EUROPEAN AND MEDITERRANEAN PLANT PROTECTION ORGANIZATION
ORGANISATION EUROPEENNE ET MEDITERRANEENNE POUR LA PROTECTION DES PLANTES

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Pest Risk assessment for

Salvinia molesta

2017

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This pest risk assessment scheme has been specifically amended from the EPPO Decision-Support Scheme for an Express Pest Risk Analysis document PM 5/5(1) to incorporate the minimum requirements for risk assessment when considering invasive alien plant species under the EU Regulation 1143/2014. Amendments and use are specific to the LIFE Project (LIFE15 PRE FR 001) 'Mitigating the threat of invasive alien plants to the EU through pest risk analysis to support the Regulation 1143/2014'.

Photo: *Salvinia molesta* in Florida USA Courtesy: Michael D. Netherland

EUROPEAN AND MEDITERRANEAN PLANT PROTECTION ORGANIZATION

Pest risk assessment for *Salvinia molesta* D.S. Mitch.

This PRA follows EPPO Standard PM5/5 Decision support scheme for an Express Pest Risk Analysis

PRA area: EPPO region **First draft prepared by:** Oliver Pescott
Location and date: Paris (FR), 2016-05-23/27

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The pest risk assessment for *Salvinia molesta* has been performed under the LIFE funded project:

LIFE15 PRE FR 001

Mitigating the threat of invasive alien plants to the EU through pest risk analysis to support the Regulation 1143/2014

In partnership with

EUROPEAN AND MEDITERRANEAN PLANT PROTECTION ORGANIZATION

And

NERC CENTRE FOR ECOLOGY AND HYDROLOGY

Review Process

- This PRA on *Salvinia molesta* was first drafted by Dr Oliver Pescott

- The PRA was evaluated under an expert working group at the EPPO headquarters between 2016-05-23/27.

- Following the finalisation of the document by the expert working group the PRA was peer reviewed by the following:

  (1) The EPPO Panel on Invasive Alien Plants (June and July 2016)
  (2) The EPPO PRA Core members (August and September 2016)
  (3) The Scientific Forum on invasive alien species (2017)[1]

Approved by the Scientific Forum on 19/03/2018

[1] Additional information has been included in the original document following review from the Scientific Forum on invasive alien species

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Summary[2] of the Express Pest Risk assessment for *Salvinia molesta*

PRA area: EPPO region (see https://www.eppo.int/ABOUT_EPPO/images/clickable_map.htm.)

Describe the endangered area: The endangered area is the Mediterranean biogeographical region (EU Member States: France, Greece, Italy, Portugal, Spain; wider EPPO region: Albania, Algeria, Morocco, Turkey, Tunisia).

Climate modelling suggests that *Salvinia molesta* is capable of establishing in the Mediterranean biogeographical region within the EPPO region including the European Union (EU). The species is capable of limited establishment in small areas of the Black Sea (Georgia) and Atlantic (France) biogeographical regions.

Salvinia molesta has already been reported as introduced, with transient populations in space and time in Austria, Belgium, France (Corsica only), Germany, Italy, Netherlands, Portugal and Israel.

Main conclusions

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

The risk of the species being introduced into other EPPO countries is considered high as the plant is widely traded especially in the EU.

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.

Based on evidence elsewhere in the world, important ecosystem services are likely to be adversely affected by the presence of the plant. Impacts are likely to be more pronounced in countries and regions where the climate is most suited to establishment, growth and spread.

Entry and establishment

In Europe, *S. molesta* has been found in Austria, Belgium, France (Corsica), Germany, Italy, the Netherlands and Portugal, but it is not clear if reports in the southern countries represent established populations. The overall likelihood of *S. molesta* entering the EPPO region is high.

The pathways identified are:
Plants for planting (high likelihood of entry)
Contaminant of plants for planting (low likelihood of entry)
Contaminant of leisure equipment (low likelihood of entry)

Salvinia molesta may establish throughout climatically and chemically suitable aquatic habitats within the EPPO region. Climate change could increase the likelihood of establishment, spread and impact in more areas of the EPPO region.

Potential impacts in the PRA area

Aquatic free floating plants are highly opportunistic and have the ability to exploit novel habitats. Other non-native mat forming species have been shown to have high impacts in the PRA area.

[2] The summary should be elaborated once the analysis is completed

The potential economic impact of *Salvinia molesta* in the EPPO region could be highly significant if the species spreads and establishes in further areas. There is potential for the species to impede transport and affect recreation, irrigation and drainage. Based on experience elsewhere in the world, management is likely to be both expensive and difficult. There are no host specific natural enemies in the EPPO region to regulate the pest species, and in many EPPO countries herbicide application in or around water bodies is highly regulated or not permitted.

Impacts in the EPPO area will likely be attenuated by climatic suitability, but, in areas where *S. molesta* is able to establish and spread, impacts are likely to be similar unless under control. For example, many of the impacts on biodiversity relate to ecosystem processes such as decomposition and the alteration of nutrient cycling, which, assuming that *S. molesta* is able to reach the levels of abundance required for these impacts to be displayed, can be assumed to occur in these areas to the same extent as in the current area of distribution.

Europe has several atypical aquatic thermal habitats such as thermal streams and waters affected by thermal discharge from industry. This may expand impacts into areas that would otherwise be considered climatically unsuitable by coarse environmental modelling. For example, the Hungarian thermal streams and the Italian Fosso Dell'Acqua calda near Pisa (Garbari et al., 2000). If these waters are connected to more typical waters they may act as a permanent source of propagules (this has been shown for *Pistia stratiotes,* Hussner *et al*., 2014).

The text within this section relates equally to EU Member States and non-EU Member States in the EPPO region.

Climate change
By the 2070s, under climate change scenario RCP8.5, projected suitability for *S. molesta* increases in the countries projected as containing currently suitable regions, and also in western Europe. Relaxation of frost constraints meant that the model projected high suitability in the Pannonian Plain (Hungary, Serbia and Croatia) and the northern coast of the Black Sea, as well as moderate suitability in much of northern France, UK, Belgium, Netherlands, Germany and the coasts of Denmark and southern Sweden. Therefore, the model suggests climate change could facilitate a major expansion of the invaded range of the species in Europe and this will include the Mediterranean, Atlantic, Continental, Boreal biogeographical regions.

Phytosanitary measures:
The results of this PRA show that *S. molesta* poses an unacceptable risk to the current and projected endangered area (mainly the Mediterranean biogeographical region) with a moderate uncertainty.

Phytosanitary risk for the *<u>endangered area</u>* (current/future climate) **Pathways for entry:** Plants for planting: High/high Contaminant of plants for planting: Low/Low Contaminant of leisure equipment: Low/Low Establishment (natural): High/High Establishment (managed): High/High Spread: Moderate/Moderate **Impact (current area of distribution)** Impact on biodiversity: High/High Impact on ecosystem services: High/High	High **X**	Moderate ☐	Low ☐

Socio-economic impact: High/High **Impact (PRA area)** Impact on biodiversity: High/High Impact on ecosystem services: High/High Socio-economic impact: High/High			
Level of uncertainty of assessment (current/future climate) **Pathways for entry:** Plants for planting: Low/Low Contaminant of plants for planting: Low/Low Contaminant of leisure equipment: Moderate/Moderate Establishment (natural): Moderate/Moderate Establishment (managed): Low/Low Spread: Moderate/Moderate **Impact (current area of distribution)** Impact on biodiversity: Moderate Impact on ecosystem services: Moderate Socio-economic impact: Moderate **Impact (PRA area)** Impact on biodiversity: High/High Impact on ecosystem services: High/High Socio-economic impact: High/High	High ☐	Moderate X	Low ☐

Other recommendations:

Inform EPPO or IPPC or EU

- Inform NPPOs that surveys are needed to confirm the distribution of the plant, in particular in the area where the plant is present; and on the priority to eradicate the species from the invaded area.

Inform industry, other stakeholders

- Encourage industry to assist with public education campaigns associated with the risk of aquatic non-native plants.

Specify if surveys are recommended to confirm the pest status

- Surveys should be conducted to confirm the current distribution and status of the species within the endangered area and this information should be shared within the PRA area

Express Pest Risk assessment: *Salvinia molesta*

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Stage 1. Initiation

Reason for performing the PRA:
Salvinia molesta has a limited distribution in the EPPO area, but is present in the natural environment. Although in EPPO countries the plant is reportedly restricted to small areas and has been subject to control measures in some of these areas, evidence from other parts of the world suggests that spread can be rapid and impacts considerable if the species' environmental requirements are met. The most serious impacts of this species are due to its ability to form thick mats on the surface of water bodies, potentially resulting in losses of native biodiversity and negative socio-economic impacts. It should be noted that there are no reported ecological or economic impacts of the species within the EPPO region. *S. molesta* was evaluated through a revised EPPO prioritisation scheme in 2016, (where the revisions were made to be compliant with the EU Regulation 1143/2014) and was considered to be a high priority for a PRA given its potential for further spread within the EPPO area, and the fact that cost-effective control may be possible through trade restrictions. The species has been on the EPPO 'List of Alien Invasive Plants' since 2012, prior to that it was on the EPPO 'Alert List' from 2007. In addition, *S. molesta* was added to the IUCN List of "100 of the World's Worse Invasive Alien Species" in 2013 (Courchamp, 2013). Although it is not clear that introductions of this species to the EPPO area have increased in the recent past, recent records from Italy and Corsica lend some weight to this perspective; the continued availability of this plant for purchase within EPPO countries, coupled with a warming climate, mean that a PRA is required.

PRA area:
The EPPO region (see https://www.eppo.int/ABOUT_EPPO/images/clickable_map.htm.)

Stage 2. Pest risk assessment

1. Taxonomy:

Salvinia molesta D.S. Mitch. (Kingdom Plantae; Phylum Pteridophyta; Class Polypodiopsida; Order Salviniales; Family Salviniaceae; Genus *Salvinia*). (Mitchell, 1972).

EPPO Code: SAVMO

Homonym: *S.* ×*molesta* D.S. Mitch. (note that under the Vienna code, Note 1, section H3.3. "taxa which are believed to be of hybrid origin need not be designated as nothotaxa").

Synonymy: *S. auriculata* auct. non Aubl. (often given in the more general formulation of *S. auriculata* auct.); *S. adnata* Desv. (note that some databases give this as the currently accepted name, e.g. http://www.theplantlist.org).

Note: de la Sota (1995) proposed that the earlier name *S. adnata* Desv. should replace *S. molesta* D.S. Mitch.; however, Moran & Smith (1999) argued that the name *S. adnata* is of uncertain application due to the type specimen of Desvaux consisting of vegetative material only, and that the name *S. molesta* should therefore be maintained.

Common names: African payal; African pyle; aquarium watermoss; Australian azolla; giant azolla; giant salvinia; Kariba weed; salvinia; salvinia moss; water fern; water spangles. Dutch: grote vlotvaren, Germany: Bueschelfarn, Lästiger Schwimmfarn, Portugal: murure-carrapatinho; China: 人厌槐叶苹 ren yan huai ye ping; Taiwan: 人厭槐菜蘋.

Plant type: Perennial floating aquatic fern (Harley & Mitchell, 1981)

Related species in the EPPO region:

Native species: *Salvinia natans* (L.) All. This species makes up a protected habitat: Revised Annex I of Resolution 4 (1996) of the Bern Convention on endangered natural habitats types using the EUNIS habitat classification (year of revision 2014)

Non-native species: *Salvinia auriculata* Aubl. **Note** that this list of non-native species is according to GBIF, and no thorough search of the literature has been performed. The expert working group considers there is some doubt about the record of this species within the EPPO region.

2. Pest overview

Introduction

Salvinia molesta is native to Brazil (Forno & Harley, 1979); it is thought to have arisen as a hybrid between two other *Salvinia* species (Mitchell, 1972; Forno, 1983). Given this, it is possible that the hybrid consists of multiple lineages with independent origins, however, there have apparently been no genetic studies on this topic to date. *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 (O.L. Pescott, April 2016; information compiled from: GBIF, 2016; GISIN, 2016; EPPO, 2016) in addition to Brazil. Note that some of these occurrences may have been transient. 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). In the EPPO region the species has so far been reported from Austria, Belgium, France (including Corsica), Germany, Italy, Netherlands, Portugal, United Kingdom and Israel but with occurrences apparently of limited extent. It is also important to note here that some of the reports from the EPPO region may refer to deposited herbarium vouchers from outside the region, as well as sightings from within, or established populations. Species distribution models suggest that the endangered area is the Mediterranean biogeographical region (see appendix 1 and 2). Southern countries within the EPPO region provide suitable climatic conditions for the plant. This includes all areas in which the water bodies are not enclosed in ice during the winter months. Furthermore, thermal waters in other EPPO countries provide potential habitats for *S. molesta*, and the suitable area is likely to increase under likely scenarios of climate change (e.g. Hallstan, 2005).

Environmental requirements

Harley & Mitchell (1981) state that *S. molesta* "grows best in sheltered, still, tropical waters", but that "[in] temperate climates the plant can withstand occasional frosts and freezing of the water surface" (also see Owen *et al.*, 2004a); however, the plant is killed "if very low temperatures persist" (Harley & Mitchell, 1981). Growth rates are reportedly more dependent on water temperature than air temperature (Harley & Mitchell, 1981); Room & Kerr (1983) found that the inclusion of water temperature data in models of *S. molesta* leaf temperature improved model fit considerably, although meteorological data were still important. Owen *et al.* (2004a) report that plants can withstand short (48 hours) air frosts of -3 °C in experimental ponds, and that complete freezing of the water layers occupied by *S. molesta* was required to completely destroy the plant. Note that the mats often formed by this species can increase its resistance to frosts above what would be expected from its intrinsic physiological tolerance, however, below 10 °C growth rates are markedly reduced, and dense mats have apparently not been observed (Harley & Mitchell, 1981). In the USA, thick mats of the plant (up to 30 cm) can withstand temperatures of -10 ^{o}C for periods of 48 – 72 hours (Personal communication, Michael Netherland, US Army Engineer Research and Development Center, 2016). Other work using growth chambers has indicated that *S. molesta* is killed when its buds are exposed to temperatures < -3°C or > 43°C for > 2-3 hours (Whiteman & Room, 1991). Whiteman & Room (1991) also state that "[n]ear its limits in hot and cold climates, the plant is more likely to survive in larger bodies of water whose larger thermal capacity dampens temperature fluctuations."

Salvinia molesta will tolerate a wide range of variation in water nutrient content, but its rate of growth is most rapid in nutrient-rich conditions. Plants can survive in waters with a salinity of around 20% of that of sea water, although rates of growth are decreased under these conditions (Harley & Mitchell, 1981). With respect to the above information, it is worth noting that experiments and observations relating to the environmental requirements of *S. molesta* may not necessarily cover the entire range of its niche, particularly if invasive populations around the world represent different genotypes or independent hybridisation events. In some waters the species can alter the water chemistry from more alkaline to acidic habitat, which favours its growth (Owens and Smart, 2004a). The optimum growth rate is in waters around pH 6 – 7 (McFarland et al., 2004, Cary and Weerts, 1984; Owens and Smart, 2004b).

Salvinia molesta is capable of high relative growth rates: reported doubling times for leaves are 2.2 days for mid-summer and 40-60 days in winter for Queensland, Australia (Farrell, 1979); doubling times for sewage lagoons made by the same author in the same area were 1.4-33 days (Farrell, 1979). Other reported doubling times for the different growth forms of *S. molesta* (see the **Identification** section below), and for laboratory experiments, are typically below 12 days (Gaudet, 1973; Mitchell & Tur, 1975; Harley & Mitchell, 1981).

Habitats
Salvinia molesta is most often found in stagnant or slow-flowing waters such as lakes, slow-flowing rivers or streams, wetlands, rice paddies, irrigation channels, ditches, ponds and canals (EPPO, 2016). See also the **Environmental requirements** section above.

Identification
Salvinia molesta is a free-floating fern (see Figure 1; Appendix 3); in general it is considered easily recognizable by botanists, although some sources state that juvenile forms may be confused with *Azolla* spp. (Weedbusters, 2016). The three growth stages (primary, secondary and tertiary), may also make identification of the species difficult (Julien *et al*., 2009). The small-leafed primary stage is typical of plants invading open water. The secondary form is slightly larger with leaves slightly folded, and the tertiary stage is typical of mature stands with larger deeply folded and densely packed leaves. 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*. The species' fronds are positioned in whorls of three along a rhizome, with individual plants growing up to 30 cm. One of the fronds is submerged and is root-like in appearance. The two floating fronds have oblong to obovate or orbicular lamina, a rounded or cordate base and emarginate apex; these fronds typically measure around 2.5 × 2.4-3 cm (length × width; Lin *et al.*, 2013), although the floating fronds of some forms can be considerably smaller, and larger forms (up to 5 cm, rarely larger) have also been reported (Harley & Mitchell, 1981). The floating fronds are oppositely positioned, and are either flat or infolded along the costa; when infolded their appearance has been compared to the wings of a butterfly. 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. As plants develop lateral branches in crowded conditions they can become interlocked, producing a mat; additional growth can lead to plants overgrowing each over, resulting in mats 3-4 plants thick (Harley & Mitchell, 1981). Mats as thick as 1 m have also been reported resulting from the overgrowing and interweaving of dead and living plants (Harley & Mitchell, 1981; Thomas & Room, 1986). Sporocarps are in long chains of up to 55, around 1 mm in diameter; however, the plant is sterile, and the sporocarps contain only empty sporangia or deformed spores.

Symptoms
Mats of *S. molesta* can cause similar problems to those caused by excessive growth of other floating plants; for example, they can reduce access to the water for recreation; interfere with various engineering structures such as weirs, floodgates or locks; block drains and cause flooding; stop livestock reaching water; prevent photosynthesis in the water below the mat; degrade potable water; impact on native animals and plants more generally by significantly altering aquatic ecosystems; reduce the aesthetic appeal of water bodies; and favour the spread of certain diseases spread by mosquitos and snails (Mitchell, 1978; Oliver 1993). The combination of dense mats and wave action may uproot native emergent species (Personal Communication, Michael Netherland, US Army Engineer Research and Development Center, 2016).

Relevant PRAs

Note The fact that a plant is included on a "black list" or a piece of national legislation does not necessarily imply that a formal PRA has taken place, although this may be a requirement in some countries. In several cases below, although formal PRAs may have taken place, they have not proven straightforward to locate.

Australia: A Weed Risk Assessment (WRA) for Australia resulted in a score of 19 and the conclusion that the species should be "reject[ed] for import" (PIER, 2001).

New Zealand: A risk assessment has been produced where the species scored 57 points out of a maximum of 100 points, indicating a high risk (Champion and Clayton, 2001).

Europe (overall): The current PRA is being conducted under the LIFE project (LIFE15 PRE FR 001) within the context of European Union regulation 1143/2014, which requires that a list of invasive alien species (IAS) be drawn up to support future early warning systems, control and eradication of IAS.

Great Britain: *S. molesta* was recently subject to a Rapid Risk Assessment by the GB Non-Native Species Secretariat (Newman, 2016). Although the risk of entry was considered "very likely" with "very high" confidence, assessments of establishment, spread and impacts were "very unlikely", "very slow" and "minimal" respectively, all with "high" confidence, resulting in an overall risk rating of "low". This result was largely due to the conclusion that regular frosts below -3 °C and low air temperatures (< 10 °C) in January are likely to restrict establishment and spread until the year 2100 (based on 6 climate change scenarios).

Spain: Andreu & Vilà (2010) performed 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 & Vilà, 2009).

USA: A WRA for Hawaii conducted by the Pacific Island Ecosystems at Risk (PIER) program resulted in a high score of 29 and the conclusion that the species was "likely to be of high risk" (PIER, 2005). McFarland *et al.* (2004) provide a comprehensive overview of the ecology and management of *S. molesta*, with a focus on infestations in the USA, although they do not provide a formal assessment of risk. A separate risk assessment scored the species 72 points (where the threshold was 31 points), classifying the species as an invader (Gordon *et al*., 2012).

Benefits

Harley & Mitchell (1981) state that the dense growth of the plant could be used for removing excess nutrients or pollutants from water bodies, with the removed biomass being a "satisfactory" mulch. However, this methodology is rarely practiced due to it being generally found to be uneconomical (McFarland *et al*., 2004). Vandecasteele et al. (2005) and Henry-Silva and Camargo (2006) argued that the plant was efficient in the removal of nutrients (mainly total nitrogen and total phosphorus). In addition, Vandecasteele et al. (2005) highlight that the potential of using the biomass as plant compost, biogas production and animal feed should be considered. However, at present these uses are not practiced within the EU.

Salvinia molesta is widely sold as an ornamental species within the EU and the EPPO region. The species is also sold/exchanged between aquarists. The species regularly features on aquatic plant websites. The Ornamental Aquatic Trade Association (UK based) carried out a survey with its members in August 2016 requesting advise on the number of plants and value that they had sold in the calendar year for 2015. Thirty-three members responded to this survey and detailed that in total 17 256 *S. molesta* plants were sold in the UK in 2015 with a value of GBP 28 200. According to van der Valk et al. (2018), the total trade value of *Salvinia molesta* as pond and aquarium plant in the Netherlands, where it is sometimes mislabelled as *Salvinia natans*, is estimated to be between 100,000 and 200,000 euro/year.

3. Is the pest a vector?	No
4. Is a vector needed for pest entry or spread?	No

5. Regulatory status of the pest

Europe (overall): *S. molesta* was evaluated through the EPPO prioritisation scheme in 2016, and was considered to be a high priority for a PRA given its potential for further spread within the EPPO area, and the fact that cost-effective control may be possible through trade restrictions. The species has been on the EPPO "List of Alien Invasive Plants" since 2012; prior to that it was on the EPPO "Alert List" from 2007. *S. molesta* was also assessed under an all-taxa horizon scanning exercise designed to help prioritise risk assessments for the "most threatening new and emerging invasive alien species" in Europe (Roy *et al.*, 2015); however, *S. molesta* was not included on the final list produced by that project.

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).

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.

Japan: *S. molesta* is subject to legal control https://www.nies.go.jp/biodiversity/invasive/DB/etoc8_plants.html

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).

6. Distribution

Continent	**Distribution** *(list countries, or provide a general indication , e.g. present in West Africa)*	***Provide comments on the pest status in the different countries where it occurs*** *(e.g. widespread, native, introduced….)*	***Reference***
Africa	Benin, Botswana, Burkina Faso, Cameroon, Democratic Republic of the Congo, Republic of the Congo, Côte d'Ivoire, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mozambique, Namibia, Nigeria, Senegal, South Africa, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe,	Introduced, established and locally invasive and still spreading unless under biological control.	Mitchell and Tur (1975), Marshall & Junor (1981), Greathead and de Groot (1993), Cilliers (1991), Smith (1993), Njuguna and Thital (1993), de Wet (1993), Cilliers *et al.* (2003), Hill (2003), Mbati & Neuenschwander 2005, GSIP (2007), Berthe and Kone (2008), Diop and Hill (2009), EPPO (2014)
Central and South America	Argentina, Brazil, Colombia, Cuba, Guatemala, Guyana, Trinidad and Tobago, Martinique, Guadeloupe	Native to Brazil. Probably introduced and locally invasive in other countries detailed.	Forno (1983), Maddi 2010 & 2014
North America	Mexico, USA (Alabama, Arizona, Arkansas, California, Connecticut, Florida, Georgia, Hawaii, Kansas, Louisiana, Maryland, Mississippi, Missouri, New Jersey, New Mexico, North Carolina, Oklahoma, Oregon, Pennsylvania, Texas, Virginia, Washington)	Introduced, established and locally invasive and still spreading unless under biological and chemical control.	Gunn and Ritchie (1982), Jacono & Pitman (2001), Jiménez *et al.* (2003), McFarland *et al.* (2004), Mora-Olivo & Yatskievych (2009)
Asia	India, Indonesia, Israel, Japan, Malaysia, Mauritius, Pakistan, Singapore, Sri Lanka, Taiwan, Thailand, Philippines	Introduced, established and locally invasive and still spreading unless under biological control (in some countries).	Cook & Gut (1971), Cook (1976), Joy (1978), Lorence (1978), Thomas (1979, 1981), Wee (1986), Corlett (1988), Jayanth and Singh (1993), Pallewatta *et al.* (2003), Chen *et al.* (2008), Qureshi (2008), Imran *et al.* (2013), NIES (2013), EPPO (2014), McFarland *et al.* (2004),
Europe	Austria, Belgium, France (including Corsica), Germany, Italy, Netherlands, Portugal Biogeographical regions: Atlantic, Continental and Mediterranean.	In all countries, introduced, transient populations in space and time.	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (ed.) 2013; Margot (1983), Garbari *et al.* (2000), Giardini *et al.* (2004), Garcia (2008), Hussner et al., 2010), Ofenböck (2008), Julien

Continent	***Distribution*** *(list countries, or provide a general indication , e.g. present in West Africa)*	***Provide comments on the pest status in the different countries where it occurs*** *(e.g. widespread, native, introduced….)*	***Reference***
			et al. (2009), Paradis and Miniconi (2011), Hussner (2012), EPPO (2014), GEFD (2016), (Verloove, 2006). Buccomino et al., 2010
Oceania	Australia, Fiji, New Zealand, Papua New Guinea, Vanuatu	Introduced, established and locally invasive and still spreading unless under biological and chemical control.	Farrell (1978, 1979), Mitchell (1979), Sundaresan & Reddy (1979), Parsons & Cuthbertson (1992), Considine (1984/ 1985), Yamoah *et al.* (2013)

Introduction

Salvinia molesta is native to south-eastern Brazil (Forno, 1983) and has spread widely throughout the world becoming an invasive alien species in many regions (see Appendix 4, Figure 1 for global distribution). The species is widespread in Africa (occurring in over 20 countries), the Indian subcontinent, Southeast Asia, Australia, New Zealand, Southern USA and some Pacific islands (Thomas and Room, 1986).

Africa

Major infestations of *S. molesta* have occurred in lake/riparian systems in Africa, including the Chobe-Linyata-Kwando River systems, Lake Naivasha and Lake Kariba on the Zambezi River. In the case of the latter, in 1962 at the peak occurrence of the species, over a quarter of the lake was covered by the plant (McFarland *et al*., 2004). Mainly biological control programs have taken place in other countries (e.g. Cilliers et al., 2003; Pieterse *et al.*, 2003; Julien *et al.*, 2009). See Appendix 4, Figure 2 for the distribution of the species in Africa.

Central and South America

Salvinia molesta is native to Brazil in the subtropical zone (between latitudes 24º 05’ S and 32º 05’ S) at elevations up to 900 m (McFarland *et al*., 2004). Its status in other countries of South America appears less certain (e.g. cf. Holm *et al.*, 1979; CABI 2016; EPPO 2016). See Appendix 4, Figure 3 for the distribution of the species in South America.

North America

Salvinia molesta has been cultivated as an ornamental plant since the 1980s (McFarland *et al*., 2004). *S. molesta* was first observed in the wild in the USA in South Carolina in 1995 (Jacono & Pitman 2001). In 1998, the species was identified in Texas and Louisiana; both states are still dealing with new infestations of this weed. Florida, Alabama, Mississippi, Hawaii, Arizona, California and Georgia all reported initial infestations of *S. molesta* in 1999. North Carolina first reported a population of *S. molesta* in 2000. The latest State to report the presence of *S. molesta* was Virginia in 2004. In Florida, before the species had been recorded in the wild it had been intercepted at two aquatic plant nurseries as a containment of aquatic plant shipments from Sri Lanka (Oliver, 1993). See Appendix 4, Figure 4 for the distribution of the species in North America.

Asia

The first established population outside its native range was in Sri Lanka in 1939 where it was introduced via the Botanical Department of the University of Colombo (Oliver, 1993). Impacts in the state of Kerala, India have been much discussed in the literature (Cook & Gut, 1971; Cook, 1976), although more recently its impact may have been reduced through competition with other invasive alien species (e.g. Chauhan & Gopal, 2005). See Appendix 4, Figure 5 for the distribution of the species in Asia. In Israel, S. molesta is classified as a casual species (Dufour-Dror, 2012).

Europe

Salvinia molesta has been found in Austria, Belgium, France (Corsica), Germany, Italy, the Netherlands and Portugal, but it is not clear if reports represent established populations. In France, the species was first found in Corsica in 2010, in a water reservoir (Paradis and Miniconi, 2011; see also the following article here). In 2013, it has also been found in a small ditch near the Salagou Lake, 40 km NW of Montpellier where the few plants observed together with *Myriophyllum aquaticum* were immediately removed (Fried, pers. com. 2016, SILENE, 2016). In Italy, the species was found in the Fosso del Acqua calda canal near Pisa in 2000 (Gabari *et al.*, 2000), and in the Rome area (the Pozzo del Merro lake, Lazio) in 2003 (Buccomimo *et al*., 2010; Giardini, 2004). *S. molesta* was eradicated from Rome in 2012 (CABI, 2016). In Portugal the species is found in Odemira, in the Algarve (EPPO, 2016). In Germany it is reported as a casual from the Rhineland-Palatinate (GEFD, 2016). It is not clear whether older localities, such as that noted by Margot (1983) in Belgium still persist (Verloove, 2006). See Appendix 4, Figure 6 for the distribution of the species in Europe.

Oceania

Salvinia molesta was introduced into Papua New Guinea in 1972, where a few plants were introduced into the Sepik River floodplain. Eight years later, the infestation had reached over 250 km^2 (Oliver, 1993). Sundaresan & Reddy (1979) reported on two large infestations in Fiji (the Rewa delta and the Waidalice River), noting impacts on rice fields. In Australia, *S. molesta* was first recorded in 1952. By 1976 the species had spread to many rivers and lakes overtaking the occurrence of other aquatic plant pests like *Eichhornia crassipes* (Cronk and Fuller, 2001; but cf. the reports of Chauhan & Gopal 2005 for India). See Appendix 4, Figure 7 for the distribution of the species in Australia and New Zealand.

7. Habitats and their distribution in the PRA area

Habitats	**EUNIS habitat types**	**Status of habitat (eg threatened or protected)**	**Present in PRA area (Yes/No)**	**Comments (e.g. *major/minor habitats* in the PRA area)**	***Reference(s)***
Freshwater bodies (e.g. canals, ponds, rivers (slow-moving), streams, canals, ditches, irrigation channels, estuaries, reservoirs, and lakes)	C1: Surface standing waters C2: Surface running waters	Protected *pro parte*: e.g. Annex 1 **Standing freshwater habitats:** 22.11 x 22.31, 22.11 x 22.34, 22.12 x (22.31 and 22.32), 22.12 x 22.44, 22.13, 22.14, 22.34. **Running freshwater habitats:** 24.225, 24.4, 24.52, 24.53 (see Habitats Directive PDF for definitions). Parts of **estuaries and lagoons** (Annex 1 habitat codes 13.2 and 21) may also be at risk if the salinity is relatively low)	Yes	Major habitats within the PRA area	Garbari *et al.* (2000); Giardini (2004); Margot (1983); Paradis & Miniconi (2011)
Wetlands	C3: Littoral zone of inland surface waterbodies	None known.	Yes	Major habitats within the PRA area	None known, but marginal habitats – e.g. C3.5 Periodically inundated shores with pioneer and ephemeral vegetation – seem likely to be affected. The presence of the species in rice paddies in other parts of the world also attests to the potential of *S. molesta* to invade tall helophyte communities (e.g. Sundaresan & Reddy, 1979).

Salvinia molesta is most often found in stagnant or slow-flowing waters such as lakes, slow-flowing rivers or streams, wetlands, rice paddies, irrigation channels, ditches, ponds and canals (EPPO, 2016).

Freshwater habitats are widely distributed throughout the EPPO region, with many freshwater bodies and wetland sites are protected within the EPPO region. Freshwater habitats are detailed within the Habitats Directive 1992 and the Water Framework Directive 2000. Such habitats often harbour rare or endangered species.

8. Pathways for entry *(in order of importance)*

Possible pathways	Pathway: Plants for planting (CBD terminology: Escape from confinement)
Short description explaining why it is considered as a pathway	*Salvinia molesta* is used in aquaria, and as an ornamental plant for outdoor ponds (where it may be mislabelled as *Salvinia natans* (L.) All.; Brunel 2009 considered this 'likely'). The species is also traded informally between aquatic plant enthusiasts. The Ornamental Aquatic Trade Association (UK based) carried out a survey with its members in August 2016 requesting advise on the number of plants and value that they had sold in the calendar year for 2015. Thirty-three members responded to this survey and detailed that in total 17 256 *S. molesta* plants were sold in the UK in 2015 with a value of GBP 28 200.
Is the pathway prohibited in the PRA area?	In 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.
Has the pest already been intercepted on the pathway?	Yes because it's the commodity itself but has been commonly mislabelled as *Salvinia natans*. In general all plants labelled as *Salvinia*, could be *S. molesta*. The size measurements and images for plants described as 'tropical *Salvinia natans*' or 'butterfly wings' on websites such as eBay make it seem highly likely that *S. molesta* is being traded.
What is the most likely stage associated with the pathway?	All three growth forms of the plant would be associated with this pathway.
What are the important factors for association with the pathway?	Plants may be widely available by mail order if mislabelling is common, for example see http://www.ebay.co.uk/itm/Salvinia-Natans-Water-Butterfly-Wings-Live-Tropical-Floating-Aquarium-Plants/131510644664?hash=item1e9ea52fb8:m:mvvpX0mIPhEWtMAXD-XT6lQ . However, the bulk of material (approximately 95%) is produced within the EPPO region.
Is the pest likely to survive transport and storage in this pathway?	Yes. As an import for ornamental purposes; plant survival is obviously essential for the intended use.
Can the pest transfer from this pathway to a suitable habitat?	Yes, through human agency (i.e. intentional introductions or the unintentional disposal (contamination) of plants into wild habitats). The species could be misused and introduced directly into freshwater bodies and ecosystems (e.g. stream, lakes, dams). The unintended habitats are freshwater bodies and ecosystems (semi-natural and natural waterbodies). Plants used in confined waterbodies could spread to unintended habitats very easily through human activities as well as through natural spread by floods downstream. Inappropriate disposal of aquarium contents has been documented as an accidental pathway promoting the spread of aquatic plants in some countries (e.g. *Cabomba caroliniana* in the Netherlands, see the EPPO PRA on the species; *Hydrilla verticillata* in the USA; Langeland, 1996).

	In France, in the location near the Salagou Lake, it is thought that *Salvinia molesta* has reached the ditch after a strong flooding event (that are common in this region) that may have spread the plants from an outdoor ponds that has been localized upstream.
Will the volume of movement along the pathway support entry?	The species is already produced within the EPPO region and therefore the volume of movement from outside the region will not support entry unless production ceases or is reduced within the EPPO region.
Will the frequency of movement along the pathway support entry?	As per the question above.
Likelihood of entry	*Low* ☐ *Moderate* ☐ *High* X
Rating of uncertainty	*Low* X *Moderate* ☐ *High* ☐

As the species is imported as a commodity, all European biogeographical regions will have the same likelihood of entry and uncertainty scores.

Possible pathways	***Pathway:* Contaminant of plants for planting** (CBD terminology: Transport- contaminant)
Short description explaining why it is considered as a pathway	Where multiple aquatic plants are collected from the wild or bred for sale, it is possible that *S. molesta* could contaminate shipments (Oliver, 1993).
Is the pathway prohibited in the PRA area?	No – checks for contaminants of other plants traded for aquaria or ornament are not currently required.
Has the pest already intercepted on the pathway?	No, but this pathway has been found in other countries (Maki and Galatowitsch, 2004).
What is the most likely stage associated with the pathway?	All three growth forms of the plant would be associated with this pathway.
What are the important factors for association with the pathway?	Aquatic plants are produced in locations where multiple species are being produced and handled therefore contamination may occur.
Is the pest likely to survive transport and storage in this pathway?	Yes, plant survival is an inherent part of the pathway.
Can the pest transfer from this pathway to a suitable habitat?	Yes, through human agency (i.e. intentional introductions or the unintentional disposal of plants into wild habitats). The species could be misused and introduced directly into freshwater bodies and ecosystems (e.g. stream, lakes, dams). The unintended habitats are freshwater bodies and ecosystems (semi-natural and natural waterbodies). Plants used in confined waterbodies could spread to unintended habitats very easily through human activities as well as through natural spread by floods downstream. Improper disposal of aquarium contents has been a source of introduction of aquatic plants in some countries, even if it is considered as an accidental pathway of introduction (e.g. *Cabomba caroliniana* in the Netherlands, see the EPPO PRA on the species; *Hydrilla verticillata* in the USA; Langeland, 1996).
Will the volume of movement along the pathway support entry?	No. The volume of movement as a contaminant along this pathway would be low.
Will the frequency of movement along the pathway support entry?	No. The frequency of movement as a contaminant would be low.
Likelihood of entry	*Low* X *Moderate* ☐ *High* ☐
Rating of uncertainty	*Low* X *Moderate* ☐ *High*

All European biogeographical regions will have the same likelihood of entry and uncertainty scores.

Possible pathways	***Pathway:*** **Contaminant of leisure equipment** **(CBD terminology: Transport – stowaway)**
Short description explaining why it is considered as a pathway	It is possible that the use of recreational equipment (e.g. fishing or canoeing gear) could spread the species, particularly in its primary form, although this is not likely to be significant pathway.
Is the pathway prohibited in the PRA area?	No. However, there are awareness campaigns within the EU to raise awareness of the movement of invasive alien plants by this pathway. For example, the "Check, Clean and Dry" campaign in Great Britain highlights the need to inspect and treat recreational material following use.
Has the pest already intercepted on the pathway?	No, but this pathway has been highlighted in other countries (Chilton *et al.*, 2002).
What is the most likely stage associated with the pathway?	All three growth forms of the plant would be associated with this pathway.
What are the important factors for association with the pathway?	Primary growth forms of the plant may survive in or on leisure equipment if not cleaned or decontaminated
Is the pest likely to survive transport and storage in this pathway?	Without adequate biosecurity measures the plant could survive in damp equipment (boots, hulls of boats and fishing material for example). After four hours of drying at ambient room temperature no new bud growth was observed (Owens *et al*., 2004b). Moisture content of less than 30 % affects viability (Owens *et al*., 2004a).
Can the pest transfer from this pathway to a suitable habitat?	Yes. Where recreational equipment is contaminated, left untreated and then transferred to another region (pond, lake or river for example), plant propagules can transfer to new areas.
Will the volume of movement along the pathway support entry?	Within the EPPO region the current occurrence of *S. molesta* in the wild is low, leading to the probability of movement through this pathway being low.
Will the frequency of movement along the pathway support entry?	It is unlikely that the frequency of movement by leisure equipment will support entry as the current occurrence of the species within the region is low.
Likelihood of entry	*Low* X *Moderate* ☐ *High* ☐
Rating of uncertainty	*Low* ☐ *Moderate* X *High* ☐

All European biogeographical regions will have the same likelihood of entry and uncertainty scores.

Do other pathways need to be considered?

No

9. Likelihood of establishment in the natural environment in the PRA area

Salvinia molesta is able to become established in the climatic zones without frequent frost events in the Mediterranean region (e.g. Portugal, Spain, Italy, Greece) and in thermal waters.

Salvinia molesta is therefore capable of establishing in the Mediterranean biogeographical region within the EU. The species is capable of limited establishment in small areas of the Black Sea and Atlantic biogeographical regions (see Appendices 1 and 2).

Habitats within the endangered area include slow moving rivers, canals, irrigation and drainage systems, lakes and reservoirs which are widespread within the EPPO region.

Despite the likelihood of establishment in the PRA area, there are no long term established populations recorded, although two populations have been eradicated (Corsica and Rome). This could be due to the plants optimum growth rate in waters around pH 6 – 7, as shown in the USA (McFarland *et al*., 2004, Cary and Weerts, 1984; Owens and Smart, 2004). This may be a potentially limiting factor in the Mediterranean biogeographical region, but requires further investigation.

A moderate rating of uncertainty has been given for likelihood of establishment as the species has become established within the EU and the EPPO region, for example in Corsica and in Rome, though as previously mentioned the species has subsequently been eradicated from these locations.

Rating of the likelihood of establishment in the natural area	*Low* ☐	*Moderate* ☐	*High* **X**
Rating of uncertainty	*Low* ☐	*Moderate* **X**	*High* ☐

10. Likelihood of establishment in the managed environment in the PRA area

Salvinia molesta is traded and normally established in protected conditions, for example under glass. The species can establish in artificial water bodies (hydro-electric power plants, irrigation channels, reservoirs, rice paddies, waste water treatment sites, etc.).

Rating of the likelihood of establishment in the managed environment	*Low* ☐	*Moderate* ☐	*High* **X**
Rating of uncertainty	*Low* **X**	*Moderate* ☐	*High* ☐

11. Spread in the PRA area

Natural spread

Salvinia molesta will tolerate a wide range of variation in water nutrient content, but its rate of growth is most rapid in nutrient-rich conditions. Plants can survive in waters with a salinity of around 20% of that of sea water, although rates of growth are decreased under these conditions (Harley & Mitchell, 1981). With respect to the above information, it is worth noting that experiments and observations relating to the environmental requirements of *S. molesta* may not necessarily cover the entire range of its niche, particularly if invasive populations around the world represent different genotypes or independent hybridisation events. In some waters the species can alter the water chemistry from more alkaline to acidic habitat, which favours its growth (Owens and Smart, 2004a). The optimum growth rate is in waters around pH 6 – 7 (McFarland et al., 2004, Cary and Weerts, 1984; Owens and Smart, 2004b).

Salvinia molesta is capable of high relative growth rates: reported doubling times for leaves are 2.2 days for mid-summer and 40-60 days in winter for Queensland, Australia (Farrell, 1979); doubling times for sewage lagoons made by the same author in the same area were 1.4-33 days (Farrell, 1979). Other reported doubling times for the different growth forms of *S. molesta* (see the **Identification** section below), and for laboratory experiments, are typically below 12 days (Gaudet, 1973; Mitchell & Tur, 1975; Harley & Mitchell, 1981).

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 have been shown for other aquatic species (Green, 2016).

Under optimal climatic conditions, natural spread by the movement of plants or plant fragments is likely to be moderate within the PRA area. Natural spread within any waterbody will facilitate transfer to a suitable habitat.

Human assisted spread

The potential for human-mediated introductions means that new populations could appear anywhere within the EPPO area, with establishment subject to climatic restrictions or survival over winter. Small plants or rhizome fragments could also be moved between waterbodies through recreation or engineering works. In such cases spread distances are likely to be minimal, but if left unchecked such processes could grow exponentially. These pathways for the spread of invasive species have prompted the "Check, Clean and Dry" Campaign in the UK (http://www.nonnativespecies.org/checkcleandry/) 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* (although not traded under the correct name) 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. Human assisted spread and the likelihood of transfer to a suitable habitat is moderate within the PRA area.

As *S. molesta* is an aquatic free floating species which is spread along water bodies and through potential flooding events, coupled with anthropogenic spread by dumping waste aquarium material, the EWG considered based on expert opinion, that the rate of spread within the PRA area is moderate with a moderate uncertainty.

Rating of the magnitude of spread	*Low* ☐	*Moderate* **X**	*High* ☐
Rating of uncertainty	*Low* ☐	*Moderate* **X**	*High* ☐

12. Impact in the current area of distribution

12.01 Impacts on biodiversity and the environment

All of the information on impacts is based on data from outside the EPPO region and thus can only be a proxy to the potential impacts within the EPPO region.

Mats of S. *molesta* can cause similar problems to those caused by excessive growth of other floating plants; for example, mats will prevent photosynthesis in the water below the mat (the impacts in any given situation will depend on the thickness of the mat). *S. molesta* can increase sedimentation by slowing the water flow, especially in shallow water bodies. Mat formation can impact on native animals and plants more generally by significantly altering aquatic habitats, this can result in the creation of floating 'sudd' islands in larger water bodies, or succession to terrestrial habitat for smaller areas (Cook & Gut, 1971; Thomas, 1981). In general, dense mono-specific growth of any aquatic plant species can incur impacts on native plant communities and other aquatic organisms such as macro and micro invertebrates, fish and waterfowl (Carpenter and Lodge, 1986; Personal Communication Iris Stiers, 2016). This can completely transform and alter trophic dynamics, resulting in long-term changes.

The presence of a *S. molesta* mat is likely to degrade the water quality beneath it by blocking sunlight, resulting in decreases in dissolved oxygen and pH, and increases in CO_2 and H_2S concentrations (Mitchell, 1969; McFarland *et al.*, 2004). Decomposition may further decrease oxygen levels, affecting fish and other organisms (Hattingh, 1961). The combination of a high growth rate with slow decomposition is likely to significantly affect water body nutrient dynamics, with likely impacts on all trophic levels (Oliver, 1993). The accumulation of *S. molesta* litter at the bottom of a water body may also reduce habitat suitability for breeding fish (Sculthorpe, 1985). McFarland *et al.* (2004) note the impacts of *S. molesta* on three endangered Hawaiian waterbirds in that country.

Specific impacts on biodiversity include (information from IUCN):

Kenya: *Salvinia* infestations reduce the quality of the wetland habitat of the Near Threatened Maccoa duck (see Oxyura maccoa in the IUCN Red List of Threatened Species) (Berrutti *et al* 2007).

Sri Lanka: The effects of alien invasive water plants (Eichhornia crassipes, *S. molesta*, Imperata cylindrica and Mikania micrantha) on the pheasant-tailed jacana (see Hydrophasianus chirugus in the IUCN Red List of Threatened Species) was studied in three reservoirs from June 2004 to May 2005 at the Annaiwilundawa Ramsar site of northwestern Sri Lanka. Fewer numbers of the pheasant were among the invasive plants compared to natural habitats.

Hawaii *Salvinia molesta* in Enchanted Lake (Kailua) threatens the habitat of three endangered waterbird species, the 'Vulnerable (VU) Hawaiian coot (Fulica alai), the Hawaiian common moorhen (Gallinula chloropus sandivicensis) and the Hawaiian stilt (Himantopus mexicanus knudseni)-both of which are listed as Endangered by the US Fish and Wildlife Service.

To-date there are no impacts recorded on red list species and species listed in the Birds and Habitats Directives.

"Moderate" uncertainty has been given because, in general, it is not possible to know that historical impacts described in the literature are still being felt in any particular geographical area.

Rating of the magnitude of impact in the current area of distribution	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate* X	*High* ☐

12.02. **Impacts on ecosystem services**

Ecosystem service	**Does the IAS impact on this Ecosystem service?** Yes/No	**Short description of impact**	**Reference**
Provisioning	Yes	Mat formation by, and decomposition of, *S. molesta* can affect water quality and availability (and so potentially fish abundance). Food production may also be affected by the increased risk of flooding agricultural land, by blocking livestock access to water bodies, and by the infestation of rice fields. Cattle have also reportedly drowned through wandering onto floating mats of *S. molesta*. In addition, impacts on dissolved oxygen and the floors of water bodies may also affect fish stocks.	Mitchell (1969); Sundaresan & Reddy (1979); Hattingh (1961); McFarland *et al.* (2004)
Regulating	Yes	Native biodiversity can be heavily impacted through the alteration of aquatic ecosystems. Mats can block engineering structures.	Sculthorpe (1985); Cook & Gut (1971); Hattingh (1961); Coates (1982)
Supporting	Yes	The high growth rate and slow decomposition of *Salvinia* is likely to affect nutrient cycling in aquatic habitats; likewise primary production by aquatic plants or algae will also be affected through the blocking of light by *Salvinia* mats.	McFarland *et al.* (2004)
Cultural	Yes	Thick mats may limit access to water bodies, reducing opportunities for swimming, fishing and boating. Aesthetic impacts can also occur when the species forms mats in natural areas.	Holm *et al.* (1977); Barrett (1989); Chilton *et al.* (2002); Sculthorpe (1985)

The IUCN SSC Invasive Species Specialist Group details the following impacts on ecosystem services for Salvinia molesta (see http://issg.org/database/species/reference_files/salmol/salmolimp.pdf)

Dense mats of S. molesta reduce the amount of light and oxygen penetrating the water surface, preventing submerged aquatic plants from photosynthesizing efficiently. Submerged plant biomass decreases, reducing the vegetation available to herbivorous fauna, increasing carbon dioxide levels and decreasing oxygen levels. In contrast to the thick mats, a single layer of Salvinia can increase oxygen levels.

Salvinia may be a catalyst of habitat alteration. The buildup of vegetation and decaying matter reduces water flow and increases siltation, which further reduces the water flow. The vegetation mats provide a suitable substrate for non-aquatic plants to take root in, increasing the buildup of vegetative matter. Salvinia causes more water to be lost due to evapotranspiration than would be lost from an open water body of the same size. This problem is more serious in areas where water is scarce or infrequently replenished. Shallow open water-bodies may be converted into marshes. In summary, Salvinia degrades freshwater habitats by:

- *(i) Competing with and/or shading other aquatic plants*
- *(ii) (ii) Causing an accumulation of decaying debris and secondary vegetation which lowers oxygen levels and encourages anaerobic conditions and water stagnation (harming aquatic fauna)*
- *(iii) (iii) Covering open water bodies*
- *(iv) (iv) Increased siltation rates*
- *(v) (v) Causing habitat alteration or loss (by reducing the water flow and increasing water loss).*

These impacts are rather hard to assess, given that many descriptions in the literature are of historical events, with the current status of impacts in any particular area unknown. The EWG which has evaluated this species and compiled the PRA consider that the magnitude of impact in the current area of distribution is high with a moderate uncertainty. A moderate uncertainty rating reflects the lack of published material on the species.

Rating of the magnitude of impact in the current area of distribution	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate* X	*High* ☐

12.03. Describe the adverse socio-economic impact of the species in the current area of distribution

Economic impacts

Recorded economic impacts include interference with engineering structures such as weirs, floodgates or locks; *S. molesta* mats blocking drains and causing flooding; mats stopping livestock reaching water; and the degradation of potable water through decomposition processes (Oliver, 1993; McFarland *et al.*, 2004). *S. molesta* has also been reported as a serious pest of rice paddy fields in Sri Lanka, Fiji, India and Borneo (Thomas & Room, 1986; Sundaresan & Reddy, 1979; GISP, 2007). However, it is not clear if these impacts are realized in intensive agricultural systems.

The potential economic impact could be significant if the species establishes and spreads in the EPPO region; especially when consideration is given to the loss of earnings and costs associated with management for other aquatic species. Based on a national survey in France, the cost of water primrose (*Ludwigia* spp.) and waterweed (*Elodea* spp.) were estimated at nearly €8 million a year (low estimate) (Chas & Wittmann, 2015). The annual cost of just one such species, *Hydrocotyle ranunculoides* to the British economy alone was estimated at €33 million (Williams *et al.*, 2010).

Chemical control can be expensive and can range from US$210 to $900 per ha (Julien *et al.*, 2009). Chemical control would require repeated application where all plants need to be treated otherwise re-infestation is likely to occur.

In 2017, the Texas (US) Legislature appropriated $6.3 million to be spent trying to eradicate *S. molesta* and other invasive aquatic vegetation using a combination of herbicides and raising/releasing a weevil that feeds exclusively on the plant (see weblink).

S. molesta infestations also clog irrigation and drainage canals thus negatively affecting the agricultural industry (Room and Thomas, 1986). It reduces nutrients, space, and water for crops (Julien et al., 2012) and is a noxious weed in rice paddies all over the world (Room and Thomas, 1986). Mats also block access to drinking water for humans, livestock, and wildlife. This hindrance can seriously affect threatened and endangered species, and human communities in developing countries.

In 1939, Sri Lanka experienced economic decline in agriculture due to *S. molesta* infestations. Because the country relies heavily on the production of rice, the losses due to *S. molesta* infestations were devastating. *S. molesta* infestations in rice paddies cost the country between USD$61,000 to USD$152,000 a year. There were other costs associated with *S. molesta* infestations, such as: fishing losses, health costs, environmental costs, and abatement costs. The highest cost was from rice paddy losses, followed by losses due to health concerns and abatement. Altogether, Sri Lanka lost between $USD163,000 to $USD375,000 a year.

Zimbabwe has also experienced some economic turmoil because of *S. molesta* infestations. Lakes lost entire species of fish which impacted commercial fisheries, severely impacting the community's livelihood. Although eradication was completed, there were costs associated with reintroduction of fish and wildlife species into the areas that were affected (Chikwenhere and Keswani, 1997).

Transportation is also hindered by *S. molesta*. Dense mats block boat access and impede recreational activities. Countries that rely on tourism are most affected by this hindrance. Tungog Rainforest Eco Camp in Malaysia has been negatively affected by *S. molesta* infestations. They rely heavily on ecotourism to continue conservation and restoration of the surrounding rainforests. The eco-camp has experienced a decrease in tourism since the adjacent lake, Tungog Lake, was invaded by *S. molesta*

Impacts on human activities

Salvinia molesta mats can reduce access to the water for recreation (e.g. swimming, fishing, boating or canoeing) and reduce the aesthetic appeal of water bodies; in addition, water bodies altered by *Salvinia* mats may favour the spread of diseases, such as elephantiasis, encephalitis, malaria and dengue fever (Oliver, 1993), by providing habitat for the mosquito vectors. This may also apply to the snail-mediated disease bilharzia (Personal Communication, Martin Hill, Dept. of Zoology and Entomology, Rhodes University, 2016).

In Asia and Africa Salvinia has caused a decline in the tourism, hunting, and fishing sectors (Howard and Harley 1989; Swearingen et al. 2002; McFarland et al. 2003).

"Moderate" uncertainty has been given because, in general, it is not possible to know that historical impacts described in the literature are still being felt in any particular geographical area.

Rating of the magnitude of impact in the current area of distribution	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate* X	*High* ☐

13. Potential impact in the PRA area

Aquatic free floating plants are highly opportunistic and have the ability to exploit novel habitats. Other non-native mat forming species have been shown to have high impacts in the PRA area.

The potential economic impact of *Salvinia molesta* in the EPPO region could be highly significant if the species spreads and establishes in further areas. There is potential for the species to impede transport and affect recreation, irrigation and drainage. Based on experience elsewhere in the world, management is likely to be both expensive and difficult. There are no host specific natural enemies in the EPPO region to regulate the pest species, and in many EPPO countries herbicide application in or around water bodies is highly regulated or not permitted.

Impacts in the EPPO area will likely be attenuated by climatic suitability, but, in areas where *S. molesta* is able to establish and spread, impacts are likely to be similar unless under control. For example, many of the impacts on biodiversity relate to ecosystem processes such as decomposition and the alteration of nutrient cycling, which, assuming that *S. molesta* is able to reach the levels of abundance required for these impacts to be displayed, can be assumed to occur in these areas to the same extent as in the current area of distribution.

Europe has several atypical aquatic thermal habitats such as thermal streams and waters affected by thermal discharge from industry. This may expand impacts into areas that would otherwise be considered climatically unsuitable by coarse environmental modelling. For example, the Hungarian thermal streams and the Italian Fosso Dell'Acqua calda near Pisa (Garbari et al., 2000). If these waters are connected to more typical waters they may act as a permanent source of propagules (this has been shown for *Pistia stratiotes*, Hussner *et al*., 2014).

In the PRA area, *S. molesta* has the potential to impact on native plant species due to its invasive smothering behaviour. The invasion of alien invasive plants can increase competition for space with native aquatic plants (Bilz et al., 2011).

Potential red list species and species from the Habitat Directive which may be impacted on both under current climate and future climate include *Isoetes malinverniana* (Critically Endangered, Italy), *Elatine brochonii* (Vulnerable, France and Spain), *Anagallis crassifolia* and *Marsilea strigosa* (Vulnerable, France, Italy and the Iberian Peninsula), *Pilularia minuta* (Endangered), *Damasonium polyspermum* and *Ipomoea sagittata* (Vulnerable).

The text within this section relates equally to EU Member States and non-EU Member States in the EPPO region.

Will impacts be largely the same as in the current area of distribution? **Yes (in part)**

Impacts on biodiversity

Rating of the magnitude of impact in PRA area	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate*	*High* X

Impacts on ecosystem services

Rating of the magnitude of impact in PRA area	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate*	*High* X

Socio-economic impacts

Rating of the magnitude of impact in PRA area	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate* ☐	*High* X

13.01. Negative environmental impacts with respect to biodiversity and ecosystem patterns and processes

See above **Overall assessment**

13.02. Negative impact the pest may have on categories of ecosystem services

See above **Overall assessment**

13.03 Socio-economic impact of the species

See above **Overall assessment**

14. Identification of the endangered area

The endangered area is the Mediterranean biogeographical region (Albania, Algeria, France, Greece, Italy, Morocco, Portugal, Spain, Turkey, Tunisia).

Salvinia molesta is a frost-sensitive free-floating species. The southern countries within the EPPO region provide suitable climatic conditions for the plant. This includes regions in which the water bodies are not enclosed in ice during the winter months. Furthermore, thermal waters in other EPPO countries provide potential habitats for *Salvinia molesta*.

Salvinia molesta is capable of establishing in the Mediterranean biogeographical region. The species is capable of limited establishment in small areas of the Black Sea and Atlantic biogeographical regions. Additionally, areas around the Adriatic Sea have the potential for establishment (see appendix 1).

Significant impact could be expected in man-made water bodies.

Habitats within the endangered area include slow moving rivers, canals, irrigation and drainage systems, lakes and reservoirs which are widespread within the EPPO region.

15. Climate change

15.01. Define which climate projection you are using from 2050 to 2100*

Climate projection RCP 8.5: 2070, **2070**

Note: RCP8.5 is the most extreme of the RCP scenarios, and may therefore represent the worst-case scenario for reasonably anticipated climate change.

15.02 Which component of climate change do you think is <u>most</u> relevant for this organism? Delete (yes/no) as appropriate

Temperature **(yes)**	Precipitation **(no)**	$C0_2$ levels **(no)**
Sea level rise **(no)**	Salinity **(no)**	Nitrogen deposition **(no)**
Acidification **(yes)**	Land use change **(no)**	Other (please specify)

Are the **introduction pathways** likely to change due to climate change? **(If yes, provide a new risk and uncertainty score)**	**Reference**

The introduction pathways are unlikely to change as a result of climatic change as the species enters the EPPO region as a result of the horticultural trade. The overall rating for introduction will not change with climate change: Plants for planting: High rating with low uncertainty Contaminant of plants for planting: Low rating with low uncertainty Contaminant of leisure equipment: Low rating with low uncertainty	(Personal Communication J. van Valkenburg, 2016).
Is the **risk of establishment** likely to change due to climate change? **(If yes, provide a new risk and uncertainty score)**	**Reference**
The risk of establishment will increase with increasing temperature in some countries, in which frost events currently hinder establishment of *S. molesta.* By the 2070s, under climate change scenario RCP8.5, projected suitability for *S. molesta* increases in the countries projected as containing currently suitable regions, and also in western Europe. Relaxation of frost constraints meant that the model projected high suitability in the Pannonian Plain (Hungary, Serbia and Croatia) and the northern coast of the Black Sea, as well as moderate suitability in much of northern France, UK, Belgium, Netherlands, Germany and the coasts of Denmark and southern Sweden. Therefore, the model suggests climate change could facilitate a major expansion of the invaded range of the species in Europe. The overall rating for establishment will not change with climate change: Establishment (natural): High with moderate uncertainty Establishment (managed): High with low uncertainty	See appendix 1
Is the **risk of spread** likely to change due to climate change? **(If yes, provide a new risk and uncertainty score)**	**Reference**
The risk of spread into countries from interconnecting water bodies, in which frost events currently hinder the establishment of *S. molesta* will increase with increasing temperature. Increased flood events resulting from climate change could facilitate the spread of the species into new regions (see Appendix 1). The risk of spread will remain as moderate but the level of uncertainty could be reduced from moderate to low.	See appendix 1
Will **impacts** change due to climate change? **(If yes, provide a new risk and uncertainty score)**	**Reference**
With increasing temperature the impacts of *Salvinia molesta* will be more profound than under the current climatic conditions. As the species spreads, impacts will manifest across a larger part of the PRA area. More rapid growth and biomass accumulation will result in higher impacts to native species. Impacts in the PRA area Biodiversity: High with high uncertainty Ecosystem services: High with high uncertainty Socio-economic impacts: High with high uncertainty	See appendix 1

16. Overall assessment of risk

Salvinia molesta presents a high phytosanitary risk for the endangered area within the EPPO region with a moderate uncertainty. Further spread within and between countries is likely. The overall likelihood of *Salvinia molesta* continuing to enter the EPPO region is high because the species is widely cultivated and continuously traded within the EPPO region. The risk of the species being introduced into other EPPO countries is considered high as the plant is widely traded especially in the EU.

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.

The potential economic impact of *Salvinia molesta* in the EPPO region could be highly significant if the species spreads and establishes in further areas. There is potential for the species to impede transport and affect recreation, irrigation and drainage. Based on experience elsewhere in the world, management is likely to be both expensive and difficult. There are no host specific natural enemies in the EPPO region to regulate the pest species, and in many EPPO countries herbicide application in or around water bodies is highly regulated or not permitted.

Impacts in the EPPO area will likely be attenuated by climatic suitability, but, in areas where *S. molesta* is able to establish and spread, impacts are likely to be similar unless under control. For example, many of the impacts on biodiversity relate to ecosystem processes such as decomposition and the alteration of nutrient cycling, which, assuming that *S. molesta* is able to reach the levels of abundance required for these impacts to be displayed, can be assumed to occur in these areas to the same extent as in the current area of distribution.

Based on evidence elsewhere in the world, important ecosystem services are likely to be adversely affected by the presence of the plant. Impacts are likely to be more pronounced in countries and regions where the climate is most suited to establishment, growth and spread.

In view of the risk of entry, establishment and spread, it is surprising that despite the long history of trade as an ornamental and the climatic match with the Mediterranean, it is not yet widely established.

Pathways for entry:

Plants for planting

Rating of the likelihood of entry for the pathway, plants for plating	*Low* ☐	*Moderate* ☐	*High* **X**
Rating of uncertainty	*Low* **X**	*Moderate* ☐	*High* ☐

Contaminant of plants for planting

Rating of the likelihood of entry for the pathway, contaminant of plants for plating	*Low* **X**	*Moderate* ☐	*High*
Rating of uncertainty	*Low* **X**	*Moderate* ☐	*High* ☐

Leisure equipment

Rating of the likelihood of entry for the pathway, leisure equipment	*Low* X	*Moderate* ☐	*High*
Rating of uncertainty	*Low*	*Moderate* X	*High* ☐

Likelihood of establishment in the natural environment in the PRA area

Rating of the likelihood of establishment in the natural environment	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low*	*Moderate* X	*High* ☐

Likelihood of establishment in managed environment in the PRA area

Rating of the likelihood of establishment in the managed environment	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* X	*Moderate* ☐	*High* ☐

Magnitude of Spread

Rating of the magnitude of spread	*Low* ☐	*Moderate* X	*High* ☐
Rating of uncertainty	*Low* ☐	*Moderate* X	*High* ☐

Impacts (current area of distribution)

Biodiversity

Rating of the magnitude of impact on biodiversity in the current area of distribution	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate* X	*High* ☐

Ecosystem services

Rating of the magnitude of impact on ecosystem services in the current area of distribution	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate* X	*High* ☐

Socio-economic impacts

Rating of the magnitude of socio-economic impact in the current area of distribution	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate* X	*High* ☐

Potential impact in the PRA area

Will impacts be largely the same as in the current area of distribution? **Yes (in part)**

Impacts on biodiversity

Rating of the magnitude of impact in PRA area	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate*	*High* X

Impacts on ecosystem services

Rating of the magnitude of impact in PRA area	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate*	*High* X

Socio-economic impacts

Rating of the magnitude of impact in PRA area	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate* ☐	*High* X

18. Uncertainty

Overall uncertainty for the PRA: Moderate

Currently the species is not invasive in natural habitats in the PRA area. However, in view of the overwhelming evidence from elsewhere in the world it is likely to exhibit a similar behaviour in aquatic habitats with suitable water chemistry characteristics.

Uncertainty should also be considered in the context of species distribution modelling (SDM).

Here records for *S. molesta* and synonyms were retrieved from GBIF and other online sources, and were also digitised from occurrences that were either mapped or clearly georeferenced in published sources. This may mean that the realised climatic niche of *S. molesta* is under-characterised. In addition, georeferenced records used in our SDMs were usually without information on population persistence – if records within the EPPO area, or in climatically similar areas, are typically of 'casual' occurrences, rather than established populations, it may be that our SDMs over-emphasise the likelihood of establishment in climatically marginal habitats. See also appendix 1.

To remove spatial recording biases, the selection of the background sample was weighted by the density of Tracheophyte records on the Global Biodiversity Information Facility (GBIF). While this is preferable to not accounting for recording bias at all, a number of factors mean this may not be the perfect null model for species occurrence:

- The GBIF API query used to did not appear to give completely accurate results. For example, in a small number of cases, GBIF indicated no Tracheophyte records in grid cells in which it also yielded records of the focal species.
- We located additional data sources to GBIF, which may have been from regions without GBIF records.
- Levels of Tracheophyte recording may not be a consistent indicator of the recording of aquatic plants. There is a suggestion that aquatic plants may be disproportionately under-recorded in tropical regions (Jonathan Newman, *pers. comm*), which could have been responsible for an under-prediction of suitability in tropical regions.

Air temperatures were used in the model, while water temperatures may be more appropriate for an aquatic plant. In some cases air and water temperatures can markedly diverge, for example warming associated with industrial outflows. Wherever the water temperature is warm enough, the species is likely to be able to persist, regardless of the model's estimate of suitability.

Water chemistry and quality may have a large effect on the ability of the species to persist but were not used in the model. Factors such as water pH and nutrient concentration are likely to be important modifiers of habitat suitability.

The climate change scenario used is the most extreme of the four RCPs. However, it is also the most consistent with recent emissions trends and could be seen as worst case scenario for informing risk assessment.

19. Remarks

Other recommendations:

Inform EPPO or IPPC or EU

- Inform NPPOs that surveys are needed to confirm the distribution of the plant, in particular in the area where the plant is present; and on the priority to eradicate the species from the invaded area.

Inform industry, other stakeholders

- Encourage industry to assist with public education campaigns associated with the risk of aquatic non-native plants.

Specify if surveys are recommended to confirm the pest status

- Surveys should be conducted to confirm the current distribution and status of the species within the endangered area and this information should be shared within the PRA area.

20. REFERENCES

Andreu, J., & 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 17 April 2016].

Australian Weeds Committee. 2016. Noxious Weeds List. http://www.weeds.org.au/noxious.htm. [Accessed 17 April 2016]

Barrett, SCH. 1989. Waterweed invasions. *Sci. Amer.* 261:90-97.

Berthe A, Kone B, 2008. Wetlands and Sanitation - A View from Africa. Healthy Wetlands, Healthy People: Report of the Shaoxing City Symposium [ed. by Ounsted, M. \Madgwick, J.]. http://global.wetlands.org/Portals/0/publications/Book/WI_HEALTHY%20WETLANDS%20HEALTHY%20PEOPLE.pdf#page=43

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

Buccomino G., Buonfiglio V., 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 Flora Italicae - Indice dei nomi delle specie botaniche presenti in Italia

Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (ed.) 2013. Aquatische Neobiota in Österreich.

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

CABI. 2016. *Salvinia molesta* (Kariba weed). http://www.cabi.org/isc/datasheet/48447. [Accessed 15 April 2016]

Carpenter SR, Lodge DM (1986) Effects of submersed macrophytes on ecosystem processes. *Aquatic Botany*. **26**, 341-370.

Cary, P. R., and P. G. J. Weerts. 1984. Growth of Salvinia molesta as affected by water temperature and nutrition. III. Nitrogen-phosphorus interactions and effect of pH. Aquat. Bot. 19:171-182.

Champion PD and Clayton JS (2001) Boarder control for potential aquatic weeds. Stage 2. Weed Risk assessment. Science for Conservation. 185.

Chauhan, M., & Gopal, B. 2005. Vegetation structure and dynamics of a floodplain wetland along a subtropical regulated river. *River Research and applications, 21*(5), 513-534.

Chen RS, Huang CC, Li JC, Tsay JG, 2008. First report of *Simplicillium lanosoniveum* causing brown spot on *Salvinia auriculata* and *S. molesta* in Taiwan. *Plant Disease*, 92(11):1589. HTTP://www.apsnet.org

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

Cilliers, C. J. 1991. Biological control of water fern, *Salvinia molesta* (Salviniaceae), in South Africa." *Agriculture, ecosystems & environment* 37,1: 219-224.

Cilliers, C. J., Hill, M. P., Ogwang, J. A., & Ajuonu, O. 2003. Aquatic weeds in Africa and their control. *Biological Control in IPM systems in Africa*, 161-178.
Coates, D. 1982. Salvinia – possible biological effects on fish in Papua New Guinea? *Aquatics* 4(3), 2.

Considine M, 1984/1985. Weevils take on the water weeds. *Ecos*, 42:16-21.

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

Cook, C. D., & Gut, B. J. 1971. Salvinia in the state of Kerala, India. *PANS Pest Articles & News Summaries*, *17*(4), 438-447.

Corlett, R. T. (988. The naturalized flora of Singapore. *Journal of Biogeography*, 657-663.

Cronk QCB and Fuller JL 2001. Plant invaders: the threat to natural ecosystems. Earthscan Publications, USA.

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.

Courchamp, F. 2013. Alien species: Monster fern makes IUCN invader list. *Nature*, 498(7452), 37-37.

de la Sota, E.R. 1995: Nuevos sinónimos en *Salvinia* Ség. (Salviniaceae, Pteridophyta). *Darwiniana* 33: 309–313.

de Wet C, 1993. The control of floating water weeds in the SARCCUS region. Proc. Workshop, Harare, Zimbabwe, 24-27 June 1991. Agriculture Programme Series No. CSC(93)AGR-18, Integrated Pest Mgt. Proc. Series No. 295.

Diop O, Hill MP, 2009. Quantitative post-release evaluation of biological control of floating fern, Salvinia molesta D.S. Mitchell (Salviniaceae), with Cyrtobagous salviniae Calder and Sands (Coleoptera: Curculionidae) on the Senegal River and Senegal River Delta. *African Entomology*, 17(1):64-70. http://journals.sabinet.co.za/essa

Doeleman, J.A. (1990) Biological control of *salvinia* in Sri Lanka: an assessment of cost and benefits. Economic Assessment Series. Australian Centre for International Agricultural Research, Canberra, Australia.

Dufour-Dror JM (2012) Alien invasive plants in Israel. Israel Nature and Parks Authority. Ahva, Jerusalem.

Emierine SE, Richardson RJ, True, SL, West AM, Roten RL (2010) Greenhouse response of six aquatic invasive weeds to Imazamox. Journal of Aquatic Plant management. 48: 105-111.

EPPO (2006) Guidelines for the management of invasive alien plants or potentially invasive alien plants which are intended or have been intentionally imported. EPPO Bulletin 36, 417–418.

EPPO. 2007. EPPO Reporting service no. 1 (Rse-0701.doc) (http://archives.eppo.org/EPPOReporting/2007/Rse-0701.pdf) [Accessed 14 April 2016]

EPPO (2009) EPPO guidelines on the development of a code of conduct on horticulture and invasive alien plants. EPPO Bulletin 39, 263–266.

EPPO (2014) PM 9/19 (1) Invasive alien aquatic plants. EPPO Bulletin 44, 457–471

EPPO 2014. PQR database. Paris, France: European and Mediterranean Plant Protection Organization. http://www.eppo.int/DATABASES/pqr/pqr.htm

EPPO 2016. *Salvinia molesta* (Salviniaceae). https://www.eppo.int/INVASIVE_PLANTS/iap_list/Salvinia_molesta.htm. [accessed 14 April 2016]

EUBARnet 2013. EUBARnet. [accessed 18 March 2015].

Farrell T, 1978. The spread and control of *Salvinia molesta* in Lake Moodarra, Mount Isa, Queensland. In: Proc. 1st Conf. Counc. Austral. Melbourne, Australia: Weed Sci. Soc., 179-187.

Farrell, T. P. 1979. Control of *Salvinia molesta* and *Hydrilla verticillata* in Lake Moondarra, Queensland. In *Aust. Water Resources Council Seminar on Management of Aquatic Weeds* (pp. 57-71).

Forno, I.W. 1983. Native distribution of the *Salvinia auriculata* complex and keys to species identification. *Aquatic Botany*, *17*(1), 71-83.

Forno IW, Harley KLS, 1979. The occurrence of *Salvinia molesta* in Brazil. Aquatic Botany, 6(2):185-187.

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

Garcia R, 2008. The risk of introducing exotic plants. (Du danger d'introduire des plantes exotiques.) *Courrier international*, 969:57-58.

Gaudet, J. J. 1973. Growth of a floating aquatic weed, *Salvinia* under standard conditions. *Hydrobiologia*, *41*(1), 77-106.

GBIF 2016. *Salvinia molesta* Mitchell – Checklist view. http://www.gbif.org/species/527486. [accessed 14 April 2016]

GEFD 2016. Florenlist von Deutschland – Gefäßpflanzen. Version 7 (August 2015). http://www.kp-buttler.de/florenliste/index.htm. [Accessed 04 May 2016]

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.

GISIN, 2016. Information for *Salvinia molesta*. http://www.gisin.org/cwis438/websites/GISINDirectory/GISIN_ScientificName_Info.php?GISIN

_ScientificNameID=36749&CallingPage=%2Fcwis438%2Fwebsites%2FGISINDirectory%2FCountry_Info.php%3FTakeAction%3DReturned%26Country_AreaID%3D314801&CallingLabel=To%20Country%20Info&WebSiteID=4. [accessed 14 April 2016]

Gordon, D.R., Gantz, C.A., Jerde, C.L., Chadderton, W.L., Keller, R.P., and Champion, P.D. 2012. Weed risk assessment for aquatic plants: modification of a New Zealand system for the United States. PLoS ONE 7(7): e40031, doi:10.1371/journal.pone.0040031. Invasive Alien Species Working Group (IASWG). 2008. Alberta Invasive Alien Species Risk

Greathead A, de Groot P, 1993. Control of Africa's floating water weeds. Proc. Workshop, Harare, Zimbabwe, 24-27 June 1991, Agriculture Programme Series No. CSC(93)AGR-18, Integrated Pest Mgt. Proc. Series No. 295.

Green AJ (2016) The importance of waterbirds as an overlooked pathway of invasion for alien species. Diversity and Distributions. 22, 239-247.

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

Gunn C, Ritchie C, 1982. Report of the Technical Committee to Evaluate Noxious Weeds. 1982. Unpublished report on taxa proposed for listing as Federal Noxious Weeds. U.S. Dep. Agric., An. Plt. Hlth. Serv., Plt. Prot. and Quar. Riverdale, MD, USA.

Hallstan, S. 2005. Global warming opens the door for invasive macrophytes in Swedish lakes and streams. PhD diss., Sveriges lantbruksuniversitet.

Harley, KLS & Mitchell, DS. 1981. The biology of Australian weeds, 6: *Salvinia molesta* DS Mitchell. *Journal of the Australian Institute of Agricultural Sciences (Australia).* 47 (2) p. 67-76.

Hattingh, E. R. 1961. Problem of *Salvinia auriculata* Aubl. and associated aquatic weeds on Kariba Lake. *Weed Research, 1*(4), 303-306.

Henry-Silva , G.G., Camargo F.M. (2006): Efficiency of aquatic macrophytes to threat Nile Tilapia ponds effluents. – Science and Agriculture, Piracicaba, Brazil. 63(5): 433-438.

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

Holm, L. G., Plucknett, D. L., Pancho, J. V., & Herberger, J. P. 1977. *The world's worst weeds*. University Press of Hawaii, Honolulu, Hawaii. 609 pp.

Holm LG, Pancho JV, Herberger JP, Plucknett DL, 1979. *A Geographical Atlas of World Weeds.* New York, USA: John Wiley and Sons.

Howell, CJ. 2008. *Consolidated list of environmental weeds in New Zealand*. Science & Technical Pub., Department of Conservation.

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

Hussner A, Heidbuechel P, 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 EM, Hilt S (2010) Comments on increasing number and abundance of nonindigenous aquatic macrophyte species in Germany. Weed Research 50: 519–526

Imran M, Surayya Khatoon, Sahar Zaidi, Ali QM, Ghulam Akbar, 2013. Alien and invasive plant species of the Indus Delta. *International Journal of Biology and Biotechnology*, 10(3):371-382. http://www.ijbbku.com

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

Jayanth KP, Singh SP, 1993. Biological control of aquatic weeds. *Indian Farming*, 42(11):25-30.

Jiménez MM, Fabela PS, López EG. 2003. Control de malezas aquaticas en México. [Newsletter of the] Iniversidad de México Novembre 2003, pp. 123 – 127.

Joy, P. J. 1978. Ecology and control of salvinia (African Payal) the molesting weed of Kerala. Technical Bulletin, Kerala Agricultural University, (2), 40.

Julien, M. H., Hill, M. P., & 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., & 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 & Co., Stuttgart. 472 pp

Langeland KA (1996) *Hydrilla verticillata* (L.f.) Royle (Hydrocharitaceae), the perfect aquatic weed. *Castanea*, 61(3):293-304.

Lin, Y. X., L. Shi, A. M. Funston & M. G. Gilbert. 2013. Salviniaceae. Pp. 125–127 in Z. Y. Wu, P. H. Raven & D. Y. Hong, eds., *Flora of China*, Vol. 2–3 (Pteridophytes). Beijing: Science Press; St. Louis: Missouri Botanical Garden Press.

Lorence, D. H. 1978. The pteridophytes of Mauritius (Indian Ocean): ecology and distribution. Botanical Journal of the Linnean Society, 76(3), 207-247.

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.

Maddi, F. A. 2014. *Salvinia molesta*, une fougère nouvelle à la Martinique. Actualités botaniques de la Société d'Histoire Naturelle L'HERMINIER. Publiée le 9 février 2014. http://www.shnlh.org/fr/actualites-botanique/165-bota-news-10

Margot, J. 1983. Vegetation aquatique des Springputten en foret de Meerdael. Evolution et presences floristiques. *Les Naturalistes belges*. 64, 6:199-221.

Marshall, B. E., & Junor, F. J. R. 1981. The decline of *Salvinia molesta* on Lake Kariba. *Hydrobiologia*, *83*(3), 477-484.

Mbati, G., & Neuenschwander, P. 2005. Biological control of three floating water weeds, *Eichhornia crassipes*, *Pistia stratiotes,* and *Salvinia molesta* in the Republic of Congo. *BioControl*, *50*(4), 635-645.

McFarland Nelson DGLS, Grodowitz MJ, Smart RM, Owens CS, 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, 35 pp.

Miller, IL & Pickering, SE. 1980. *Salvinia*, a noxious weed. Department of Primary Production, Div. Ag. Stock, Northern Territory, Australia, Agnote Ref. No. 80/35.

Mitchell, D.S. 1969. The ecology of vascular hydrophytes on Lake Kariba. *Hydrobiologia* 34, 448-464.

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

Mitchell, D.S. 1978. *Aquatic weeds in Australian inland waters.* AGPS: Canberra.

Mitchell DS, 1979. The incidence and management of Salvinia molesta in Papua New Guinea. Office of Environment and Conservation, Waigani, Port Moresby, 51 pp.

Mitchell D, Tur N, 1975. The rate of growth of *Salvinia molesta* (*S. auriculata* auct.) in laboratory and natural conditions. J. Appl. Ecol., 12:213-225.

Mora-Olivo, A., & Yatskievych, G. 2009. *Salvinia molesta* in Mexico. *American Fern Journal*, 99(1), 56-58.

Moran, R.C.; Smith, A.R. 1999. *Salvinia adnata* Desv. versus *S. molesta* D.S.Mitch. *American Fern Journal* 89(4): 268–269.

Murphy, KJ. 1988. Aquatic weed problems and their management: a review. II. Physical control measures. *Crop Protec*. 7:283-302.

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

Newman, J. 2016. Rapid Assessment of: *Salvinia molesta* Mitchell, Giant Salvinia. www.nonnativespecies.org/downloadDocument.cfm?id=1415. [Accessed 17 April 2016].

Njuguna S, Thital G, 1993. The control of floating water weed infestations in Kenya. Proc. Workshop, Harare, Zimbabwe, 24-27 June 1991. Agriculture Programme Series No. CSC(93)AGR-18, Integrated Pest Mgt. Proc. Series No. 295, 59-65.

Ofenböck, G. (Ed.) 2008. *Aquatische Neobiota in Österreich.* Lebensministerium, Wien.

Oliver, J. D. 1993. A review of the biology of Giant Salvinia (*Salvinia molesta* Mitchell). *J. Aquat. Plant Manage.* 31: 227-231.

Owens, C. S., Smart, R. M., & Stewart, R. M. 2004a. Low temperature limits of giant salvinia. *Journal of Aquatic Plant Management*, *42,* 91-94.

Owens CS, Smart RM, Dick GO (2004b) Regeneration of giant Salvinia from apical and axillary buds following desiccation or physical damage. Journal of Aquatic Plant Management. 42,117-119.

Pallewatta N, Reaser JK, Gutierrez AT, 2003. Invasive alien species in South-Southeast Asia: national reports and directory of resources [ed. by Pallewatta, N.\Reaser, J. K.\Gutierrez, A. T.]. Cape Town, South Africa: Global Invasive Species Programme, 111 pp. http://www.gisp.org

Paradis G, Miniconi R, 2011. A new invasive aquatic species discovered in Corsica, south of the Gulf of Ajaccio: *Salvinia molesta* D. Mitch (Salviniaceae, Pteridophyta). (Une nouvelle espece aquatique invasive decouverte en Corse, au sud du golfe d'Ajaccio: *Salvinia molesta* D.Mitch (Salviniaceae, Pteridophyta).) *Le Journal de Botanique de la Societe botanique de France*, 54:45-48.

Parsons WT, Cuthbertson EG, 1992. *Noxious Weeds of Australia.* Melbourne, Australia: Inkata Press, 692 pp.

PIER. 2001. *Salvinia molesta*. http://www.hear.org/pier/wra/australia/samol-wra.htm. [Accessed 14 April 2016]

PIER. 2001. *Salvinia molesta.* http://www.hear.org/pier/wra/pacific/salvinia_molesta_htmlwra.htm . [Accessed 14 April 2016]

Qureshi, R. 2008. Preliminary floristic list of chotiari wetland complex, Nawab Shah, Sindh, Pakistan. *Pak. J. Bot*, *40*(6), 2281-2288.

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

Room, P. M., & 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.

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., Zenetos, A. 2015. *Invasive Alien Species - Prioritising prevention efforts through horizon scanning* ENV.B.2/ETU/2014/0016. European Commission.

Sculthorpe, CD 1985. *The biology of aquatic vascular plants.* Edward Arnold, London.

Smith P, 1993. Control of floating water weeds in Botswana. Control of Africa's floating water weeds. Proceedings of a workshop held in Harare, Zimbabwe, on 24-27 June 1991, 31-39; [Agriculture Programme series No. CSC(93)AGR-18, Integrated Pest Management Proceedings series No. 295, also published by Biomass Users Network, Harare, Zimbabwe, and by CAB International, Ascot, UK].

Sundaresan, A., & Reddy, N. 1979. *Salvinia molesta* (Mitchell)-a serious water weed in Fiji. *Fiji Agricultural Journal*, 41(2), 103-107.

Thomas, K. J. 1979. The extent of *Salvinia* infestation in Kerala (S. India): Its impact and suggested methods of control. *Environmental Conservation*, *6*(01), 63-69.

Thomas, K. J. 1981. The role of aquatic weeds in changing the pattern of ecosystems in Kerala. *Environmental Conservation*, *8*(01), 63-66.

Thomas PA, Room PM, 1986. Taxonomy and control of *Salvinia molesta*. Nature, UK, 320(6063):581-584

Vandecasteele, B., Quataert, P., Tack, F.M.G. (2005) Effect of hydrological regime on the metal bioavailability for wetland plant species Salix cinerea. – Environmental Pollution 135: 303-312.

van der Valk O.M.C., van Dijk C.J., Rijk P.J., Ruijs M.N.A. (2018) Kostenraming van exoten voor tweede update van de Unielijst (EU-1143/2014). Wageningen, Wageningen Economic Research, Nota 2018-033. 40 pp.

Verloove F (2006) Catalogue of neophytes in Belgium (1800-2005). Filip Verloove. – Meise, National Botanic Garden of Belgium, 2006. 89 p – (Scripta Botanica Belgica, vol. 39).

Verbrugge, L. N., Leuven, R. S. E. W., Van Valkenburg, J. L. C. H., & 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.

Wee Y, 1986. Aquatic weed problem in Singapore's freshwater reservoir. Biotrop Special Publication No. 24. Singapore: National Univ. of Singapore, Dept. Botany, 25-29.

Weedbusters. 2016. http://www.weedbusters.org.nz/weed-information/salvinia-molesta/59/. [Accessed 16 April 2016]

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

Williams F, Eschen R, Harris A, Djeddour D, Pratt C, Shaw RS, Varia S, Lamontagne-Godwin J, Thomas SE & Murphy ST (2010) The economic cost of invasive non-native species on Great Britain. CABI, Wallingford UK

Yamoah E, Gill GSC, 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

Appendix 1 Projection of climatic suitability for *Salvinia molesta* establishment

Aim

To project the suitability for potential establishment of *Salvinia molesta* in the EPPO region, under current and predicted future climatic conditions.

Data for modelling

Climate data were taken from 'Bioclim' variables contained within the WorldClim database (http://www.worldclim.org/), originally at 5 arcminute resolution (0.083 x 0.083 degrees of longitude/latitude) but bilinearly interpolated to a 0.1 x 0.1 degree grid for use in the model. Based on the biology of the focal species, the following variables were used in the modelling:

- Mean temperature of the warmest quarter (Bio10 °C) reflecting the growing season thermal regime. As described in the main text, cold temperatures are known to limit growth of *S. molesta*.
- Mean minimum temperature of the coldest month (Bio6 °C) reflecting exposure to frost. *Salvinia molesta* is known to be highly sensitive to frosts and freezing of the water surface.
- Precipitation of the warmest quarter (Bio18 ln+1 transformed mm). Although the species is aquatic and will therefore have limited direct dependence on precipitation, seasonal drying out of waterbodies may reduce suitability. We anticipate this to be more common when the warmest quarter has low precipitation.

To estimate the effect of climate change on the potential distribution, equivalent modelled future climate conditions for the 2070s under the Representative Concentration Pathway (RCP) 8.5 were also obtained. This assumes an increase in atmospheric CO_2 concentrations to approximately 850 ppm by the 2070s. Climate models suggest this would result in an increase in global mean temperatures of 3.7 °C by the end of the 21st century. The above variables were obtained as averages of outputs of eight Global Climate Models (BCC-CSM1-1, CCSM4, GISS-E2-R, HadGEM2-AO, IPSL-CM5A-LR, MIROC-ESM, MRI-CGCM3, NorESM1-M), downscaled and calibrated against the WorldClim baseline (see http://www.worldclim.org/cmip5_5m). RCP8.5 is the most extreme of the RCP scenarios, and may therefore represent the worst case scenario for reasonably anticipated climate change.

As a measure of habitat availability, we used the Global Inland Water database provided by the Global Land Cover Facility (http://glcfapp.glcf.umd.edu/data/watercover/). The original database is a remote sensed estimate at a 30 x 30 m resolution of the presence of inland surface water bodies, including fresh and saline lakes, rivers, and reservoirs. For the PRA, this was supplied as a 0.1 x 0.1 degree raster indicating the proportion of the constituent 30 x 30 m grid cells classified as inland waters.

Species occurrences were obtained from the Global Biodiversity Information Facility (www.gbif.org), supplemented with data from the literature and the Expert Working Group. Occurrence records with insufficient spatial precision, potential errors or that were outside of the coverage of the predictor layers (e.g. small island or coastal occurrences) were excluded. The remaining records were gridded at a 0.1 x 0.1 degree resolution (Figure 1).

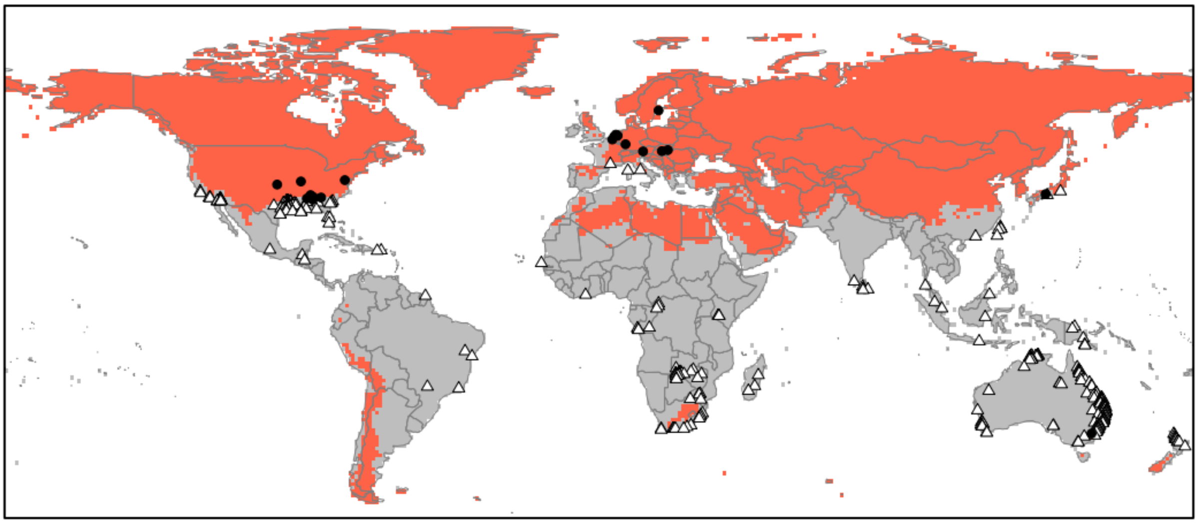
Examination of these records by the Expert Working Group indicated a number were either examples of casual occurrences introduced to climatically unsuitable regions (for example, where winter frosts are known to kill all individuals) or records of persistent populations known to occupy climatically anomalous micro-habitats such as thermal streams or warmed industrial outflows. These were removed from the occurrence data as they will impede the model's ability to characterise climatic suitability. Based on guidance from the Expert Working Group, occurrences were removed based on the following rules for determining high environmental unsuitability (Figure 1):

- Mean temperature of the warmest quarter < 10 °C (below the minimum growth temperature); OR

- Mean minimum temperature of the coldest month < 0 °C (prolonged exposure to lethal frosts); OR
- Precipitation of the warmest quarter < 5 mm AND proportion cover of inland waters == 0 (only small and seasonally dry habitat is available, which is expected to be of low suitability).

In total, there were 392 grid cells with recorded occurrence of *S. molesta* available for the modelling and a further 20 records from regions considered unsuitable and excluded (Figure 1).

Figure 1. Map with points showing the occurrence records obtained for *Salvinia molesta*. The background shading indicates regions considered highly unsuited to *S. molesta*. Records found within this region (black circles) were considered to represent casual occurrences or establishment in thermally abnormal microclimates, and were excluded from the modelling.



Species distribution model

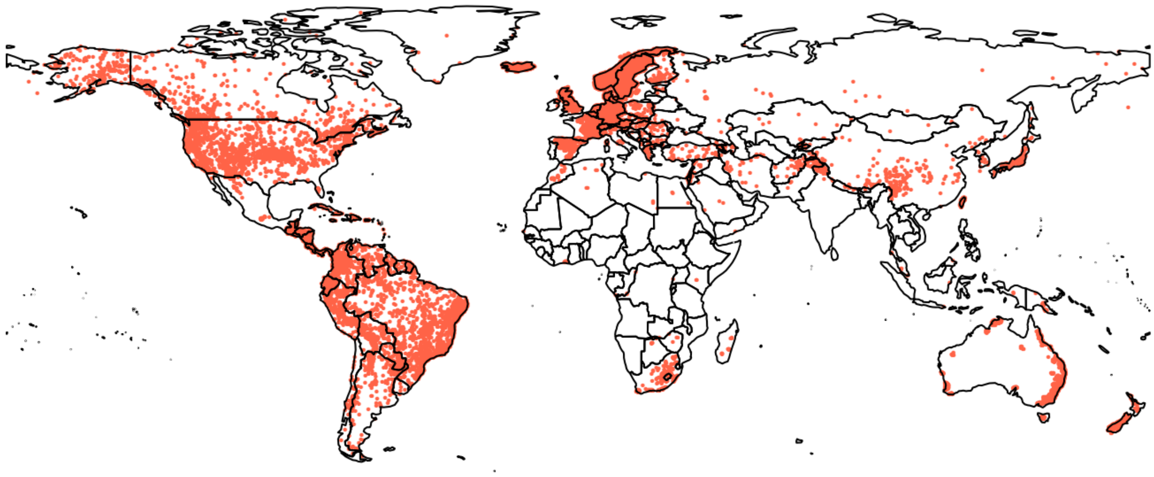
A presence-background (presence-only) ensemble modelling strategy was employed using the BIOMOD2 R package v3.3-7 (https://cran.r-project.org/web/packages/biomod2/index.html). These models contrast the environment at the species' occurrence locations against a random sample of the global background environmental conditions (often termed 'pseudo-absences') in order to characterise and project suitability for occurrence. This approach has been developed for distributions that are in equilibrium with the environment. Because invasive species' distributions are not at equilibrium and subject to dispersal constraints at a global scale, we took care to minimise the inclusion of locations suitable for the species but where it has not been able to disperse to. Therefore the background sampling region included:

- The native continent of *S. molesta*, South America, for which the species is likely to have had sufficient time to cross all biogeographical barriers; AND
- A relatively small 50 km buffer around all non-native occurrences, encompassing regions likely to have had high propagule pressure for introduction by humans and/or dispersal of the species; AND
- Regions where we have an *a priori* expectation of high unsuitability for the species, defined using the abovementioned rules (see Figure 1).

Within this sampling region there are likely to be substantial spatial biases in recording effort, which may interfere with the characterisation of habitat suitability. Specifically, areas with a large amount of recording effort will appear more suitable than those without much recording, regardless of the underlying suitability for occurrence. Therefore, a measure of vascular plant recording effort was made by querying the Global Biodiversity Information Facility application programming interface (API) for the number of phylum Tracheophyta records in each 0.1 x 0.1 degree grid cell. The sampling of background grid cells was then weighted in proportion to the Tracheophyte recording density. Assuming Tracheophyte recording density is proportional to recording effort for the focal species, this is an appropriate null model for the species' occurrence.

To sample as much of the background environment as possible, without overloading the models with too many pseudo-absences, five background samples of 10,000 randomly chosen grid cells were obtained (Figure 2).

Figure 2. Randomly selected background grid cells used in the modelling of *Salvinia molesta*.



Each dataset (i.e. combination of the presences and the individual background samples) was randomly split into 80% for model training and 20% for model evaluation. With each training dataset, ten statistical algorithms were fitted with the default BIOMOD2 settings, except where specified below:

- Generalised linear model (GLM)
- Generalised boosting model (GBM)
- Generalised additive model (GAM) with a maximum of four degrees of freedom per smoothing spline.
- Classification tree algorithm (CTA)
- Artificial neural network (ANN)
- Flexible discriminant analysis (FDA)
- Multivariate adaptive regression splines (MARS)
- Random forest (RF)
- MaxEnt
- Maximum entropy multinomial logistic regression (MEMLR)

Since the background sample was much larger than the number of occurrences, prevalence fitting weights were applied to give equal overall importance to the occurrences and the background. Variable importances were assessed and variable response functions were produced using BIOMOD2's default procedure. Model predictive performance was assessed by calculating the Area Under the Receiver-Operator Curve (AUC) for model predictions on the evaluation data, that were reserved from model fitting. AUC can be interpreted as the probability that a randomly selected presence has a higher model-predicted suitability than a randomly selected absence. This information was used to combine the predictions of the different algorithms to produce ensemble projections of the model. For this, the three algorithms with the lowest AUC were first rejected and then predictions of the remaining seven algorithms were averaged, weighted by their AUC. Ensemble projections were made for each dataset and then averaged to give an overall suitability.

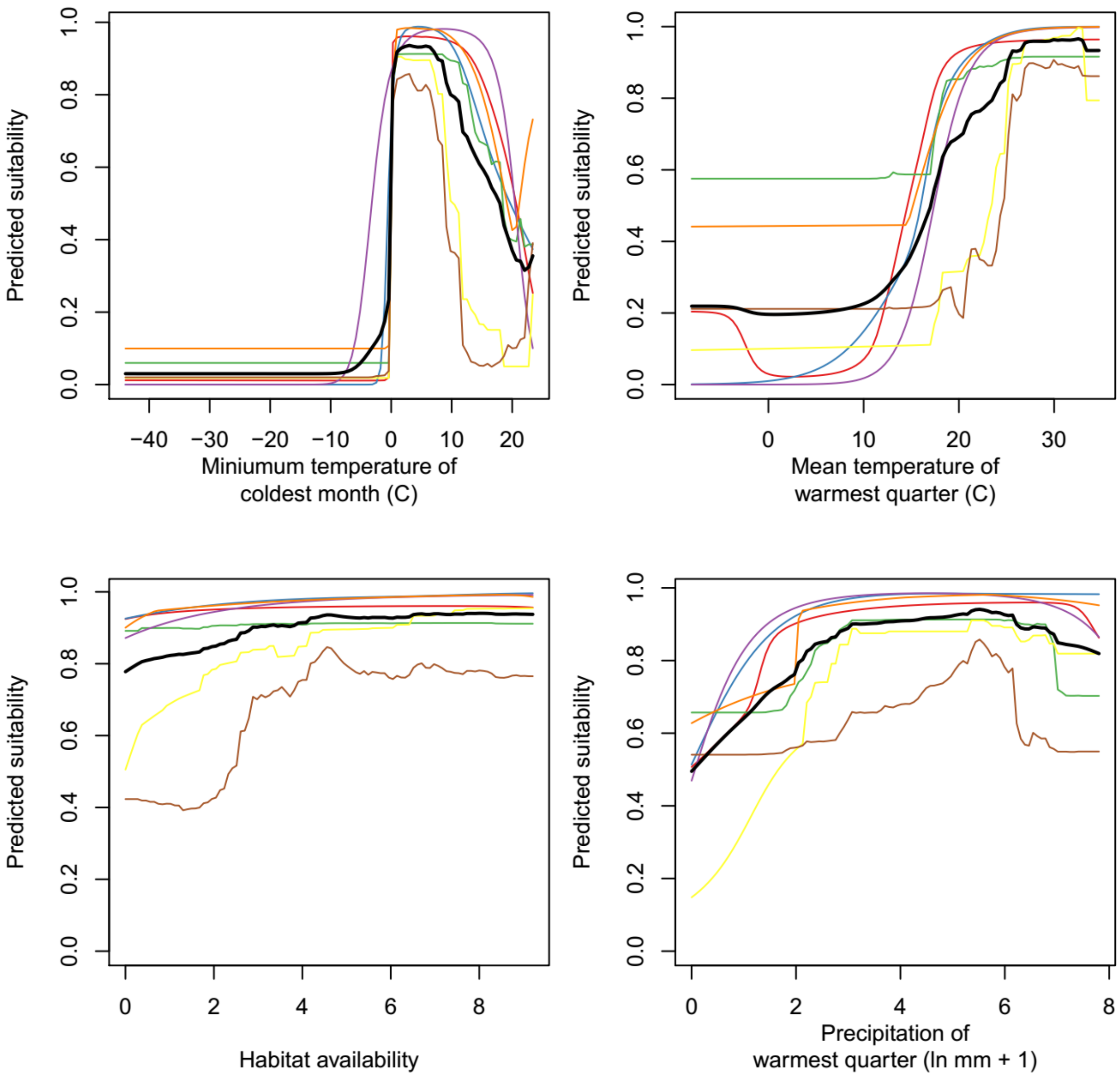
Results

The ensemble model had a better predictive ability than any individual algorithm and suggested that suitability for *S. molesta* was most strongly determined by the minimum temperature of the coldest month and mean temperature of the warmest quarter (Table 1). The response plots show that the ensemble model estimated biologically reasonable curves, with suitability limited by harsh frosts, low growing season temperatures, low cover of large water bodies and low precipitation in the growing season (Figure 3). The function also indicated that suitability was reduced if minimum temperatures were too high. The model estimates this effect because of a relative lack of occurrence records from tropical regions. The Expert Working Group considered this response to be unrealistic as in their view *S. molesta* growth would not be limited by high winter temperatures. However, this should have minimal effect on projected suitability in Europe, since winter temperatures are always lower than in tropical regions.

Table 1. Summary of the cross-validation predictive performance (AUC) and variable importances of the fitted model algorithms and the ensemble (AUC-weighted average of the best performing seven algorithms). Results are the average from models fitted to five different background samples of the data.

Algorithm	**Predictive AUC**	**Variable importance**			
		Minimum temperature of coldest month	**Mean temperature of warmest quarter**	**Precipitation of warmest quarter**	**Habitat availability**
GLM	0.9580	35.1%	55.1%	2.1%	7.6%
GBM	0.9698	75.4%	13.3%	2.6%	8.7%
GAM	0.9658	57.3%	35.4%	1.7%	5.5%
CTA	0.9366	64.1%	17.3%	4.1%	14.6%
ANN	0.9662	61.0%	23.6%	2.7%	12.7%
FDA	0.9548	36.7%	58.8%	3.3%	1.2%
MARS	0.9678	66.1%	26.2%	1.4%	6.3%
RF	0.9598	53.6%	26.9%	6.6%	12.9%
MaxEnt	0.9634	47.5%	38.1%	2.9%	11.5%
MEMLR	0.8296	43.4%	0.3%	42.4%	14.0%
Ensemble	**0.9702**	**56.6%**	**31.2%**	**2.9%**	**9.3%**

Figure 3. Partial response plots from the fitted models. Thin coloured lines show responses from the seven algorithms, while the thick black line is the response of their ensemble. In each plot, other model variables are held at their median value in the training data.



The projection of the model indicated high suitability throughout the subtropical parts of the world (Fig. 4). This included the likely native range of the species in south Brazil, even though there were very few occurrence records from there. Non-native occurrences of the species were largely consistent with this projection.

In Europe and the Mediterranean, large areas projected as currently suitable for establishment were found in Spain, Portugal, Italy, Greece, Turkey, Morocco, Algeria and Tunisia (Fig. 5). In other countries, projected suitability occurred in the coastal fringes of the Mediterranean, Black Sea and Caspian Sea.

By the 2070s, under climate change scenario RCP8.5, projected suitability for *S. molesta* increased in the countries projected as containing currently suitable regions, and also in western Europe (Fig. 6). Relaxation of frost constraints meant that the model projected high suitability in the Pannonian Plain (Hungary, Serbia and Croatia) and the northern coast of the Black Sea, as well as moderate suitability in much of northern France, UK, Belgium, Netherlands, Germany and the coasts of Denmark and southern Sweden. Therefore, the model suggests climate change could facilitate a major expansion of the invaded range of the species in Europe.

Figure 4. Global projected suitability for *Salvinia molesta* establishment in the current climate. For visualisation, the projection has been aggregated to a 0.5 x 0.5 degree resolution, by taking the maximum suitability of constituent higher resolution grid cells. The white areas have climatic conditions outside the range of the training data so were excluded from the projection. Points show the known occurrences.

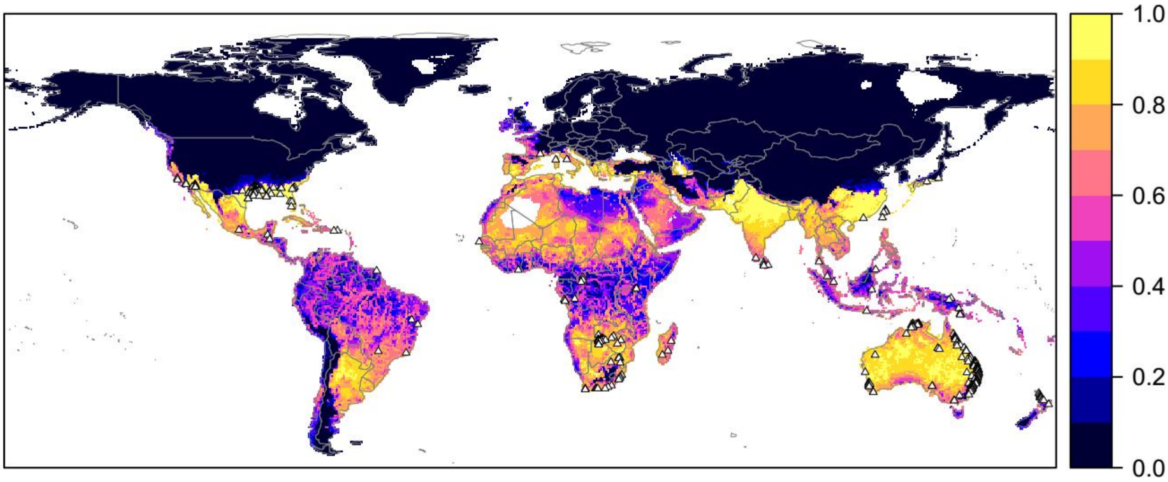


Figure 5. Projected current suitability for *Salvinia molesta* establishment in Europe and the Mediterranean region. To aid visualisation, the projected suitability has been smoothed with a Gaussian filter with standard deviation of 0.1 degrees longitude/latitude. The white areas have climatic conditions outside the range of the training data so were excluded from the projection. Points show the known occurrences used in the modelling.

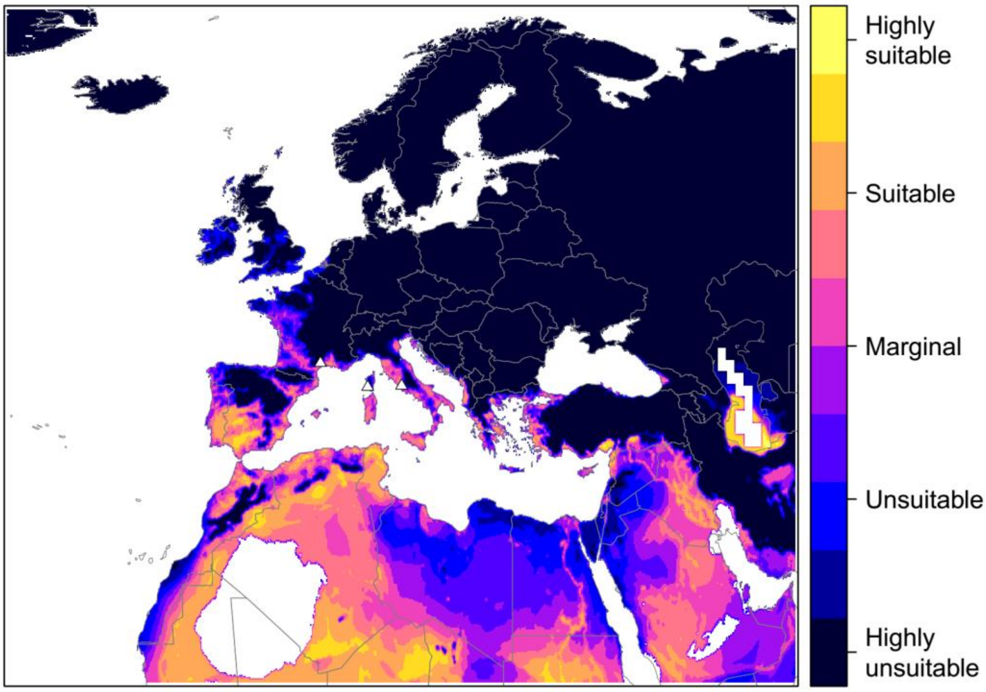
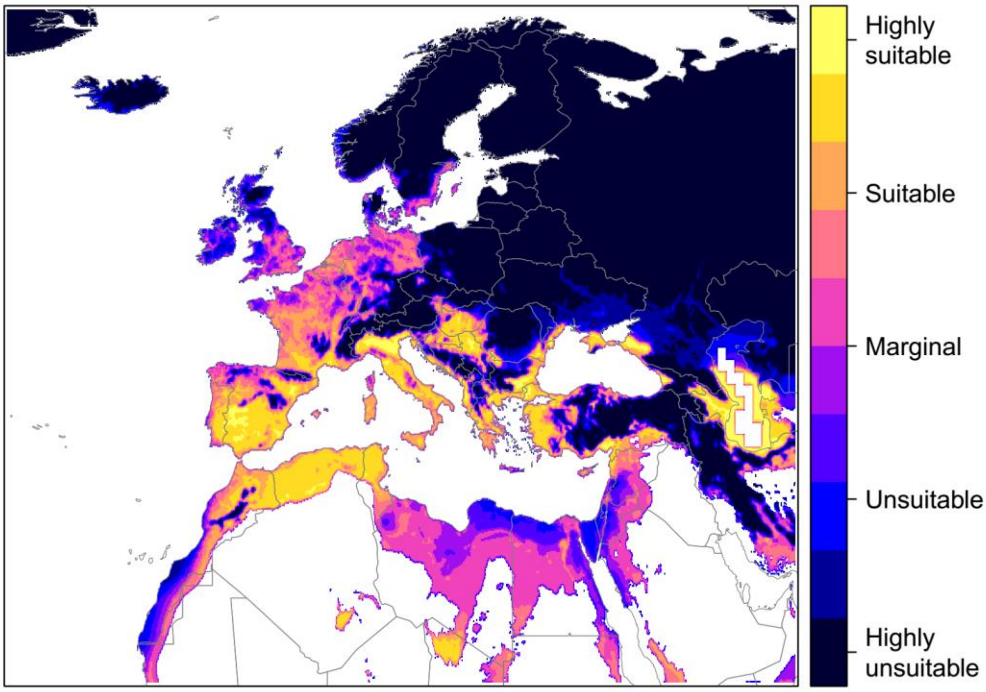


Figure 6. Projected suitability for *Salvinia molesta* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP8.5, equivalent to Fig. 5.



Caveats on the modelling

To remove spatial recording biases, the selection of the background sample was weighted by the density of Tracheophyte records on the Global Biodiversity Information Facility (GBIF). While this is preferable to not accounting for recording bias at all, a number of factors mean this may not be the perfect null model for species occurrence:

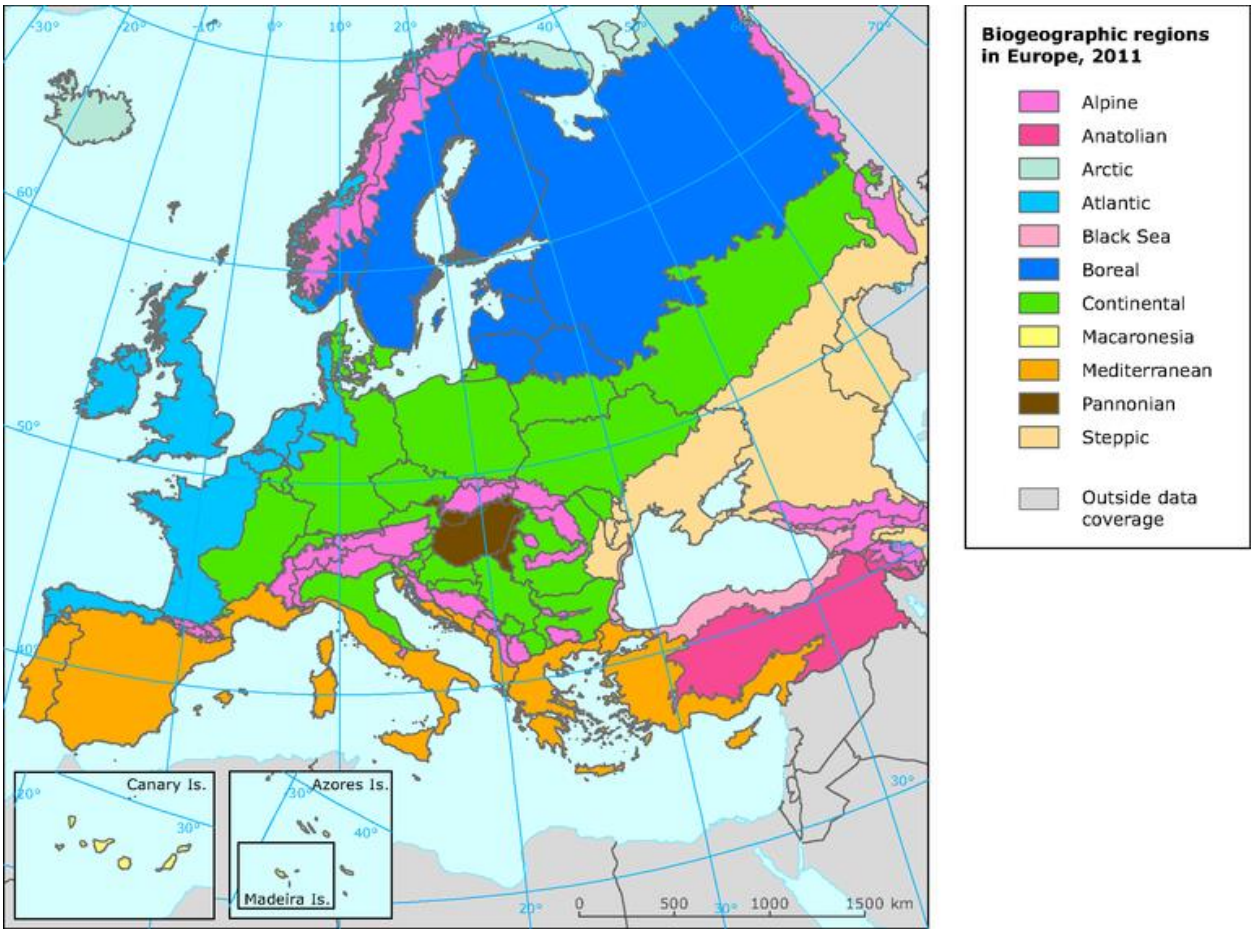
- The GBIF API query used to did not appear to give completely accurate results. For example, in a small number of cases, GBIF indicated no Tracheophyte records in grid cells in which it also yielded records of the focal species.
- We located additional data sources to GBIF, which may have been from regions without GBIF records.
- Levels of Tracheophyte recording may not be a consistent indicator of the recording of aquatic plants. There is a suggestion that aquatic plants may be disproportionately under-recorded in tropical regions (Jonathan Newman, *pers. comm*), which could have been responsible for an under-prediction of suitability in tropical regions.

Air temperatures were used in the model, while water temperatures may be more appropriate for an aquatic plant. In some cases air and water temperatures can markedly diverge, for example warming associated with industrial outflows. Wherever the water temperature is warm enough, the species is likely to be able to persist, regardless of the model's estimate of suitability.

Water chemistry and quality may have a large effect on the ability of the species to persist but were not used in the model. Factors such as water pH and nutrient concentration are likely to be important modifiers of habitat suitability.

The climate change scenario used is the most extreme of the four RCPs. However, it is also the most consistent with recent emissions trends and could be seen as worst case scenario for informing risk assessment.

Appendix 2. Biogeographic regions in Europe



Appendix 3. Relevant illustrative pictures (for information)

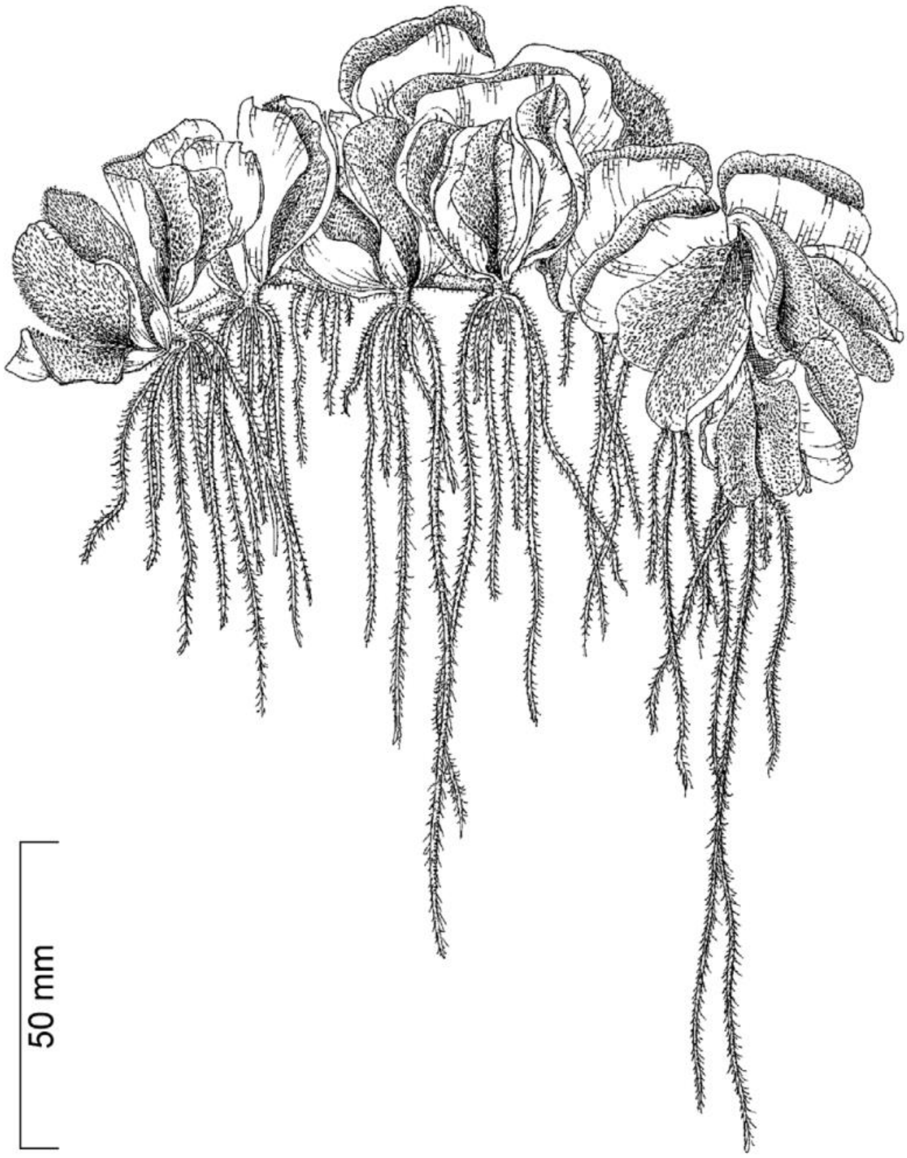
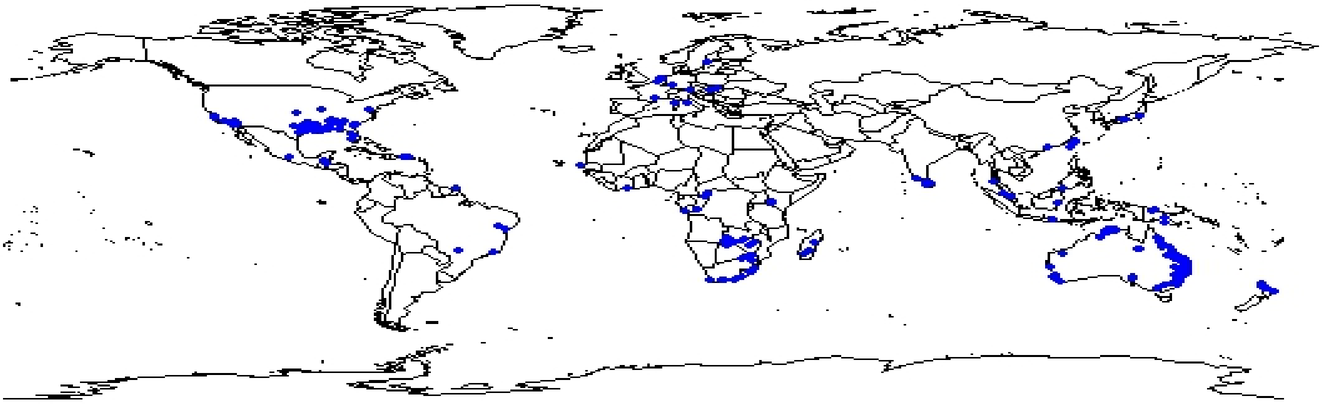


Fig. 1. *Salvinia molesta*. (Drawn by R.Weber; first published in Stirton (1978).)

Fig. 2 Mat of *Salvinia molesta* USA.

Fig 3 Large mat of *Salvinia molesta* USA.

Appendix 4 Distribution maps for Salvinia molesta[3]



[3] Note that these maps may contain records, e.g. herbarium records, that were not considered during the climate modelling stage

Figure 2. Occurrence of *Salvinia molesta* in Africa.

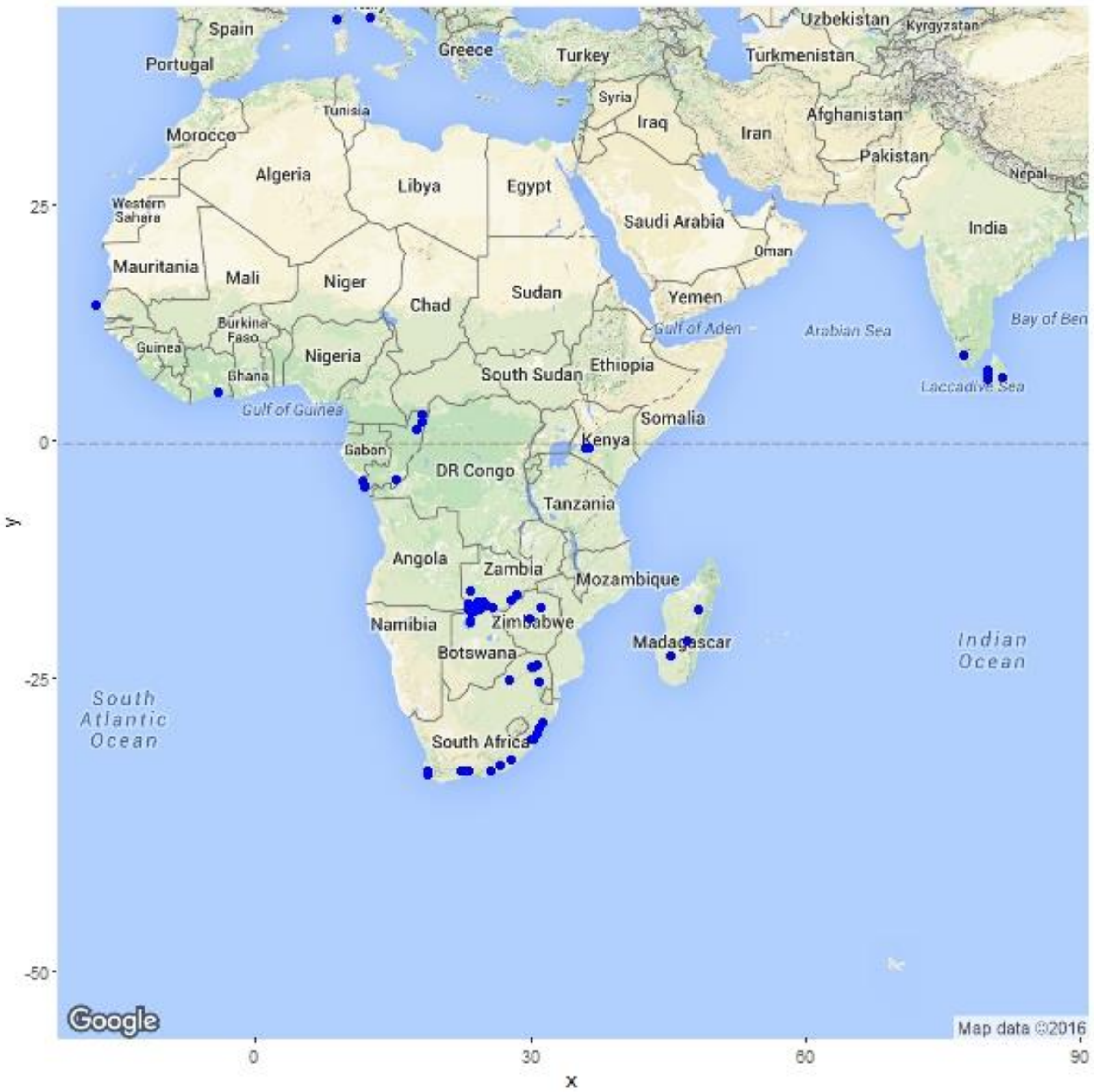


Figure 3. Occurrence of *Salvinia molesta* in Central and South America.

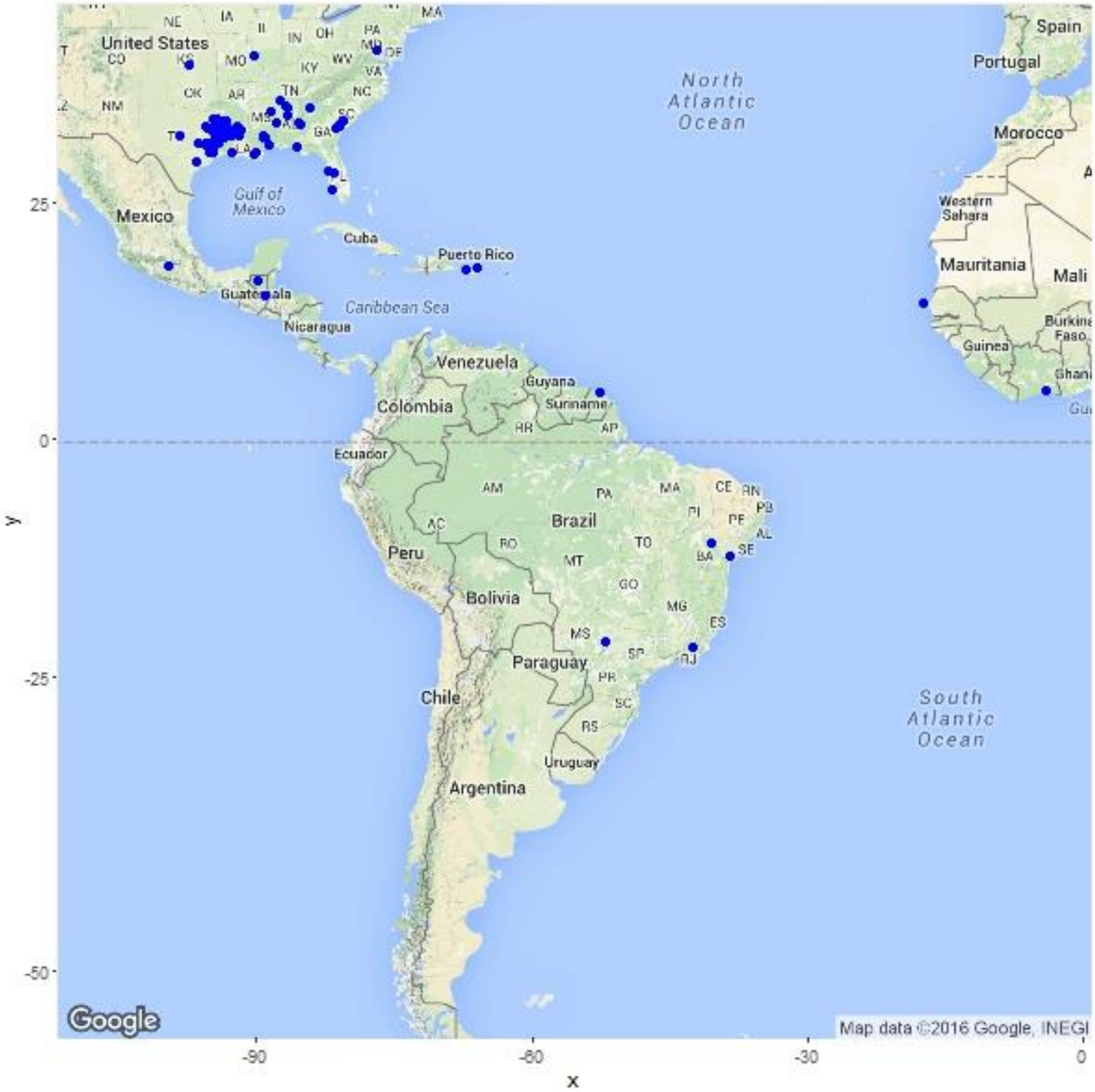


Figure 4. Occurrence of *Salvinia molesta* in North America.

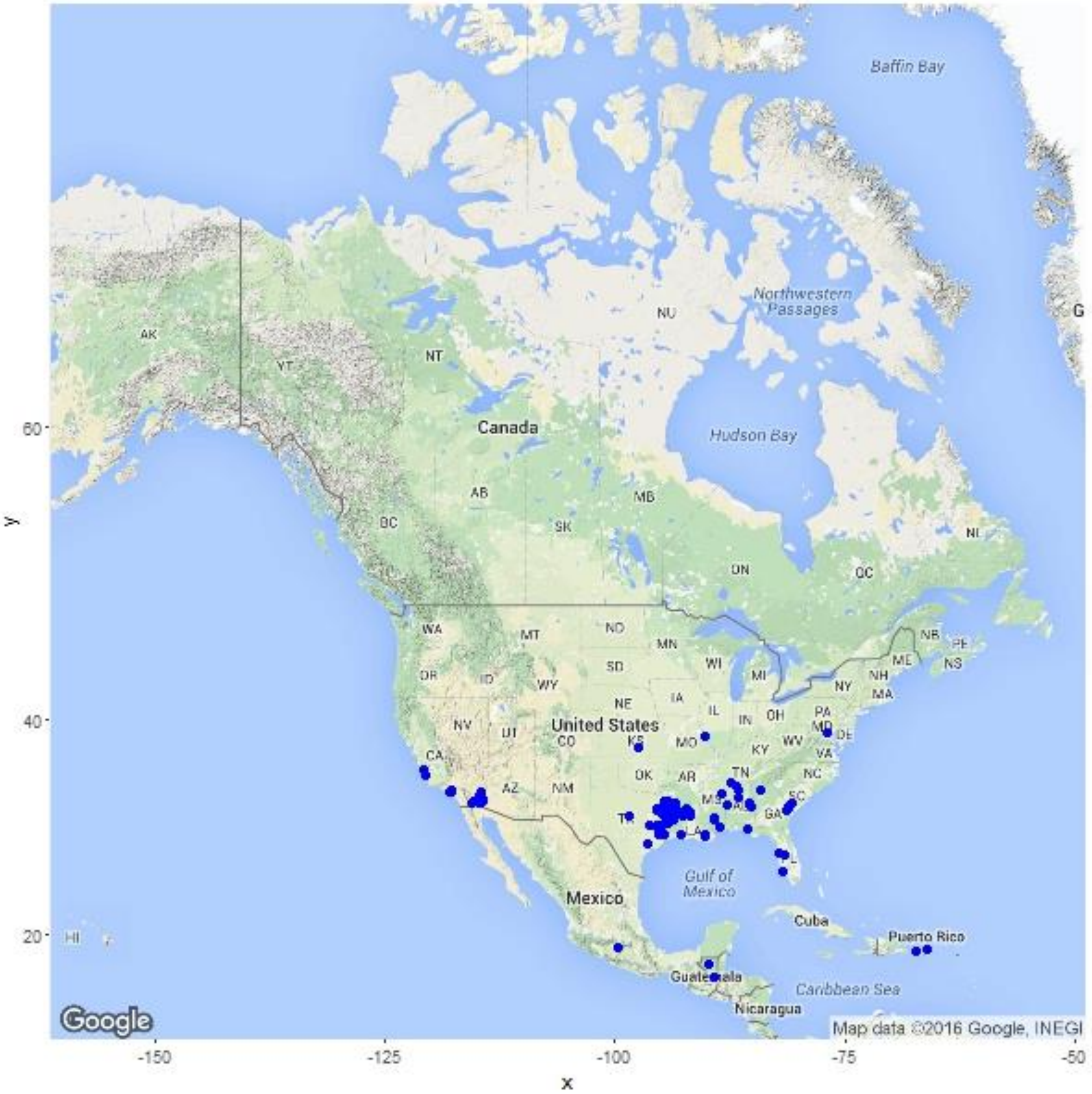


Figure 5. Occurrence of *Salvinia molesta* in Asia

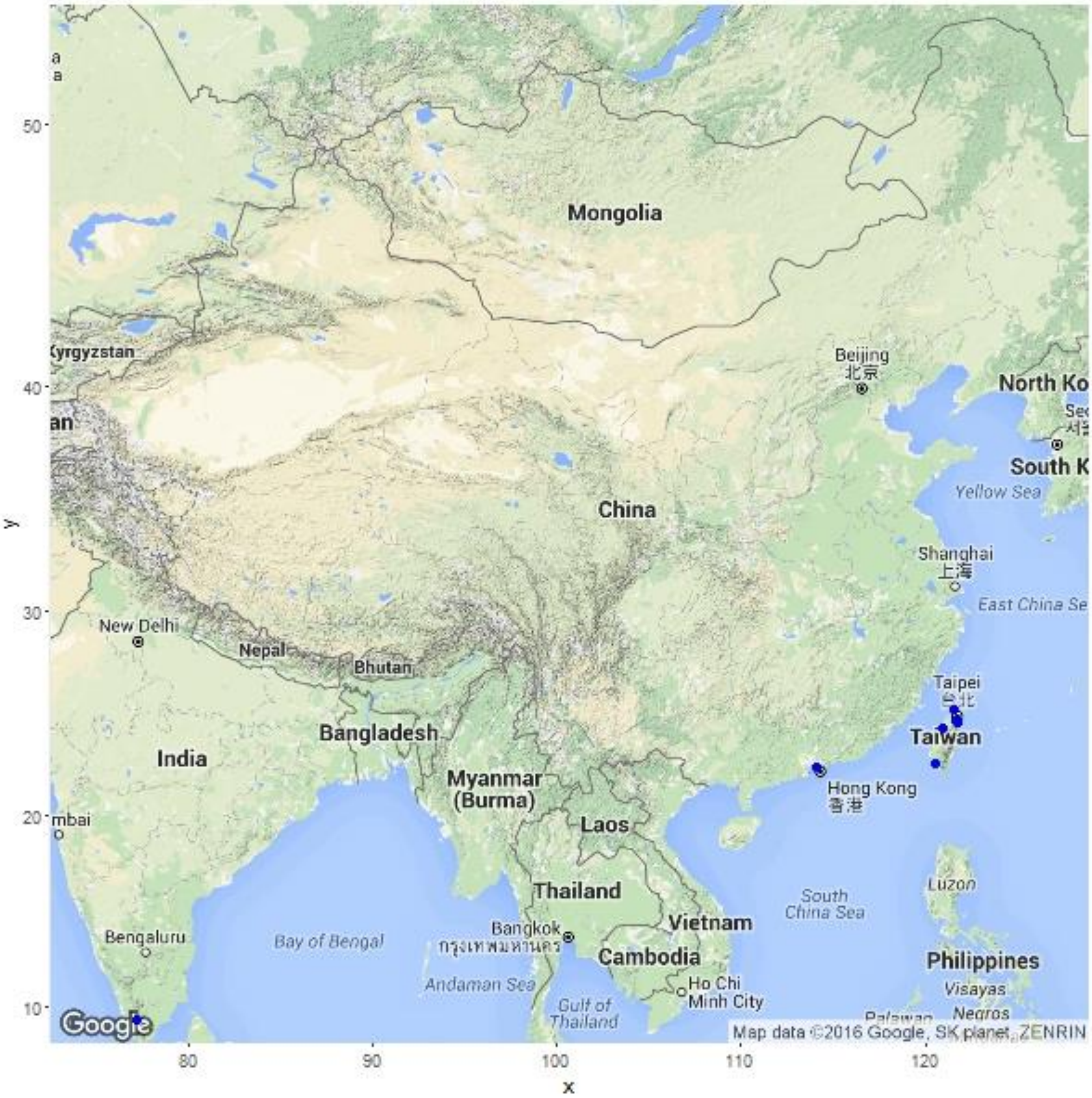


Figure 6. Occurrence of *Salvinia molesta* in Europe

Figure 7. Occurrence of *Salvinia molesta* in Europe