass of IAAPs and can result in the eradication of a target species (de Winton *et al.*, 2013; Champion and Wells, 2014). There is a variety of herbicides which have been tested and subsequently used for the control of *P. stratiotes*, including glyphosate (Martins *et al.*, 2002), diquat (Martins *et al.*, 2002), bispyribac-sodium (Glomski and Mudge, 2013) and flumioxazin (Glomski and Netherland, 2013) being the most effective. Herbicides are usually applied using hand guns or booms from boats, including airboats and sometimes aircraft.

It is important to note that EU/national/local legislation on the use of plant protection products and biocides needs to be respected.

EFFECTIVENESS OF MEASURE

Up to >99 % control can be achieved by using glyphosate (3360g a.i. ha-1; Martins *et al.*, 2002), diquat (460 g a.i. ha-1; Martins *et al.*, 2002), bispyribac-sodium (59 and 119 g a.i. ha-1; Glomski and Mudge, 2013) or flumioxazin (70 g a.i. ha-1; Glomski and Netherland, 2013). As some herbicides have been used for several decades to control aquatic plants, there are well developed protocols and the effect and behaviour of the herbicides in aquatic habitats is well understood (Netherland and Getsinger, 1995; Clayton and Matheson, 2010).

EFFORT REQUIRED

The herbicide must be applied from boats, and skilled, experienced and licenced operators are required to minimize potential side effects. The required effort depends on the goal of the management programme, if either the control and biomass reduction or eradication is required (Netherland, 2014; Champions and Wells, 2014).

RESOURCES REQUIRED

The costs of chemical control depend on the chemical used and the size of the *P. stratiotes* infestation. Health and safety instructions must be considered when herbicides are used. The application of herbicides requires skilled operators.

SIDE EFFECTS

Herbicides will affect non-target species. The use of water as drinking water after herbicide application is prohibited, but direct negative effects on public health after the application of herbicides in aquatic systems have not been reported. The rapid decomposition of plant material will lead to increased nutrients in the water column, which might cause increased turbidity of the water caused by enhanced phytoplankton growth.

ACCEPTABILITY TO STAKEHOLDERS

The use of herbicides to control aquatic plants is prohibited in most European countries (Hussner *et al.*, 2017). The acceptability of stakeholder and the public for the use of herbicides to control invasive aquatic plants must be considered as low.

ADDITIONAL COST INFORMATION

In general, the cost of chemical control is considered as low compared to other control methods (Gettys *et al.*, 2014). The costs of inaction must be considered as high, as *P. stratiotes* is still limited in Europe and any kind of control limit its future spread and limit the future impact of *P. stratiotes*.

LEVEL OF CONFIDENCE[1]

High.

Herbicides have been used for decades to control invasive aquatic plants like *P. stratiotes*. *P. stratiotes* is successfully controlled with herbicides in several countries.

1 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.

- **High:** Information comes from published material, or current practices based on expert experience applied in one of the EU countries or third country with similar environmental, economic and social conditions.
- **Medium:** Information comes from published data or expert opinion, but it is not commonly applied, or it is applied in regions that may be too different from Europe (for example tropical regions) to guarantee that the results will be transposable.
- **Low:** data are not published in reliable information sources and methods are not commonly practiced or are based solely on opinion. This is for example the case of a novel situation where there is little evidence on which to base an assessment.

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