Salvinia molesta *is an aquatic fern, native to south-eastern Brazil.*
© Julie Coetzee

The management of salvinia moss (*Salvinia molesta*)

Measures and associated costs

Scientific name(s)	*Salvinia molesta* D.S. Mitch. Salviniaceae
Common names (in English)	Salvinia moss
Synonym/other designation	Salvinia adnata Desv./ Other sources indicate this species as Salvinia×molesta D.S.Mitch.
Author(s)	M.P. Hill (Rhodes University, South Africa)
Reviewer(s)	Johan van Valkenburg (National Plant Organization, the Netherlands)
Date of completion	21/09/2017
Citation	Hill, M.P. 2017. Information on measures and related costs in relation to species included on the Union list: *Salvinia molesta*. Technical note prepared by IUCN for the European Commission.

Table of contents

Common names

BG	–
HR	Divovska salvinija
CZ	Nepukalka obtížná
DA	Kæmpe salvinia
NL	Grote vlotvaren
EN	Salvinia moss
ET	Suur salviinia
FI	Poimukellussaniainen
FR	Salvinie géante
DE	Schwimmfarn
EL	–
HU	Átellenes rucaöröm
IE	Sailvín mhór
IT	Erba pesce gigante
LV	–
LT	Didžioji plūstis
MT	Is-salvinja ta' barra
PL	Salwinia uciążliwa
PT	Salvina-molesta
RO	Feriga-de-apă-gigantică
SK	Salvínia burinná
SL	Veliki plavček
ES	Oreja de ratón
SV	Jättesimbräken

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

Salvinia molesta is native to Brazil (Forno and Harley, 1979); it is a sterile polyploid floating freshwater fern that is thought to have arisen as a hybrid between two other *Salvinia* species (Mitchell, 1972; Forno, 1983). *S. molesta* is established outside of its native range throughout the tropics, subtropics and warm temperate areas, and has been noted in at least 55 counties (information compiled from: GBIF, 2016; GISIN, 2016; EPPO, 2016) in addition to Brazil. The earliest records outside of Brazil are from Sri Lanka in 1939, with large impacts on agriculture in that country subsequently being reported in the early 1950s (Room *et al.*, 1989). This plant is problematic in many parts of North America, Africa, South East Asia and Oceania (Julien *et al.*, 2009). In Europe, the species has been reported from Austria, Belgium, France (including Corsica) (Maddi, 2010), Germany (Hussner *et al.*, 2010), Italy (Garbari *et al.*, 2000; Giardini, 2004; Buccomino *et al.*, 2010), the Netherlands, Portugal and the United Kingdom (CABI, 2016) but with occurrences apparently transient and of limited extent (Hussner, 2012).

Salvinia molesta prefers nutrient rich tropical and subtropical lentic systems, but as it has a wide temperature and nutrient tolerance, it can survive in most types of waterbody, although long term exposure to temperature of < -3 °C and > 43 °C will kill the apical buds of the plant terminating growth (Whiteman and Room, 1991). Dense mats of the weed prevent light penetration, reduce oxygenation, increase carbon dioxide and hydrogen sulphide, smother aquatic flora, and displace aquatic fauna by altering habitats, destroying niches, and reducing or eliminating food sources (food plants, benthic biota, and other fauna) (Julien *et al.*, 2009). The excessive growth rate of this plant and its damaging nature requires that it is controlled.

According to EPPO (2016) *Salvinia molesta* presents a high phytosanitary risk for the Mediterranean area within Europe with a moderate uncertainty. Further spread within and between countries is likely. The overall likelihood of *S. molesta* continuing to enter Europe is high because the species is widely cultivated and continuously traded within the region (EPPO, 2016).

Preventing the plant from entering new areas is the most effective control method, but this is difficult as the plant is actively traded in Europe. A recent pest risk analysis calls for the prohibition of trade of the species in the endangered area (Mediterranean biogeographical region) (EPPO, 2016). Thus, the demand for this species for aquaria and water gardens presents the biggest threat for introduction (Martin and Coetzee, 2011). In natural situations, spread of *S. molesta* is by water flow or wind, and by animals that use waterways; birds (everywhere), capybara (South America), hippopotamus (Africa), and water buffalo (Australasia) (Room and Julien, 1995; Forno and Smith, 1999). Once established, the control options available include manual removal for small infestations, mechanical and herbicide application (EU/national/local legislation on the use of plant protection products and biocides needs to be respected) and biological control (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) (Julien *et al.*, 2009).

With the exception of Europe, biological control of *S. molesta* using the host specific weevil, *Cyrtobagous salviniae* has been successfully employed around the world (Julien *et al.*, 2009). Thus for this technical note it was difficult to source data on the costs of interventions such as eradication using manual removal and/or herbicide application.

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.

Trade bans and codes of conduct.

MEASURE DESCRIPTION

Salvinia molesta is used in aquaria, and as an ornamental plant for outdoor ponds (where it may be mislabelled as *Salvinia natans* (L.) All.). It is still traded as an ornamental in Europe. The species is also traded informally between aquatic plant enthusiasts across the world (Martin and Coetzee, 2011) and it regularly features on aquatic plant websites.

Consequently, the prevention of further introductions of the species via trade is considered to be the cheapest and easiest way to close this pathway and to subsequently reduce the future negative impact and management costs. Voluntary codes of conducts, and both national and international trading bans can be implemented to stop the future introduction via trade (Verbrugge *et al.*, 2014).

There are several pieces of legislation from around the world that have banned the importation of *S. molesta*, listing it as a phytosanitary pest (see below), for example:

- Spain: the species is included in the list of the prohibited species of the Real Decreto 630/2013 http://www.boe.es/boe/dias/2013/08/03/pdfs/BOE-A-2013-8565.pdf. Otherwise there are no restrictions to trade within the EPPO region. Andreu and Vilà (2010) performed weed risk assessments (WRAs) for 80 species for Spain, including *S. molesta*. For both the Australian WRA and Weber-Gut WRA methodologies *S. molesta* was ranked in the top four, with a recommendation that this species should be "prohibited or kept out of trade" (Andreu and Vilà, 2010).

- Great Britain: If found in the wild, *S. molesta* is subject to Schedule 9A of the Wildlife and Countryside Act (WCA) 1981, as amended by the Infrastructure Act 2015, Schedule 23; this amendment gives power to environmental authorities to issue "species control orders", or to enter into "species control agreements" with land owners. *S. molesta* is also listed on Part II of Schedule 9 of the WCA, which prohibits the introduction of the species into the wild.

- the Netherlands: A Code of Conduct agreed to by organizations representing the horticultural trade means that *S. molesta* should be sold with a warning label. This warning label informs customers about the risks associated with plant invasiveness, and provides instructions for ownership designed to reduce the risk of release of the plant to the environment (Verbrugge *et al.*, 2014).

- New Zealand: *S. molesta* is listed on the National Plant Pest Accord prohibiting it from sale and commercial propagation and distribution. The species has been included on many other weed lists in New Zealand (see Howell, 2008 for an overview), but was excluded from a "consolidated list" by Howell (2008) due to its absence from "conservation land".

- Australia: *S. molesta* is a "Weed of National Significance" (Australian Government, 2016) and is on the national list of "Noxious weeds", with some form of notification or control process listed for every state (Australian Weeds Committee, 2016).

- South Africa: Control of the species is enabled by the Conservation of Agricultural Resources (CARA) Act 43 of 1983, as amended, in conjunction with the National Environmental Management: Biodiversity (NEMBA) Act 10 of 2004. *S. molesta* was specifically defined as a Category 1b "invader species" on the NEMBA mandated list of 2014 (Government of the Republic of South Africa, 2014). Category 1b means that the invasive species "must be controlled and wherever possible, removed and destroyed. Any form of trade or planting is strictly prohibited" (www.environment.gov.za).

- USA: *S. molesta* is included on the Federal Noxious Weeds List (making it illegal in the U.S. to import or transport the plant between states without a permit). State governments listing the species as an invasive species or noxious weed include Arizona, California, Colorado, Florida, Georgia, Louisiana, North and South Carolina, and Texas (http://

www.invasivespeciesinfo.gov/aquatics/salvinia.shtml#cit; McFarland *et al.*, 2004).

- Kenya: *Salvinia molesta* has been declared a noxious weed in Kenya under the Suppression of Noxious Weeds Act (CAP 325). Under this act the Minister of Agriculture, can compel land owners who have such declared noxious weeds growing on their land to remove or have it otherwise removed.

In addition, *S. molesta* is listed as an invasive species in Japan, but is not subject to legal control prohibiting its import (https://www.nies.go.jp/biodiversity/invasive/DB/etoc8_plants.html).

EFFECTIVENESS OF MEASURE

Much of this legislation has been implemented only after *S. molesta* had become problematic in a particular country and was then subjected to eradication and management control if eradication failed, and the legislation was only implemented to prevent further import and dissemination of the plant through trade. Europe is in the unique situation in that the plant is still actively traded in this region and not yet a problem (EPPO, 2016).

However, for prevention of intentional introduction to be effective legislation/regulation within a country must be aligned. For example, *S. molesta* is prohibited as a Federal Noxious Weed, from transport across state lines and from being imported to the United States (Chilton *et al.* 2002; Jacono and Pitman 2001). However, for the species to be restricted from sale, cultivation, and ownership within a given state, the plant must be listed by the state as a State Noxious Weed (Jacono and Pitman, 2001). Presently, *S. molesta* can be freely cultivated and sold within 42 states (including Hawaii) as long as it is not transported across state lines (Jacono and Pitman, 2001). It is listed as a State Noxious Weed in Arizona, California, Florida, Georgia, Louisiana, North Carolina, South Carolina, and Texas but should be prohibited by others, especially those states with a history of infestation within their boundaries (e.g., Mississippi, Alabama, and Hawaii) (Jacono and Pitman, 2001).

The success or failure of control measures depends on parameters such as the level of education of the relevant authorities (particularly at the customs control) and the labelling of plants. Additionally, illegitimate names, spelling mistakes and mis-labelling make it difficult to identify the target species (Hussner *et al.*, 2014).

Salvinia molesta *is a free floating plant that remains buoyant on the surface of a body of water. © Julie Coetzee*

EFFORT REQUIRED

Trading bans and codes of conduct must be applied over the long-term to support any significant and sustainable success in controlling the spread of *S. molesta*.

RESOURCES REQUIRED

The implementation of trading bans require a good species knowledge and identification skills on the part of the responsible authorities. The molecular phylogeny of the genus Salvinia has been well studied, with several regions having been accessioned in GenBank (Nagalingum *et al.*, 2008), and therefore while morphological identification of several species can be confusing, molecular identification is available.

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

SIDE EFFECTS

No negative side effects are foreseeable.

ACCEPTABILITY TO STAKEHOLDERS

In many regions of the world, the prevention of intentional introduction of *S. molesta* would have very positive socio-economic impacts as this plant is considered problematic and not traded (Doeleman, 1989). In regions of the world where *S. molesta* is traded, such as Europe, direct cost impact to the aquarium trade could be high.

ADDITIONAL COST INFORMATION

No data on the costs of the implementation and action of trading bans and codes of conducts are available, but due to the high number of *S. molesta* plants found in trade (Brunel, 2009), the economic loss to traders can be considered as high. However, promoting indigenous alternatives in the trade could offset the direct economic costs/loss to traders.

The cost of inaction would be very high. All evidence from elsewhere in the world shows that *S. molesta* is a highly damaging weed. For example, the estimate cost of *S. molesta* to rice production in Sri Lanka was between $USD 163,000 to $USD 375,000 a year in the mid-1980s, or a 3% reduction in yield (Doeleman, 1989).

LEVEL OF CONFIDENCE[1]

High.

As the information comes from published material (see bibliography), and current practices based on expert experience applied in one of the EU countries or third country with similar environmental, economic and social conditions (e.g. the USA, Australia and most of Africa).

1 See Appendix

Public awareness raising campaigns to reduce unintentional introduction movement of seeds of the species.

MEASURE DESCRIPTION

Salvinia molesta is an aquatic macrophyte and thus has very specific environmental requirements in that it has to remain moist. Thus, the likelihood of introduction of this species as a contaminant of plants for planting is low.

The introduction of *S. molesta* as a contaminant of leisure equipment (hitchhiking on boats and boat trailers and in holds of leisure craft) is high. This pathway for the spread of invasive species has prompted the "Check, Clean and Dry" and "Be Plant Wise" campaigns in the UK (www.nonnativespecies.org/checkcleandry and www.nonnativespecies.org/beplantwise) and other regional information portals (EUBARnet, 2013). Similar "Clean, Drain and Dry" campaigns have been employed in the USA (Stop Aquatic Hitchhikers, http://www.protectyourwaters.net) and Canada (British Colombia) (http://bcinvasives.ca) to increase awareness of this potential pathway.

The use of *S. molesta* has been very popular with gardeners because of its attractive form. Inappropriate disposal of aquaria by pouring the content into public waters is another possibility of stochastic spread.

Potential movement through irrigation and interconnected waterways may act to facilitate spread nationally and regionally. The potential high impact of the species within the EPPO region should be considered similar to that seen in other regions where the species has established and become invasive; i.e. Australia, Africa and the southern states of the USA. *Salvinia molesta* does not produce fertile spores, so natural spread is limited to the physical movement of plants or plant fragments along waterways. The floating form of the plant facilitates its spread within waterbodies (McFarland *et al.*, 2004); likewise, flooding also has the potential to carry plants to new waterbodies or wetland habitats (McFarland *et al.*, 2004). Wildfowl or other wetland animals could also contribute to spread, particularly for juvenile forms as has been shown for other aquatic species (Green, 2016).

EFFECTIVENESS OF MEASURE

The "Check, Clean and Dry" and other regional information portals (EUBARnet, 2013) and the "Clean, Drain and Dry" campaigns that have been employed in the UK and USA (Stop Aquatic Hitchhikers, http://www.protectyourwaters.net) have created awareness around the unintentional movement of aquatic weeds, including *S. molesta* and appear to have curbed its spread. The Check Clean Dry (CCD) campaign in the UK, led to a 9% increase in the numbers of general public in the Broads following the recommended biosecurity procedures (Burchnall, 2013), 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).

EFFORT REQUIRED

The implementation of such stakeholder engagement and awareness raising campaigns needs to be long-term.

RESOURCES REQUIRED

The costs of generating a public campaign are relatively low compared to the costs of managing established *S. molesta* infestations, but data about the total costs of these campaigns are not available.

SIDE EFFECTS

No side negative effects are foreseeable. A positive side effect is that the campaigns and resulting increase in biosecurity practices will target multiple invasive alien species.

ACCEPTABILITY TO STAKEHOLDERS

Recreational boat users, and other recreational user groups, might object to the "Check, Clean and Dry", "Clean, Drain and Dry" and "Stop Aquatic Hitchhikers" as it may limit their access to certain waters and have a direct cost in terms of spraying boating equipment.

ADDITIONAL COST INFORMATION

The prevention of unintended introductions and movement of *S. molesta* is far more cost effective than inaction or management once the weed has established (see sections below). Data on the cost of prevention campaigns such as the "Stop Aquatic Hitchhikers" in the USA are not available.

LEVEL OF CONFIDENCE[1]

High.

As the information comes from published material (see bibliography), and current practices based on expert experience applied in one of the EU countries or third country with similar environmental, economic and social conditions (e.g. the USA, Australia and most of Africa).

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.

Active monitoring of high risk sites, supported by citizen science.

MEASURE DESCRIPTION

The early detection of invasive alien aquatic plant species is a proactive approach and is a key factor in the successful eradication of new infestations. Thus programmes centred on Early Detection and Rapid Eradication (EDRE) are crucial for effective management and successful eradication (Genovesi *et al.*, 2010; Hussner *et al.*, 2017). The early detection of *S. molesta* and other floating aquatic weed species is likely to be easier than submerged species as they are more obvious.

Successful early detection relies on a well-trained workforce of conservationists and water resource managers (and general public) who are able to prioritise high risk sites and identify *S. molesta*, and a repository to verify and store the information for the rapid response team. This can be supported by citizen science activities, and also through using remote sensing technologies.

Thus an early detection system might include:
- identification and active monitoring of high risk sites,
- vouchering of submitted specimens (by designated botanists),
- verification of suspected new local or national record of the weed (potentially through citizen science records),
- archival of new record(s) in designated regional and plant databases,
- rapid assessment of confirmed new records (by qualified scientists), and
- rapid response to new records (see below).

Fortunately there are several identification keys for *S. molesta* (e.g. Sainty and Jacobs, 2003). Misidentification may occur between *S. natans* and the primary and secondary stage of *S. molesta* given that *S. natans* will be the most familiar *Salvinia* species to regional botanists. According to Kasselmann (1995), *S. molesta* is especially misidentified as *S. auriculata*. Egg-beater-shaped hairs on the upper (adaxial) surface of the floating leaves are a notable feature of *S. molesta*, and serve to distinguish it from the European native *S. natans*, in which the ends of the 'beater' are not joined together (Booy *et al.*, 2015); *S. natans* is also a smaller species.

The European Alien Species Information Network (EASIN) (https://easin.jrc.ec.europa.eu) provides a platform for the identification, biology and impact of invasive alien species. However, besides a map there is little information available on *Salvinia molesta*.

The Southern African Plant Invader Atlas (SAPIA) through the Agricultural Research Council of South Africa, which relies on both active monitoring and citizen science, provides an example of an early detection programme for invasive plants (Henderson, 2007).

EFFECTIVENESS OF MEASURE

Early detection and rapid response have been documented as successful methods in the eradication of new infestations of invasive species (Anderson, 2005). Although *S. molesta* is widespread in South Africa, it was only in 2013 that the SAPIA database, through active monitoring of waterbodies in the region detected *S. minima*, a highly invasive and damaging weed in the USA, from one locality allowing for a rapid response and eradication of this species (Hill and Coetzee, 2017).

EFFORT REQUIRED

The active surveillance of aquatic habitats is much more time-consuming and costly than terrestrial habitats. However, new techniques such as hyperspectral remote sensing (Hestir *et al.*, 2008), can be used for the large-scale surveillance of water bodies, but require an element of ground-truthing. However, Hung and Sukkarieh (2013) showed that unmanned robotic aircraft (drones) fitted with a camera was effective in detecting *S. molesta* infestations in remote areas of Australia.

RESOURCES REQUIRED

Early detection is only achievable through comprehensive and repeated monitoring. Resources would require trained professional staff able to undertake active monitoring, database to store records (though this is likely to be multi-species), and remote sensing technology if being used. By developing identification keys for the public and developing apps for mobiles, the cost of monitoring can be reduced and larger areas can be surveyed via citizen science.

SIDE EFFECTS

During active monitoring for *S. molesta*, other aquatic weeds can be identified (e.g. the detection of *S. minima* in South Africa (Hill and Coetzee, 2017)), which reduces the total cost of weed monitoring.

ACCEPTABILITY TO STAKEHOLDERS

Early detection allowing for a rapid response, and thereby eradication of *S. molesta* will have the least impact on aquatic biodiversity and the utilization of the water resource. Community engagement through an area-wide awareness campaign will ensure stakeholder buy-in and acceptance of eradication and control efforts.

ADDITIONAL COST INFORMATION

The cost of inaction is considered to be high, as *S. molesta* is known to have severe impacts and thus early detection followed by rapid response and possible eradication is the most cost effective method for the control of this weed. There is no published information available on the overall costs of early detection, but while they are likely to be high, the potential return on investment in this method will be higher.

LEVEL OF CONFIDENCE[1]

Medium.

Information comes from published data in the grey literature and expert opinion.

1 See Appendix

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

Manual removal.

MEASURE DESCRIPTION

Salvinia molesta is a sterile polyploid fern and therefore only reproduces vegetatively (Julien *et al.*, 2009). Unlike other aquatic weeds such as *Eichhornia crassipes*, which has a long-lived seed bank, eradication should therefore be possible. Eradication measures should be promoted where feasible with a planned strategy to include surveillance, containment, treatment and follow-up measures to assess the success of such actions. As highlighted by EPPO (2014), regional cooperation is essential to promote phytosanitary measures and information exchange in identification and management methods. Eradication may only be feasible in the initial stages of infestation, and this should be a priority.

Thus, early detection followed by prompt management action would help to eradicate *S. molesta* in its initial stages within a water body. However, given past experiences with this species and other invasive aquatic plants, eradication, even within any single system, is almost always unattainable. It seems more likely that management approaches will need to be developed that seek to reduce the extent of *S. molesta* infestations to acceptable levels.

In small sites of less than 1 ha, *S. molesta* can be manually removed (using drag nets or pitch forks) and either dried or incinerated, or disposal by deep burial. Intensive monitoring of treated sites is essential to deal with reinvasion, from missed plants.

EFFECTIVENESS OF MEASURE

There are a few cases where *S. molesta* has been eradicated from small waterbodies, but generally this method is not effective. For example, a programme in New Zealand targeted four invasive species, including *S. molesta* for eradication from the country, and while the plant was eradicated from 55 sites, new sites of infestation continually occurred and thus the country-wide eradication programme has failed (Yamoah *et al.*, 2013).

Manual removal from small water bodies can be useful in the early stages of an infestation, but once the weed is established, biomasses of about 80 tonnes/ha fresh weight and the potential for rapid regrowth make this impractical. The use of weed harvesting machines was considered in Australia, but even in winter, when Salvina molesta doubling times are as long as 40–60 days, the capacity of large infestations for regrowth exceeded the removal capacity of the machines.

Because post-treatment monitoring is expensive, it is rarely conducted over the long-term and, therefore, manual methods usually fail to provide acceptable and sustainable levels of weed control (Julien *et al.*, 2009).

EFFORT REQUIRED

Once the removal has taken place intensive monitoring is required to identify (and treat) re-invasions.

RESOURCES REQUIRED

The eradication attempts on *S. molesta* have usually been through manual removal using drag nets or pitch forks and this relies on a trained staff who can swim, and a site of disposal of the plant material once it has been removed

The fern Salvinia molesta *floating on a pond surface.*
© Jean-Marc Dufour-Dror

from the waterbody. The estimated costs vary depending on whether volunteers conduct removal, and on the plant density if divers need to be contracted, costs may range from $500–$2,400 per day in the USA (Gibbons *et al.*, 1999). These costs can be reduced if volunteers are used, but then there has to be a greater emphasis on training. There may be additional fees for disposal of plant material.

SIDE EFFECTS

The potential negative side effect of manual removal is that indigenous plants and invertebrates may be removed, and riparian zones may be scoured. Thus this method should not be considered in sensitive areas such as protected areas with highly threatened plant species.

ACCEPTABILITY TO STAKEHOLDERS

Eradication will be highly acceptable to stakeholders, however, correct disposal of the biomass of the weed removed from the site is vital as the public perception of large mounds of rotting *S. molesta* plants and associated odours will be negative.

ADDITIONAL COST INFORMATION

There is no information available on the overall costs of eradication actions on small infestations of *S. molesta*. However, the costs of inaction will be much higher, as the control and eradication of large infestations of this weed are much more time-consuming and costly (Hussner *et al.*, 2017). The cost-effectiveness of EDRE actions on aquatic plants has not been studied thoroughly and will differ between species, infested habitats and the management methods required for the eradication of the species.

The costs of eradication programmes can exceed the benefits when weed growth exceeds removal rates, or the lack of follow-up monitoring and management allows recolonization by remaining plants (Thomas and Room, 1986).

LEVEL OF CONFIDENCE[1]

High.

As the information comes from published material (see bibliography), and current practices based on expert experience.

1 See Appendix

Herbicide application.

MEASURE DESCRIPTION

Salvinia molesta can be treated with an appropriate herbicide, however it is important to note that EU/national/local legislation on the use of plant protection products and biocides needs to be respected. Herbicides utilized for *S. molesta* control in Australia include diquat, glyphosate, calcium dodecyl benzene sulphonate, and orange oil (van Oosterhout, 2006). In South Africa, diquat and 2,4-D are no longer permitted and only glyphosate is currently registered (Hill, 2003). Herbicides permitted in the United States include diquat dibromide, fluridone, glyphosate, and several chelated copper compounds (Julien *et al.*, 2009). These herbicides can be applied from the shore, a boat, or through aerially from a fixed-wing aircraft or a helicopter. Intensive monitoring of treated sites is essential to deal with reinvasion, from missed plants.

EFFECTIVENESS OF MEASURE

The trichomes or leaf hairs on the upper surface of *S. molesta* fronds form a waterproof barrier to most herbicides and thus the uptake of the active ingredient is poor unless the herbicide formulation has a suitable wetter (Nelson, 2009). There is no evidence that a herbicide programme alone has resulted in eradication of *S. molesta*.

Despite the availability of herbicides, attempts to control *S. molesta* chemically have, without exception, failed in the long-term. Regrowth from the inevitable unsprayed plants of a spraying programme is exponential until the density of the weed approaches the level that initiated the herbicide application. For example, at Lake Moondarra, Australia, use of herbicide sprayed from a hovercraft and a helicopter was abandoned in December 1978 after $AUS 160,000 had been spent. At the time, the plant was doubling in size in less than 3 days, resulting the need to kill more than half the total infestation every 3 days for effective control, much less eradication (Thomas and Room, 1986).

In addition, because post-treatment monitoring is expensive, it is rarely conducted over the long-term and, therefore, herbicide methods usually fail to provide acceptable and sustainable levels of weed control (Julien *et al.*, 2009).

EFFORT REQUIRED

Once the treatment has taken place intensive monitoring is required to identify (and treat) re-invasions.

RESOURCES REQUIRED

Herbicide application relies on well-trained staff with access to the correct equipment, including spray rigs, boats and where necessary helicopter and plane hire. The costs for herbicide application range from US$210 to $900 per ha (Julien *et al.*, 2009), but this is only for one application and given the poor uptake of the herbicide, the fact the dense mats are made up of layers and layers of plants that do not come into contact with the herbicide, and the fact that the weed often occurs in inaccessible areas, up to three applications are often required in an attempt to eradicate the weed (Nelson, 2009).

SIDE EFFECTS

The potential negative side effect of herbicide application is non-target effects on other vegetation and residue remaining in the aquatic ecosystem (Kam-Wing and Furtado, 1977). Thus this method should not be considered in sensitive areas such as protected areas.

ACCEPTABILITY TO STAKEHOLDERS

Eradication of *S. molesta* will be highly acceptable to stakeholders, however, there is considerable resistance to the use of herbicides, in particular in aquatic ecosystems.

ADDITIONAL COST INFORMATION

There is no information available on the overall costs of eradication actions on *S. molesta*. However, the costs of inaction will be much higher, as the control and eradication of large infestations of this weed are much more time-consuming and costly (Hussner *et al.*, 2017). The cost-effectiveness of EDRR actions on aquatic plants has not been studied thoroughly and will differ between species, infested habitats and the management methods required for the eradication of the species.

The costs of eradication programmes can exceed the benefits when weed growth exceeds removal rates, or the lack of follow-up monitoring and management allows recolonization by remaining plants (Thomas and Room, 1986).

LEVEL OF CONFIDENCE[1]

High.

As the information comes from published material (see bibliography), and current practices based on expert experience.

1 See Appendix

Measures for the species' management.

Integrated control.

MEASURE DESCRIPTION

Integrated control uses a combination of control strategies (see *Management* sections below) to put greater pressure on the weed, or to treat the weed according to the conditions in different sections of an infestation. In most cases, managers will have to consider each control method (discussed separately in the sections below) and make decisions about how to combine them in site-specific management strategies. For example, containing floating mats with booms allows for more effective use of control methods, such as mechanical or chemical control.

If the presence of an infestation is unacceptable for any amount of time (i.e. if it occurs in a high-use recreation area or a high-value conservation zone), the bulk of the infestation can be removed with herbicides or physical removal. Biocontrol can then be used as part of the ongoing management.

Note that EU/national/local legislation on the use of plant protection products and biocides needs to be respected. In addition, 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

Integrated control has been effective in a number of cases, and the following combinations are most successful:

- Herbicide spot spraying and manual removal methods are good follow-up techniques, once the bulk of an infestation has been removed through either mechanical removal or broadscale herbicide treatments.
- Herbicide strip treatments or small-scale mechanical removal can assist biocontrol by maintaining ideal weevil habitat (keeping the *S. molesta* in a single, actively growing layer).
- Small-scale mechanical removal can be used to thin out multi-layered *S. molesta*, allowing herbicide applications to be more effective.
- Floating booms and containment can be used in combination with all of the control methods and generally increase the effectiveness of any control strategy.

EFFORT REQUIRED

The effort required depends on the combination of techniques to be employed, and again, the size and accessibility of the water body. Integrated control relying on biological control in combination with another method will take longer than a herbicide strategy, but the long term benefits of biological control, and the cost effectiveness often outweigh those of a herbicide approach.

RESOURCES REQUIRED

Again, this is dependent on the combination of methods used, where manual and mechanical control will have high labour costs, while chemical control is very expensive due to the cost and application of the herbicides. Biological control is far cheaper, with longer term environmental benefits. Julien *et al.* (2009) estimated the costs of using herbicides to vary between US$ 210 and US$ 900 per ha in 2005. While Chikwenhere and Keswani (1997) estimated the cost of controlling *S. molesta* through biological control in a 16 ha lake in Zimbabwe to be US$ 5–6/ha between 1989 and 1995. A fully integrated approach to the management of *S. molesta* was implemented in the Hawkesbury River, Australia, between 2004 and 2005 where the average cost of controlling some 364 ha of the weed was estimated at US$1900 per ha per year (Coventry, 2006).

SIDE EFFECTS

See measure specific sections below, but if biological control is used in combination with manual control, there will be very few non-target effects apart from hand pulling non-target species. If chemical control is integrated with biological control, the side effects on water quality and non-target effects on non-target species will initially be high, but the use of biological control will maintain the infestation at a low level for a long period of time, allowing the system to recover.

ACCEPTABILITY TO STAKEHOLDERS

See measure specific sections below, but integrated control is likely to be acceptable to stakeholders, depending on the combination of methods used. Mechanical or herbicidal control resulting in a quick clearing of the infestation, in combination with biological control might be perceived as the best option in the long run, depending on the water use requirements.

ADDITIONAL COST INFORMATION

The cost of inaction far outweighs the cost of any control method. The socioeconomic benefits associated with a functional aquatic ecosystem are enhanced by the best combination of control methods for the system.

LEVEL OF CONFIDENCE[1]

Medium.

Information comes from published data or expert opinion, but it is not legislated in Europe to guarantee that the results will be transposable

.

1 See Appendix

Manual control.

MEASURE DESCRIPTION
This method requires manually removing *S. molesta* from the waterbody by hand, using pitch forks, scoops, nets, shovel rakes, bins, bags, waders and wetsuits. This method is labour intensive as adequate numbers of personnel are required. Hand removal and giant nets have been used in Australia (Miller and Pickering, 1980). Intensive monitoring is essential to deal with reinvasion or rapid recolonization from missed plants (Julien *et al.*, 2009).

EFFECTIVENESS OF MEASURE
Manual removal can be effective in the early stages of an infestation when:
- plants are in primary form, scattered, or lining the edges of a water body
- salvinia is growing amongst other vegetation, such as in wetlands or swampy areas, particularly if the vegetation has high conservation status
- follow-up is required, after the bulk of an infestation has been removed using other forms of control.

Manual removal has also been applied to smaller infestations in open water, where nets can be hauled across the surface to remove the bulk of a more established infestation. There are cases where extensive and careful ongoing manual removal has effectively eradicated *S. molesta*, reducing infestations to undetectable levels. However, once *S. molesta* is established in a given area, increased biomass and rapid growth makes harvesting and hand pulling unfeasible. Manual control measures are very expensive depending on the size and accessibility of the infestation, and need frequent deployment for acceptable results.

Salvinia molesta *grows from fragments that have broken off or dormant buds that have been detached from the main plant.*
© Jean-Marc Dufour-Dror

EFFORT REQUIRED
Initially, continual follow ups are required to ensure re-infestation does not occur. Annual repetition, and intensive monitoring is required to maintain control (Cook, 1976; Murphy, 1988; Julien *et al.*, 2009).

RESOURCES REQUIRED
Costs and staff will vary depending on the size and accessibility to the infestation. Equipment needed could include wetsuits and waders, nets, scoops, rakes, bins and bags. On bigger, less accessible infestations, canoes or boats are required to access the plants.

SIDE EFFECTS
There are potential non-target effects, which include removal of non-target species and scouring of riparian vegetation. Wading could disturb sediments, increasing turbidity, which could have negative consequences, although not long lasting.

ACCEPTABILITY TO STAKEHOLDERS
Opening up of infested areas would be acceptable to communities reliant on the invaded water body for recreational and economic activities.

Water quality for both human and animal consumption improve with the removal of *S. molesta*. Correct disposal of the removed material is vital as mound of rotting *S. molesta* will create a negative perception.

ADDITIONAL COST INFORMATION
Disposal of removed material can be costly, depending on the amount to be removed. As with all management methods, the cost of inaction is usually high and will result in spread of the target species, reducing the likelihood of future eradication and increasing management costs and time frames.

LEVEL OF CONFIDENCE[1]
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.

1 See Appendix

Mechanical control.

MEASURE DESCRIPTION

Mechanical removal uses purpose-built machinery to remove or 'harvest' *S. molesta* from the surface of the water. Machinery can remove the bulk of an infestation in accessible areas, and other control methods are then required for the remnant *S. molesta* left close to edges, or in shallow or inaccessible areas. Mechanical removal can be broad scale or small scale.

EFFECTIVENESS OF MEASURE

Broad scale mechanical harvesting may be appropriate when:

- an infestation occurs in a priority area, such as an area where there is high recreational use, high value conservation or potable water uptake,
- the *S. molesta* can be contained during the harvesting operation,
- the rate of removal can exceed the rate of weed growth,
- the harvested *S. molesta* can be adequately disposed of.

However, Oliver (1993) concludes that mechanical harvesting is not economically competitive compared to chemical control (see below), and that the large biomass associated with severe infestations can make the use of both harvesting machines and hand removal impractical.

Physical removal using booms to accumulate or control the location of mats and machines to collect and remove the weed have been used in many instances, rarely with great success and always at great expense, for example on the Hawkebury River, Australia (Coventry, 2006). Because post treatment monitoring is expensive, it is rarely conducted over the long term, and therefore, mechanical methods usually fail to provide acceptable and sustainable levels of weed control.

EFFORT REQUIRED

As with manual control, initial continual follow ups are required to ensure re-infestation does not occur. Intensive monitoring is essential to deal with reinvasion or rapid recolonization from missed plants (Julien *et al.*, 2009). Annual repetition is required to maintain control (Cook, 1976; Murphy, 1988).

RESOURCES REQUIRED

Broad scale mechanical removal is expensive because of the high operating costs and the ancillary plant and machinery required to process the weed once removed. Again, the costs will depend on the size of the infestation and the accessibility, and also the choice of machinery. In, Australia, in 2004, costs of two mechanical harvesters were estimated – the Aquamarine H-7–400 (12 cubic metre load, 500 mm minimum water depth, 1.5 m depth cut) cost AUS$1,030/day plus relocation, while the HV2600 (11 cubic metre load, 600 mm minimum water depth, 2.7 m depth cut), cost AUS$ 1,680/day plus set-up, including a compacting garbage truck (van Oosterhout, 2006).

SIDE EFFECTS

The removal of non-target vegetation is a negative side effect as the method is not specific, as is scouring of the banks, which could decrease the stability of the system.

ACCEPTABILITY TO STAKEHOLDERS

Opening up of infested areas would be acceptable to communities reliant on the invaded water body for recreational and economic activities. Water quality for both human and animal consumption improve with the removal of *S. molesta*.

ADDITIONAL COST INFORMATION

In cases where infestations have become extensive (usually over the summer growth period) it is important to know whether the rate of mechanical removal will exceed *S. molesta* growth rates; where and how the removed weed will be disposed of; the associated costs of the whole operation; and whether adequate follow up can be carried out to ensure the operation is worthwhile.

As with all management methods, the cost of inaction is usually high and will result in spread of the target species, reducing the likelihood of future eradication and increasing management costs and time frames.

LEVEL OF CONFIDENCE[1]

Low.

Data are not published in reliable information sources and methods are not commonly practiced or are based solely on opinion.

1 See Appendix

Booms and Containment Fences.

MEASURE DESCRIPTION

The erection of booms in conjunction with mechanical and manual removal (see above) may aid control of *S. molesta*.

Floating booms range in size and capacity. Small areas of *S. molesta* can be temporarily contained using a rope floating on the water surface, but for ongoing containment or for larger infestations, a floating boom needs to sit approximately 10 cm above and below the water surface. Commercially available booms can be hired or purchased, or possibly borrowed from a marine or waterways authority. Smaller-scale booms can be made up in-house. Booms need to be durable and strong enough to hold the considerable amount of force created by the weight and movement of the floating *S. molesta*, the wind, tidal influences and currents. They can be designed to accommodate rises and falls in water levels (i.e. leaving some slack will accommodate small rises), and should also be designed to let go when floodwaters occur, so as not to lose the boom completely. Debris can damage or displace a boom.

EFFECTIVENESS OF MEASURE

Floating booms and containment fences are used to:

- contain sections of *S. molesta* in one area to minimise costs and the time required to carry out herbicide treatments or physical removal,
- separate areas that have had different control treatments (i.e. different herbicides, herbicide and biocontrol, mechanical removal and biocontrol),
- keep certain areas salvinia free,
- separate and protect biocontrol release sites from disturbances and other control treatments,
- allow for monitoring of treatment efficacy,
- collect regrowth and leftover salvinia for further treatment or removal,
- prevent downstream spread,
- allow for early detection of new infestations.

The installation of booms for integrated control (i.e. using a variety of control methods) is invaluable particularly during periods of heavy rain when water levels rise, as they retain infestations in the boomed off area, preventing large scale spread downstream.

EFFORT REQUIRED

Booms and fences usually need to stay in place for the duration of the management effort (i.e. a number of years, possibly permanently). All booms and containment fences should be checked regularly and routinely after rainfall, and cleared of debris. When possible, booms and fences should be removed or opened before flooding occurs.

RESOURCES REQUIRED

The type of boom required is dependent on the size and extent of the infestation, as well as the waterbody type. Different booms are required in running water in comparison to still water. The cost also depends on whether the boom is homemade, or commercially sourced. For example, industrial strength booms are available commercially for oil spill control which are generally more durable than in-house designs, are able to cover larger spans, and can be used on a permanent basis. In Australia the cost of the booms used in one example was AUS$ 55–AUS$ 65 dollars (in 2006 dollar values) per metre (van Oosterhout, 2006).

SIDE EFFECTS

Potential side effects of the installation of booms include build-up of material during floods, and knock on side effects.

ACCEPTABILITY TO STAKEHOLDERS

The visual presence of booms and fences is often an indication that action is being taken, and although their presence may be unsightly, their benefit in integrated management is great.

ADDITIONAL COST INFORMATION

As with all management methods, the cost of inaction is usually high and will result in spread of the target species, reducing the likelihood of future eradication and increasing management costs and time frames.

LEVEL OF CONFIDENCE[1]

Medium.

Information comes from published data in the grey literature and expert opinion, but booms have been used successfully in one example from Australia.

1 See Appendix

Chemical control using herbicides.

MEASURE DESCRIPTION

Chemical control relies on herbicides registered for use against *S. molesta*. Herbicides utilized for *S. molesta* control in Australia include diquat, glyphosate, calcium dodecyl benzene sulphonate, and orange oil (van Oosterhout, 2006). In South Africa, diquat and 2,4-D are no longer permitted and only glyphosate is currently registered. Herbicides permitted in the United States include diquat dibromide, fluridone, glyphosate, and several chelated copper compounds. Herbicides are usually applied using hand guns or booms from boats, including airboats and sometimes aircraft.

Long-term management with herbicides requires follow-up monitoring to spot-spray any plant material that survived the initial application. As a good management practice, herbicides should be routinely rotated and/or combined with other control strategies to minimize the potential development of herbicide resistance.

EFFECTIVENESS OF MEASURE

Chemical control of *S. molesta* has been successful in small contained systems, particularly in combination with mechanical control, where access is relatively easy, especially as the plant is sterile so no recruitment from spores occurs. However, chemical control is neither practical nor affordable in large natural systems or in inaccessible areas.

The trichomes or leaf hairs on the upper surface of *S. molesta* fronds form a waterproof barrier to most herbicides and thus the uptake of the active ingredient is poor unless the herbicide formulation has a suitable wetter (Nelson, 2009). There is no evidence that a herbicide programme alone has resulted in eradication of *S. molesta*.

EFFORT REQUIRED

There are no situations where a single application of herbicide will provide ongoing control of *S. molesta*. Initial treatments will always need to be followed up with further

Salvinia molesta's *mats can put a halt to recreational activities on lakes and waterways. © Jean-Marc Dufour-Dror*

treatments. *S. molesta* is difficult to manage using herbicides because it is a small floating plant that produces dense stands with plants layered on top of one another. This layering of plants presents a challenge when applying herbicides because plants in lower layers of the mats are protected from herbicides by plants in the upper layers of the mats. If plants are dense and a thick vegetative mat has formed, multiple applications will be required to achieve successful long-term control.

Research trials show that a good initial knockdown after herbicide application can be misleading, and that regrowth is likely to occur after treatment with any of the registered herbicides. The decaying biomass of sunken herbicide-treated *S. molesta* will also return nutrients to the water, creating ideal conditions for regrowth of surviving plants and making the need for ongoing follow-up and monitoring more critical.

RESOURCES REQUIRED

Herbicidal control is often prohibitively expensive, and depends on the size and accessibility of the infestation. Costs for the chemicals alone can range from US$ 210 to US$ 900 per ha (Julien *et al.*, 2009). The method of application also determines the cost of the application – costs differ significantly between aerial spraying using fixed wing aircraft or helicopters, boats, booms, and/or knapsack sprayers. In addition, the adjuvants added to the herbicide differ in cost, but are essential in order to actively target the frond material.

SIDE EFFECTS

Herbicides can affect fish and other aquatic organisms through deoxygenation of water caused by decay of the biomass of the treated weed, or through contamination of the water with high concentrations of the herbicide itself. While both effects can kill fish, the removal of the mat and the initial changes in water chemistry could outweigh the negative impacts of the presence of the weed.

ACCEPTABILITY TO STAKEHOLDERS

Depending on the herbicide used, water extraction for irrigation may be compromised. Water for human and animal consumption may also be compromised initially.

However, opening up of infested areas would be acceptable to communities reliant on the invaded water body for recreational and economic activities.

Water quality for both human and animal consumption improve with the removal of *S. molesta* following ecosystem recovery after chemical treatment.

ADDITIONAL COST INFORMATION

The effects of complete coverage of a water body (i.e. cost of inaction) by *S. molesta* can be equally detrimental to fish and aquatic organisms in terms of lowering dissolved oxygen levels, changing the temperature profiles in the water, changing water chemistry and reducing light penetration as chemical control.

LEVEL OF CONFIDENCE[1]

Medium.

Information comes from published data or expert opinion, but it is not legislated in Europe to guarantee that the results will be transposable.

1 See Appendix

Biological Control.

MEASURE DESCRIPTION

Biological control of *S. molesta* employs the host specific weevil *Cyrtobagus salviniae* Calder and Sands (Coleoptera: Curculionidae), and is “recognized throughout the world as the method of choice for *S. molesta* management”. The insect has been released in 22 countries around the world including: Australia, Fiji, India, Kenya, Namibia, South Africa, Sri Lanka, USA, Zambia and Zimbabwe (Doeleman, 1989).

Biological control will not eradicate *S. molesta*. Weevils are able to reduce an infestation to very low levels, with small amounts of *S. molesta* left growing along edges or in shaded areas, leaving open water mostly *S. molesta* free. Successful use of biocontrol allows a reduction in total control inputs over time. Other methods may still be required to maintain critical areas of open water or to keep the *S. molesta* in a state that allows weevils to be effective. The use of biocontrol depends on the time frame and the climate.

EFFECTIVENESS OF MEASURE

Biological control using Cyrtobagous salviniae has proved to be successful wherever it has been introduced (Room *et al.*, 1989; Forno and Bourne, 1984; Room and Thomas, 1985; Julien *et al.*, 2009; Coetzee *et al.*, 2011). The first release of this weevil was made on Lake Moondarra near Mt. Isa, Australia, in 1980 and this resulted in a spectacular reduction in weed abundance (Room *et al.*, 1981). Subsequently successful control was repeated at a number of large and small infestations such as the Sepik River in Papua New Guinea (Thomas and Room, 1986) and the many ponds throughout Sri Lanka (Room and Fernando, 1992) as well as numerous infestations in Australia, South Africa and elsewhere. The success of these projects led to a number of awards for the scientists involved including being awarded the UNESCO Science Prize in 1984. To date at least 18 countries have benefited from releases of this insect.

EFFORT REQUIRED

Biocontrol does not produce instant effects. Weevils need time and favourable conditions to build up a population that will reduce an infestation, and it is difficult to generalise about the time required. In tropical and subtropical climates weevils usually reduce an infestation within 2 years, sometimes less. In temperate climates it can take 3 or more years for weevil populations to increase enough to reduce an infestation. However, under ideal conditions weevils have reduced infestations in less than 12 months.

RESOURCES REQUIRED

Resources required for an effective biological control programme against *S. molesta* largely include the costs of setting up and maintaining mass-rearing facilities. These include greenhouse poly tunnels, large pools, such as plastic portable pools, for growing the plants and maintaining the weevil culture, and then staff to manage the facility. Once the control agents are released into a system, there are very few ongoing costs because with time, weevil populations build up, and often do not require re-inoculation. They are also very good dispersers, so if there are infested sites nearby, the weevils often get to them unaided.

SIDE EFFECTS

There are no documented non-target impacts due to the rigorous host-specificity requirements of biological control.

ACCEPTABILITY TO STAKEHOLDERS

The release of biological control agents in Europe may face significant opposition from a number of stakeholder groups, requiring long-term public engagement activities. Opening up of infested areas would be acceptable to communities reliant on the invaded water body for recreational and economic activities. Water quality improves as the density of the infestation is reduced, thereby enhancing biodiversity and associated benefits.

Time frames required for biological control, particularly in temperate areas, are often unacceptable to managers, but the benefits of biological control far outweigh the costs, and convincing landowners and managers to see out the wait is crucial.

ADDITIONAL COST INFORMATION

Successful biological control of *S. molesta* relies on healthy plants that allow rapid population build-up of the insect populations. Most inland waters susceptible to *S. molesta* invasion are eutrophic.

LEVEL OF CONFIDENCE[1]

Medium.

Information comes from published data or expert opinion, but it is not legislated in Europe to guarantee that the results will be transposable.

1 See Appendix

Bibliography

Arson, L.G., White, P.C., Stebbing, P.D., Stentiford, G.D. and Dunn, A.M. (2014). Biosecurity and vector behaviour: Evaluating the potential threat posed by anglers and canoeists as pathways for the spread of invasive non-native species and pathogens. PLOS ONE, 9(4) https://doi.org/10.1371/journal.pone.0092788

Andreu, J., and Vilà, M. (2010). Risk analysis of potential invasive plants in Spain. *Journal for Nature Conservation*, 18(1): 34–44.

Australian Government. (2016). Weeds of National Significance. http://www.environment.gov.au/biodiversity/invasive/weeds/weeds/lists/wons.html. [Accessed 23 July 2017].

Australian Weeds Committee. (2016). Noxious Weeds List. http://www.weeds.org.au/noxious.htm. [Accessed 23 July 2017]

Booy, O., Wade, M., and Roy, H. (2015). Field guide to invasive plants and animals in Britain. Bloomsbury Publishing, UK.

Buccomino G., Buonfiglio V. and Vinci M. (2010). *Salvinia molesta* D.S. Mitch. : considerazioni sulle misure di controllo e gestione della specie aliena invasiva nel Pozzo del Merro (Sant'Angelo Romano – Roma). Annali del Museo Civico di Rovereto 26. (in stampa) Index Plantarum Florae Italicae – Indice dei nomi delle specie botaniche presenti in Italia.

Brunel, S. (2009). Pathway analysis: aquatic plants imported in 10 EPPO countries. *EPPO Bulletin*, 39(2): 201–213.

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

CABI. (2016). *Salvinia molesta* (Kariba weed). http://www.cabi.org/isc/datasheet/48447. [Accessed 23 July 2017]

Champion, P.D. and Clayton, J.S. (2001). Border control for potential aquatic weeds. Stage 2. Weed Risk assessment. *Science for Conservation*. 185.

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

Chikwenhere, G. P. and Keswani, C. L. (1997). Economics of biological control of Kariba weed (*Salvinia molesta* Mitchell) at Tengwe in north-western Zimbabwe – a case study. Inter*national Journal of Pest Management*, 43: 109–112.

Chilton, E., Jacono, C.C., Grodowitz, M. and Dugas, C. (2002). *Salvinia molesta*: Status report and action plan. *Unpublished report by the Giant Salvinia Interagency Task Force*. pp. 41.

Coetzee, J.A., Hill, M.P., Byrne, M.J., and Bownes, A. (2011). A Review of the Biological Control Programmes on *Eichhornia crassipes* (C.Mart.) Solms (Pontederiaceae), *Salvinia molesta* Dsmitch. (Salviniaceae), *Pistia stratiotes* L. (Araceae), *Myriophyllum aquaticum* (Vell.) Verdc. (Haloragaceae) and *Azolla filiculoides* Lam. (Azollaceae) in South Africa. *African Entomology*, 19: 451–468

Cook, C. (1976). Salvinia in Kerala, S. India and its control. In: Varshney C.K., Rzoska J. (eds.). Aquatic Weeds in Southeast Asia. The Hague, Netherlands: W. Junk, 241–243.

Coventry, R. (2006). Hawkesbury River: managing salvinia on the Hawkesbury – a $1.8 million cooperative effort. In: Salvina Control Annual: Management and Control for Salvinia (*Salvinia molesta*) in Australia, ed. E. van Oosterhout. Orange, Australia: NSW Department of Primary Industries, pp. 64–69.

Doeleman, J.A. (1989). Biological control of salvinia in Sri Lanka: an assessment of cost and benefits. ACIAR Technical Reports No. 12, l4p.

EPPO. (2007). EPPO Reporting service no. 1 (Rse-0701.doc) (http://archives.eppo.org/EPPOReporting/2007/Rse-0701.pdf) [Accessed 22 July 2017]

EPPO. (2012). *Salvinia molesta* (Salviniaceae). (https://www.eppo.int/INVASIVE_PLANTS/iap_list/Salvinia_molesta.htm) [Accessed 22 July 2017]

EPPO. (2014). PQR database. Paris, France: European and Mediterranean Plant Protection Organization. (http://www.eppo.int/DATABASES/pqr/pqr.htm) [Accessed 22 July 2017]

EPPO. (2016). Pest risk analysis for *Salvinia molesta*. EPPO, Paris.

EUBARnet. (2013). EUBARnet. [Accessed 22 July 2017].

Forno, I.W. (1983). Native distribution of the *Salvinia auriculata* complex and keys to species identification. *Aquatic Botany*, 7(1): 71–83.

Forno, I.W. and Harley, K.L.S. (1979). The occurrence of *Salvinia molesta* in Brazil. *Aquatic Botany*, 6(2): 185–187.

Forno, I.W. and Bourne, A.S. (1984). Studies in South America of arthropods on the *Salvinia auriculata* complex of floating ferns and their effects on *S. molesta*. *Bulletin of Entomological Research*, 74: 609–621.

Garbari. F., Giovannini, A. and Marchetti, D. (2000). [*Salvinia molesta* D.S. Mitchell (Salviniaceae) new for the Flora of Italy]. Arch. *Geobot*., 6(1): 73–78 (in Italian).

GBIF. (2016). *Salvinia molesta* Mitchell – Checklist view. (http://www.gbif.org/species/527486) [Accessed 24 July 2017]

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

Giardini, M. (2004). *Salvinia molesta* DS Mitchell (Salviniaceae): the second record for Italy (Latium) and consideration about the control of this invasive species. *Webbia*, 59(2): 457–467.

Gibbons, M.V., M.G. Rosenkranz, H.L. Gibbons, Jr. and M.D. Sytsma. (1999). Guide for Developing Integrated Aquatic Vegetation Management in Oregon. Center for Lakes and Reservoirs, Portland State University, Portland, OR. USA. pp. 113

GISIN. (2016). Information for *Salvinia molesta*. http://www.gisin.org/cwis438/websites/GISINDirectory/GISIN_ScientificName_Info.php?GISIN_ScientificNameID=36749andCallingPage=%2Fcwis438%2Fwebsites%2FGISINDirectory%2FCountry_Info.php%3FTakeAction%3DReturned%26Country_AreaID%3D314801andCallingLabel=To%20Country%20InfoandWebSiteID=4. [Accessed 24 July 2017].

GISP. (2007). Development of case studies on the economic impact of invasive weeds in Africa: *Salvinia molesta*. Psi-Delta: Victoria.

Green, A.J. (2016). The importance of waterbirds as an overlooked pathway of invasion for alien species. *Diversity and Distributions*, 22: 239–247.

Henderson, L. (2007). Invasive, naturalized and casual alien plants in southern Africa: a summary based on the Southern African Plant Invaders Atlas (SAPIA). *Bothalia*, 37: 215–248.

Hill, M.P. (2003). The impact and control of alien aquatic vegetation in South African aquatic ecosystems. *African Journal of Aquatic Science*, 28(1): 19–24.

Hill, M.P. and Coetzee, J. (2017). The biological control of aquatic weeds in South Africa: Current status and future challenges. *Bothalia*, 47(2): https://doi.org/10.4102/abc.v47i2.2152

Howell, C.J. (2008). Consolidated list of environmental weeds in New Zealand. Science and Technical Pub., Department of Conservation. pp. 42.

Hung, C. and Sukkarieh, S. (2013). Robotic aircraft and intelligent surveillance system for weed detection. 17th NSW Weeds Conference Proceedings Corowa, New South Wales, 9–12 September 2013. pp. 90–94.

Hussner, A. (2012). Alien aquatic plant species in European countries. *Weed Research*, 52(4): 297–306.

Hussner, A., Heidbuechel, P. and Heiligtag, S. (2014). Vegetative overwintering and viable seed production explain the establishment of invasive *P. stratiotes* in the thermally abnormal Erft River (North Rhine-Westphalia, Germany). *Aquatic Botany*, 119: 28–32.

Hussner, A., van de Weyer, K., Gross, E.M. and Hilt, S. (2010). Comments on increasing number and abundance of nonindigenous aquatic macrophyte species in Germany. *Weed Research*, 50: 519–526.

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

Jacono, C.C., and Pitman, B. (2001). *Salvinia molesta*: Around the world in 70 years. *Aquatic Nuisance Species Digest*, 4(2): 14–16.

Julien, M.H., Hill, M.P., and Tipping, P.W. (2009). *Salvinia molesta* DS Mitchell (Salviniaceae). Weed biological control with arthropods in the tropics. Cambridge University Press, Cambridge, 378–407.

Kam-Wing, L., and Furtado, J.I. 1977. The chemical control of *Salvinia molesta* (Mitchell) and some related toxicological studies. *Hydrobiologia*, 56(1): 49–61.

Kasselmann, C. (1995). Aquarienpflanzen. Egen Ulmer GMBH and Co., Stuttgart. 472 pp

Maddi, F.A. (2010). Contribution à l'inventaire de la flore dulçaquicole de la Guadeloupe: les « espèces exotiques envahissantes ». Bilan des prospections. Société d'Histoire Naturelle L'Herminier (Nantes, France) – DEAL (Guadeloupe): 41 p.

Martin, G.D. and Coetzee, J.A. (2011). Pet stores, aquarists and the internet trade as modes of introduction and spread of invasive macrophytes in South Africa. *Water SA*, 37: 371–380.

McFarland Nelson, D.G.L.S., Grodowitz, M.J., Smart, R.M. and Owens, C.S. (2004). *Salvinia molesta* D. Mitchell (Giant Salvinia) in the United States: A review of species ecology and approaches to management. Final Report. Vicksburg, Mississippi: US Army Corps of Engineers – Engineer Research and Development Center. pp. 35.

Miller, I.L. and Pickering, S.E. (1980). Salvinia, a noxious weed. Department of Primary Production, Div. Ag. Stock, Northern Territory, Australia, Agnote Ref. No. 80/35.

Mitchell, D.S. (1972). The Kariba weed: *Salvinia molesta*. *British Fern Gazette*, 10: 251–252.

Murphy, K.J. (1988). Aquatic weed problems and their management: a review. II. Physical control measures. *Crop Protection*, 7: 283–302.

Nagalingum, N.S., Nowark, M.D. and Pryer, K.M. (2008). Assessing phylogenetic relationships in extant heterosporous ferns (Salviniales), with a focus on *Pilularia* and *Salvinia*. *Botanical Journal of the Linnean Society*, 157: 673–685.

Nelson, L.S. 2009. Chapter 13.4: Giant and common salvinia pp. 105–111. In: Biology and control of aquatic plants: a best management practices handbook (Gettys LA, WT Haller and M Bellaud, eds.). Aquatic Ecosystem Restoration Foundation, Marietta GA. 210 pages.

NIES, 2013. *Salvinia molesta*. Invasive Species of Japan., Japan: National Institute for Environmental Studies. (http://www.nies.go.jp/biodiversity/invasive/DB/detail/81170e.html) [Accessed 23 July 2017].

Oliver, J.D. (1993). A review of the biology of Giant Salvinia (*Salvinia molesta* Mitchell). *Journal of Aquatic Plant Management* 31: 227–231.

Room, P.M. and Fernando, I.V.S. (1992). Weed invasions countered by biological control: *Salvinia molesta* and *Eichhornia crassipes* in Sri Lanka. *Aquatic Botany*, 42: 99–107.

Room, P.M., and Kerr, J.D. (1983). Temperatures experienced by the floating weed *Salvinia molesta* Mitchell and their prediction from meteorological data. *Aquatic Botany*, 16(1): 91–103.

Room, P.M. and Thomas, P.A. (1985). Nitrogen and establishment of a beetle for biological control of the floating weed salvinia in Papua New Guinea. *Journal of Applied Ecology*, 22: 139–156.

Room, P.M. and Thomas, P.A. (1986). Population growth of the floating weed *Salvinia molesta*: field observations and global model based on temperature and nitrogen. *Journal of Applied Ecology*, 23: 1013–1028.

Room, P.M., Gunatilaka, G.A., Shivanathan, P. and Fernando, I.V.S. (1989). Control of *Salvinia molesta* in Sri Lanka by Cyrtobagous salviniae. *Proceedings of the 7th International Symposium on the Biological Control of Weeds*, pp. 285–290.

Roy, H.E., Adriaens, T., Aldridge, D.C., Bacher, S., Bishop, J.D.D., Blackburn, T.M., Branquart, E., Brodie, J., Carboneras, C., Cook, E.J., Copp, G.H., Dean, H.J., Eilenberg, J., Essl, F., Gallardo, B., Garcia, M., García-Berthou, E., Genovesi, P., Hulme, P.E., Kenis, M., Kerckhof, F., Kettunen, M., Minchin, D., Nentwig, W., Nieto, A., Pergl, J., Pescott, O., Peyton, J., Preda, C., Rabitsch, W., Roques, A., Rorke, S., Scalera, R., Schindler, S., Schönrogge, K., Sewell, J., Solarz, W., Stewart, A., Tricarico, E., Vanderhoeven, S., van der Velde, G., Vilà, M., Wood, C.A. and Zenetos, A. (2015). Invasive Alien Species – Prioritising prevention efforts through horizon scanning ENV.B.2/ETU/2014/0016. European Commission.

Sainty, G.R. and Jacobs, S.W. (2003). *Waterplants in Australia. A Field Guide.* ISBN: 9780958105514. pp. 428.

Thomas, P.A. and Room, P.M. (1986). Taxonomy and control of *Salvinia molesta*. Nature, UK, 320 (6063): 581–584.

van Oosterhout, E. (2006). Salvinia control manual (Management and control options for salvinia in Australia). NSW Department of Primary Industries, New South Wales. pp. 80.

Verbrugge, L.N., Leuven, R.S.E.W., van Valkenburg, J.L.C.H., and van den Born, R.J. (2014). Evaluating stakeholder awareness and involvement in risk prevention of aquatic invasive plant species by a national code of conduct. *Aquatic Invasions* 9(3): 369–381.

Whiteman, J.B., and Room, P.M. (1991). Temperatures lethal to *Salvinia molesta* Mitchell. *Aquatic Botany*, 40(1): 27–35.

Yamoah, E., Gill, G.S.C. and Massey, E. (2013). Eradication programme for four noxious weeds in New Zealand. New Zealand Plant Protection. New Zealand Plant Protection Society's Annual Conference, Napier War Memorial Conference Centre, Napier, New Zealand, 13–15 August 2013. 66: 40–44. (http://www.nzpps.org/journal/66/nzpp_660400.pdf) [Accessed 25 July 2017].

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.

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