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

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Pest Risk Analysis for

Pistia stratiotes

2017

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This pest risk analysis 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'.

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Photo: *P. stratiotes*. Courtesy: Andreas Hussner

EUROPEAN AND MEDITERRANEAN PLANT PROTECTION ORGANIZATION

Pest risk analysis for *P. stratiotes* L.

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

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

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The pest risk analysis for *Pistia stratiotes* 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 *Pistia stratiotes* was first drafted by Dr Andreas Hussner

- 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)

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Summary[1] of the Express Pest Risk Analysis for *P. stratiotes*

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 (Albania, Algeria, France, Greece, Italy, Morocco, Portugal, Spain, Turkey, Tunisia).

Climate modelling suggests that the species is also capable of establishment in small areas of the Black Sea, Anatolian and Atlantic biogeographical regions. The southern countries within the EPPO region provide suitable climatic conditions for *P. stratiotes*. All water bodies not enclosed in ice during the winter months, including thermally abnormal waters in other EPPO countries, provide potential habitats for *P. stratiotes.*

Pistia stratiotes has already been reported as a casual occurrence in Austria, Belgium, Czech Republic, France, Germany, Hungary, Italy, The Netherlands, Norway, Portugal, Romania, Russia, Slovenia, Spain and the United Kingdom. In addition, the species is established in Morocco and Israel. The species is established in Germany, Russia and Slovenia in thermal waters, and it is thought to be in the process of establishment in southern France.

Main conclusions

Pistia stratiotes presents a high phytosanitary risk for the endangered area within the EPPO region with a low uncertainty. Further spread within and between countries is likely. The overall likelihood of *P. stratiotes* 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 establishing in other EPPO countries is considered high as the plant is widely traded. However, the species is already banned from trade in Spain and Portugal.

Potential spread as movement through irrigation and river systems 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

Pistia stratiotes is imported into the EPPO region. The species is already present and established within the PRA area – Morocco, Israel, France, Germany, Slovenia and Russia, in the case of the three latter, in thermal waters. The overall likelihood of *P. stratiotes* entering the EPPO region is high. As the species reproduces sexually, local adaptation is possible.

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

Pistia stratiotes may establish throughout climatically suitable aquatic habitats within the EPPO region. *P. stratiotes* is tolerant of a wide range of environmental aquatic conditions. Frost will limit the northern and eastern distribution of this species. Climate change could increase the likelihood of establishment, spread and impact in more areas of the EPPO region.

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

Potential impacts in the PRA area
Impacts in the EPPO area will of course likely be attenuated by climatic suitability, but, in areas where *P. stratiotes* will overwinter and spread, impacts are likely to be similar. For example, many of the impacts on biodiversity relate to ecosystem processes such as decomposition and the alteration of nutrient cycling, which, assuming that *P. stratiotes* is able to reach the levels of abundance required for these impacts to be displayed, can be assumed to occur in these areas just as much as in the current area of distribution.

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. Ecological impacts occur within the PRA area on flora and fauna, specifically documented for the former in the River Erft in Germany, where floating mats shade out native submerged vegetation.

The potential economic impact of *P. stratiotes* in the EPPO region could be 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 indigenous 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.

Even though the EWG considers the magnitude of impacts to remain the same, uncertainty will increase for all categories (impact on biodiversity, impact on ecosystem services and socio-economic impact. This is mainly due to the fact that impacts have not been measured in the PRA area.

Successful on-going control of *P. stratiotes* is underway in Morocco using the classical biological control agent *Neohydronomus affinis* combined with manual removal.

Climate change
By the 2070s, under climate change scenario RCP8.5, the projected suitability for *P. stratiotes* in Europe and the Mediterranean increased substantially. The model suggested that in this climate, much of Mediterranean, western and Pannonian Europe could become suitable for invasion, and suitability also increases around the coasts of the Black Sea and Caspian Sea. Therefore, the model suggests climate change could facilitate a major expansion of the species in Europe.

Phytosanitary measures:
The results of this PRA show that *P. stratiotes* poses an unacceptable risk to the endangered area (Mediterranean biogeographical region) with a moderate uncertainty.

The major pathway being considered is:

Plants for planting

Given the significant impact of the species in other parts of the world and the identified risk to the PRA area, the expert working group recommends the following measures for the endangered area:

International measures:

For the pathway plants for planting:

- Prohibition of import into and within the countries, of plants labeled or otherwise identified as *P. stratiotes*,

- Recommend that *P. stratiotes* is banned from sale within the endangered area,

- *P. stratiotes* should be recommended as a quarantine pest within the endangered area.

National measures:

National prevention measures on the sale of *P. stratiotes* already exist in Spain and Portugal. The expert working group recommends similar measures are adopted by countries identified as at risk of invasion within this PRA.

Pistia stratiotes should be monitored and eradicated, contained or controlled where it occurs in the environment. In addition, public awareness campaigns to prevent spread from existing populations or from botanic gardens in countries at high risk are recommended. If these measures are not implemented by all countries, they will not be effective since the species could spread from one country to another. National measures should be combined with international measures, and international coordination of management of the species between countries is recommended.

The expert working group recommends the prohibition of selling, planting, movement, and causing to grow in the environment, combined with management plans for early warning; obligation to report findings; eradication and containment plans; and public awareness campaigns.

Containment and control of the species in the PRA area
Eradication measures should be promoted where feasible with a planned strategy to include surveillance, containment, treatment and follow-up measures to assess the success of such actions. As highlighted by EPPO (2014), regional cooperation is essential to promote phytosanitary measures and information exchange in identification and management methods. Eradication may only be feasible in the initial stages of infestation, and this should be a priority. The expert working group considers that this is possible at the current level of occurrence the species has in the EPPO region.

General considerations should be taken into account for all potential pathways, where, as detailed in EPPO (2014), these measures should involve awareness raising, monitoring, containment and eradication measures. NPPOs should facilitate collaboration with all sectors to enable early identification including education measures to promote citizen science and linking with universities, land managers and government departments. The funding of awareness campaigns, targeting specific sectors of society, eg. anglers, and the water based leisure trade will target groups most prone to facilitate spread.

Import for (aquatic) plant trade: Prohibition of the import, selling, planting, and movement of the plant in the endangered area.

Unintended release into the environment: The species should be placed on NPPO's alert lists and a ban from sale would be recommended in countries most prone to invasion. Management measures would be recommended to include an integrated management plan to control existing populations including manual and mechanical techniques, targeted herbicides and biological control techniques. Monitoring and surveillance including early detection for countries most prone to risk. NPPOs should report any finding in the whole EPPO region in particular the Mediterranean area.

Intentional release into the environment: Prohibition on planting the species or causing the plant to grow in the environment.

Natural spread (method of spread within the EPPO region): Increase surveillance in areas where there is a high risk the species may invade. NPPOs should provide land managers and stakeholders with identification guides and facilitate regional cooperation, including information on site specific studies of the plant, control techniques and management.

See Standard PM3/67 'Guidelines for the management of invasive alien plants or potentially invasive alien plants which are intended for import or have been intentionally imported' (EPPO, 2006). See Standard PM9/19 (1) 'Invasive alien aquatic plants' (EPPO, 2014). See Standard PP 3/74(1) 'EPPO guidelines on the development of a code of conduct on horticulture and invasive alien plants' (EPPO, 2009).			
Phytosanitary risk for the *endangered area* (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 Socio-economic impact: High/High Impact (PRA area) Impact on biodiversity: High/High Impact on ecosystem services: High/High Socio-economic impact: High/High	High X	Moderate ☐	Low ☐
Level of uncertainty of assessment (current/future climate) 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/Low Impact (current area of distribution) Impact on biodiversity: Low/Low Impact on ecosystem services: Low/Low Socio-economic impact: Low/Low 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 Analysis: *P. stratiotes* L.

First draft prepared by: *Dr. Andreas Hussner, Jackels Umweltdienste GmbH, Siemensring 9, 41334 Nettetal*

Date: 2016-05-03

Stage 1. Initiation

Reason for performing the PRA:
Pistia stratiotes currently has a limited distribution within the natural environment in the EPPO region. In Europe, *P. stratiotes* has been found in Belgium, Czech Republic, France, Germany, Hungary, Italy, The Netherlands, Portugal, Romania, Russia, Slovenia and Spain (Hussner 2012, EPPO 2012). Further spread is predicted as the species is traded and used in aquaria and ponds within the EPPO region. Due to the frost sensitivity of the species, it can only become established in waters which are not covered by ice during winter months. Consequently, large infestations of the species have only been reported for the southern parts of the EPPO region and for thermal waters in Germany, Slovenia, and Russia (Sajna *et al*. 2007, Brundu *et al*. 2012, Hussner *et al*. 2014a). The dense mats of *P. stratiotes* block sunlight which limits the growth of submerged plant species and prevents wind induced mixing of the water column causing reductions in dissolved oxygen that may result in anoxia with serious effects on fish and invertebrate species. The plant also increases evapotranspiration resulting in water loss. The presence of the species in the EPPO region, and the continued availability of this plant for purchase within EPPO countries, coupled with a warming climate, mean that a PRA is required. In 2016, the species was prioritized (along with 36 additional species from the EPPO List of Invasive Alien Plants and a recent horizon scanning study[2]) for PRA within the LIFE funded project “Mitigating the threat of invasive alien plants to the EU through pest risk analysis to support the Regulation 1143/2014’. *P. stratiotes* was one of 16 species identified as having a high priority for PRA.

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

[2] http://ec.europa.eu/environment/nature/invasivealien/docs/Prioritising%20prevention%20efforts%20through%20horizon%20scanning.pdf

Stage 2. Pest risk assessment
1. Taxonomy: *Pistia stratiotes* L. (Kingdom Plantae; Phylum Tracheophyta; Class Liliopsida; Order: Arales; Family Araceae; Genus *Pistia*) **according to IUCN**, APHI [http://www.mobot.org/MOBOT/research/APweb/].

Domain: Eukaryota ; Kingdom: Plantae; Phylum: Spermatophyta; Subphylum: Angiospermae; Class: Monocotyledonae, Order: Arales **according to CABI**

EPPO Code: PIIST

Synonyms: *Pistia spathulata* Michaux, *P. stratiotes* var. *cuneata* Engl., *P. stratiotes* var. *linguiformis* Engl., *P. stratiotes* var. *obcordata* (Schleid.) Engl., *P. stratiotes* var. *spathulata* (Michx.) Engl., *Zala asiatica* Loureiro, *Apiospermum obcordatum* (Schleiden) Klotzsch, *Limnonesis commutata* (Schleiden) Klotzsch, *Limnonesis friedrichsthaliana* Klotzsch,, *Pistia aegyptiaca* Schleiden, *Pistia aethiopica* Fenzl ex Klotzsch, *Pistia africana* C. Presl, *Pistia amazonica* C. Presl, *Pistia brasiliensis* Klotzsch, *Pistia commutata* Schleiden, *Pistia crispata* Blume, *Pistia cumingii* Klotzsch, *Pistia gardneri* Klotzsch, *Pistia horkeliana* Miquel, *Pistia leprieurii* Blume, *Pistia linguaeformis* Blume, *Pistia minor* Blume, *Pistia natalensis* Klotzsch, *Pistia obcordata* Schleiden, *Pistia occidentalis* Blume, *Pistia schleideniana* Klotzsch, *P. stratiotes* Linnaeus, var. obcordata (Schleiden) Engler, *Pistia texensis* Klotzsch, *Pistia turpinii* Blume, *Pistia weigeltiana* C. Presl
(source : www.theplantlist.org; http://florida.plantatlas.usf.edu/Plant.aspx?id=4002#synonym)

Common names: water lettuce, tropical duckweed, Nile cabbage
German name: Muschelblume, Wassersalat, **French name**: Laitue d'eau, pistie, **Spanish name**: Lechuguilla de agua, lechuguita de agua, repollo de agua, **Dutch name**: watersla, Mosselplant.

Plant type: Perennial floating aquatic macrophyte

Related species in the EPPO region: none

2. Pest overview
Introduction

Pistia stratiotes is a free floating aquatic plant. The native range of the species is not clear, but it is suggested, that the species is either native to South America (Neuenschwander *et al*. 2009), or that *P. stratiotes* is a pan-tropical species occupying a native range across the tropical and sub-tropical regions of Asia, Africa, Australia and South America (Gillett *et al*., 1988; Evans 2013). However, other studies suggest that the species has a palearctic origin (Renner & Zhang, 2004). In the USA, there is some uncertainty to whether the species is native to Florida, while it was described for the first time in 1765 from William Bartram (https://plants.ifas.ufl.edu/plant-directory/pistia-stratiotes/#1). Regardless of this, the species is considered a management priority. The species is present in Africa, Asia, Europe, North America and Oceania (Neuenschwander *et al*. 2009), and appears in the list of the world's worst weeds (Holm *et al*., 1977). The species is sold as an ornamental aquatic plant in the PRA area. *P. stratiotes* was added to the EPPO Alert List in 2007 and subsequently transferred to the List of Invasive Alien Plants in 2012. Within the EPPO region the species has the capacity to become established in the Mediterranean region and in thermal water bodies. In addition, species distribution models suggest that the endangered area is the Mediterranean biogeographical region (see appendix 1, Figure 5 and Appendix 2, Figure 1). Southern countries within the EPPO region currently provide suitable climatic conditions for the plant. This includes at least all regions, in which the water bodies are not enclosed in ice during the winter months. The suitable area is likely to increase under likely scenarios of climate change (e.g. Hallstan, 2005).

Environmental requirements
Pistia stratiotes grows in slow moving rivers and reservoirs, irrigation channels, ponds, lakes, canals and ditches (Cilliers 1991, Venema 2001, Adebayo *et al*. 2011, Hussner *et al*. 2014a). *P. stratiotes* can grow under varying physical and chemical conditions. Its growth is optimal at temperatures between 22-30 °C and high nutrient conditions (Pieterse *et al*., 1981, Henry- Silva *et al*. 2008). However, plants still develop at temperatures as low as > 10 °C (Hussner *et al.*, 2014a, Pieterse *et al*., 1981). The plants are susceptible to low temperatures and frost and die back when enclosed in ice and at temperatures slightly above 0 °C (MacIsaac *et al*., 2016) (Appendix 3; Figure 1). *P. stratiotes* can withstand freezing air temperatures as the small floating form, as long as the leaves are in direct contact with the water surface in water temperatures >10 °C (Hussner *et al*., 2014) (Appendix 3; Figure 2). Seeds of *P. stratiotes* germinate at a lower temperature limit of 20 °C, are resistant to frost and can withstand temperatures of -5 °C, however, germination rates decrease with a prolonged frost period (Pieterse *et al*., 1981, Kan & Song, 2008, Hussner *et al*., 2014a, Kurugundla, 2014). *P. stratiotes* was found to be tolerant to salt and can withstand 200 mmol/l NaCl in the water (6 PSU) (Upadhyay and Panda, 2005).

Habitats
Pistia stratiotes grows in aquatic habitats such as lakes, canals, reservoirs and slow moving rivers. The species often invades rice paddies in Asia as well as other wetland habitats. The species can survive drying, and can reinfest ephemeral waters which are subject to seasonal drying, beacause of seed survival and germination. See also the Environmental requirement section above.

Identification
Pistia stratiotes is a free floating plant with a rosette of obovate to spatulate, short haired leaves (up to 40 cm in length in African forms and up to 35 cm in European forms (Neuenschwander *et al*., 2009, Hussner unpublished)) (Appendix 3; Figure 3). *P. stratiotes* is a clonal plant that forms small colonies with daughter plants attached to the mother plant through stolons. Dispersal is enhanced through detachment of daughter plants which form new colonies. The upper sides of the leaves are light-green, while the undersides are almost white. The floating plants have a large feathery root systems which hangs freely in the water (Appendix 3; Figure 3). The solitary

inflorescence is axillary and inconspicuous, with short peduncles in the center of the rosette. The spadix, with a single pistillate flower and several staminate flowers enclosed in a whitish spathe, is pale green, hairy outside and glabrous inside (Neuenschwander *et al*., 2009; Buzgo 2015, http://www.aroid.org/genera/pistia/buzgopistia.php). The peduncle bends after fertilization and pushes the fruits underwater where up to 30 seeds per fruit can be released (Neuenschwander *et al*., 2009; Kurugundla, 2014) (Appendix 3; Figure 4).

Flowering plants are widely observed within the EPPO region and the plants produce numerous viable seeds (Hussner *et al*., 2014a).

Symptoms

Pistia stratiotes forms dense mats at the surface of the water body reducing light penetration, which reduces suitable habitats for native submerged plants (Appendix 3; Figure 5 & 6). Additionally, *P. stratiotes* reduces wind induced mixing of the water column, which decreases the levels of dissolved oxygen, sometimes resulting in anoxia, decreases pH, increases the CO_2 concentration and reinforces stratification. Overall, this results in a reduction of native macrophytes, macroinvertebrates and fish species (Attionu, 1976; Sridhar & Sharma, 1980; Sajna *et al*., 2007). *P. stratiotes* produces allelochemicals against algae (Aliotta *et al*., 1991), thus if shading is not sufficient then additional effects on algae growth in infested waters are likely. The changes in hydrochemistry reduce the water quality, especially for its use as drinking water (Neuenschwander *et al*., 2009). In addition, the mat forming habit can result in the clogging of water bodies and this is likely to obstruct access for water based recreational activities.

Pistia stratiotes mats clog waterways and limit the recreational use of water bodies, reduce the efficiency of irrigation and drainage systems and increase water loss due to evapotranspiration. Moreover, dense mats of *P. stratiotes* reduce water flow and can damage flood control structures. Moving mats of *P. stratiotes* can form blockages against bridges and reduce hydropower generation (Howard and Harley, 1998). In areas of high wave action, mats of *P. stratiotes* can physically damage rooted aquatic plants in shallow waters.

Pistia stratiotes mats serve as preferred host sites for the larvae of several mosquito species (Holm *et al*., 1969). These include *Anopheles* and *Mansonia*, which act as vectors for malaria (Lounibos & Dewald, 1989; Rejmankova *et al*., 1991; Parsons & Cuthbertson, 2001).

Existing PRAs for *P. stratiotes*

Pacific Island Ecosystems at Risk (PIER): This risk assessment predicts the likelihood of invasiveness of the species in Australia, Hawaii and the high islands of the Pacific, and in the State of Florida. The PRA was prepared for Australia and scored *P. stratiotes* with 18 indicating that the species poses a high risk of becoming a serious pest.

New Zealand (Aquatic Weed Risk Assessment Model, AWRAM): In a risk assessment for New Zealand, *P. stratiotes* received a score 42 out of 100 points, indicating the species has a moderate weed potential (Champion *et al*., 2007).

Europe: This 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.

Ireland: *P. stratiotes* is considered to have only a minor overall risk of becoming invasive in Ireland (Millane & Caffrey, 2014).

Socio-economic benefits

Pistia stratiotes is widely sold as an ornamental species within the EPPO region. The species is also sold/exchanged between aquarists. The species regularly features on aquatic plant websites and online retailers. For example aquabase, amazon and other specialist suppliers:

http://www.aquabase.org/plant/view.php3?id=36&desc=pistia-stratiotes

https://www.amazon.co.uk/Lettuce-Pistia-Stratiotes-Aquarium-Floating/dp/B00CPUXE2O

http://www.lilieswatergardens.co.uk/pistia-stratiotes-british-grown-raised-loose-plants-p-1315.html

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 27 982 *P. stratiotes* plants were sold in the UK in 2015 with a value of GBP 101 133.

Pistia stratiotes is widely used for phytoremediation of metals (Aurangzeb *et al*., 2014; Farnese *et al*., 2014), chemical products (hepatotoxin: Somdee *et al*., 2016), oil (Yang *et al*., 2014), removal of pharmaceuticals and personal care products (Lin & Li, 2016) or for urban sewage treatment (Zimmels *et al*., 2006). *P. stratiotes* biomass can be used for bioethanol production, with ethanol yields per unit biomass comparable to other agricultural biomasses (Mishima *et al*., 2008), and biogas production (Abbasi & Nipaney, 1991). However, the implementation of this is unlikely to be economically viable based on experiences in Uganda and elsewhere (Personal Communication, Martin Hill, 2016).

The fiber content, carbohydrate and crude protein content of *P. stratiotes* is comparable to quality forages (Parsons & Cuthbertson, 2001). While cows find *P. stratiotes* unpalatable, the plants can be fed to pigs (Nonindigenous Aquatic Species Database, 2015). *P. stratiotes* is also used for Ayurvedic medicine and used for its diuretic, antidiabetic, antidermatophytic, antifungal and antimicrobial properties (Nonindigenous Aquatic Species Database, 2015).

Pistia stratiotes is used as a soil conditioner in rice where it improves crop yield (Roger *et al*., 1984).

Apart from being sold in the EPPO region, none of the other detailed benefits have been utilised in the region.

3. Is the pest a vector? **No**

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

No vector is needed for *P. stratiotes* spread or entry into the PRA area.

5. Regulatory status of the pest

Europe (overall): *Pistia stratiotes* 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. *P. stratiotes* 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, *P. stratiotes* was not included on the final list produced by that project.

Netherlands: a Code of Conduct recommended that the sale of *P. stratiotes* is only allowed when additional information is provided on a label. The warning label must inform customers about the potential invasion risk of the species to reduce the risk of release into the wild (Verbrugge *et al*., 2014).

Germany: *Pistia stratiotes* has been listed as a potentially invasive plant (Nehring & Hussner 2013) and it is recommended not to trade the species the Federal Agency for Nature Conservation, Germany (Schmiedel *et al*. 2015).

Portugal: In Portugal the species is included in the list of Prohibited plants Decreto-Lei n.º 565/99http://www.silvaplus.com/fotos/editor2/LegislacaoPT/Floresta/dec_lei_565_99.pdf .

Spain: 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

North America: *P. stratiotes* is listed as an alien species in Alabama (class C, noxious weed), California (B list, noxious weed), Connecticut (potentially invasive, banned), Florida (prohibited aquatic plant, Class 2), South Carolina (invasive aquatic plant) and Texas (noxious plant) (USDA, 2015).

New Zealand: *Pistia stratiotes* is legally prohibited from sale (Champion *et al*., 2014).

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

South Africa: In 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. *P. stratiotes* 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).

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	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Comoros, Democratic Republic of Congo, Côte d'lvoire, Egypt, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bassau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Réunion, Rwanda, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe	Introduced, established and invasive and still spreading unless under biological control.	CABI, 2016; Cilliers *et al*., 2003
North America	Canada: Ontario USA: Alabama, Arizona, California, Colorado, Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Illinois, Kansas, Louisiana, Maryland, Michigan, Minnesota, Mississippi, Missouri, New Jersey, New York, North Carolina, Ohio, Rhode Island, South Carolina, Texas	Canada: Casual USA: Introduced, established and invasive in Southern States and casual in Northern States.	Adebayo *et al*., 2011; http://nas.er.usgs.gov/queries/GreatLakes/FactSheet.aspx?SpeciesID=1099 CABI, 2016
Central America and the Caribbean	Antigua and Barbuda, Belize, Costa Rica, Cuba, Dominican Republic, El Salvador, Guadeloupe, Guatemala, Haiti, Honduras, Jamaica, Martinique, Monserrat, Nicaragua, Panama, Puerto Rico, Saint Lucia, Saint Vincent, Trinidad and Tobago	Introduced, established and invasive.	CABI, 2016
South America	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela	Considered native to the Pantanal region of South America	(CABI, 2016), Forzza *et al*., 2012
Europe	Austria, Belgium, Czech Republic, France, Germany, Hungary, Italy, Netherlands, Norway, Portugal, Romania, Russia, Slovenia, Spain, United Kingdom	Introduced in all countries, possibly established in the Mediterranean region. Established in thermally abnormal waters in Slovenia and Germany.	Aquatische Neobiota in Österreich, 2013; Diekjobst, 1984; Mennema, 1977; Brundu et a., 2012; Pilipenko, 1993; Garcia Murillo, 2005;

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***
			Sajna *et al*., 2007; Verloove, 2006). Somerset Rare Plants Group, 2010
Asia	Afghanistan, Bangladesh, Brunei Darussalam, Cambodia, China, India, Indonesia, Israel, Japan, Kazakhstan, Laos, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, Vietnam	Introduced, established and invasive, although not in all countries.	(CABI, 2016)
Oceania	Australia, Papua New Guinea, Solomon Islands, Vanuatu, New Caledonia, New Zealand	Introduced, established and invasive in some areas, under biological control in Australia. New Zealand: Eradicated	(Gillet *et al*. 1998) https://www.niwa.co.nz/sites/niwa.co.nz/files/sites/default/files/pest_guide_potrt_feb_2013.pdf;

Introduction:
Pistia stratiotes has a pan-tropical and subtropical distribution See Appendix 4 Figure 1.

Africa
Pistia stratiotes is widespread throughout Africa. In South Africa, the plant is recorded as invasive, the first record was in 1865 from KwaZulu-Natal (Hill, 2003). *P. stratiotes* was first recorded on a small multipurpose impoundment near the town of Fez in Morocco in 2012 (Hill, 2013). See Appendix 4 Figure 2 for the distribution of the species in Africa.

Asia
In Asia, *P. stratiotes* has a wide distribution and is recorded as invasive (CABI, 2016). See Appendix 4 Figure 3 for the distribution of the species in Asia. The plant was recorded in the Philippines as early as 1925, floating in abundance in shallow waters (Merrill and Elmer, 1925; Waterhouse, 1997).

North America:
Pistia stratiotes occurs in several states of the USA. It is generally considered as an introduced plant species and classified as a pest species and under regulation in some states (see section 5). There are casual records from the Great Lakes (Adebayo *et al*., 2011). See Appendix 4 Figure 4 for the distribution of the species in North America (see also Figure 5 for the distribution in South America).

Oceania:
Pistia stratiotes is widespread in the Northern Territory in Australia. The species was eradicated from New Zealand (North Island). *P. stratiotes* is invasive in Papua New Guinea and first recorded in 1971 (Forman, 1971). See Appendix 4 Figure 6 for the distribution of the species in Oceania.

Europe
Pistia stratiotes has been reported for: Austria (Neuenschwander *et al*. 2009), Belgium (Verloove, 2006), Czech Republic, France (Fried, 2012), Germany (Nehring & Hussner 2013 *et al*., 2015),

Hungary, Italy (Brundu *et al*., 2012), Netherlands (Mennema 1977), Norway (ARTSDATABANKEN, 2016), Portugal, Romania, Russia (Schanzer *et al*., 2003), Slovenia (Sajna *et al*., 2007), Spain and the United Kingdom (Somerset Rare Plants Group, 2010). See Appendix 4 Figure 4 for the distribution of the species in Europe. *P. stratiotes* was found for the first time in the Netherlands in 1973 but the plants did not become established (Mennema 1977). First reports from Austria and Germany were made in 1980 (Schmiedel *et al*., 2015). Repeated introductions failed to establish in Germany up until 2005, however, since 2008, an established population has been permanently present in thermal sections of the River Erft (Hussner *et al*., 2014a). In Italy, *P. stratiotes* was found first in 1998 (Brundu *et al*., 2012). In France, *P. stratiotes* was found once in the Landes department in 2003, but is no longer present (EPPO 2012). Several casual populations have also been recorded in the Mediterranean parts of France since 1998 (SILENE, 2016). *P. stratiotes* is now considered as established in at least one location, in a canal along the Rhône river, where first observations dated back to 2005 (Fried, com. pers., update 2016). In 2012, a first management action has been undertaken due to the high density reached by *P. stratiotes* colonies at the end of the summer. In September 2016, *P. stratiotes* has been recorded all along 17 km of the canal, including several portions with 100% cover, one of them on about 1 km of the canal. In Slovenia, an established population has been documented from a thermal river (Sajna *et al*., 2007). In Belgium, the species was first observed in 2000, and is still present in 2015 mainly in East Flanders (Verloove, 2006, update 2015). In Russia, *P. stratiotes* is known from some ponds and rivers around Moscow (Schanzer *et al*., 2003). *P. stratiotes* was found in Spain (Garcia Murillo, 2005), though the species is no longer present on the mainland. On the Canary Islands, the species is considered invasive. In the United Kingdom, the species has been recorded around 45 times; four of these occurrences are detailed as persisting for more than five years in the database of the Botanical Society of Britain and Ireland. However, it is not clear if all occurrences still remain. *P. stratiotes* was first discovered in Somerset (United Kingdom) in 2004, when a few plants were discovered on the Burnham Level. The plant is now “well established” in Bridgwater and Taunton Canal (United Kingdom) (Somerset Rare Plant Group Newsletter, 2010). See Appendix 4 Figure 7 for the distribution of the species in Europe.

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***
Freshwater bodies such as canals, rivers (slow moving), ponds, 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 habitat(s) within the PRA area and the habitat(s) at the highest risk of invasion	Mennema, 1977, Sajna *et al*., 2007, Brundu *et al*., 2012, Hussner *et al*., 2014a

Pistia stratiotes grows in aquatic habitats such as lakes, canals, reservoirs and slow moving rivers. The species often invades rice paddies in Asia as well as other wetland habitats. The species can survive drying, and can reinfest ephemeral waters which are subject to seasonal drying, beacause of seed survival and germination.

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

Possible pathways *(in order of importance)*	**Pathway:** Plants for planting
Short description explaining why it is considered as a pathway	*P. stratiotes* is imported into the EPPO region from outside and plants are widely sold within the EPPO region as an ornamental plant for ponds and aquaria. Plants are released intentionally or unintentionally (unintentional disposal of plant material where *P. stratiotes* is a contaminant) into the field. Brunel (2009) reports that more than 3600 individual plants were imported into the EPPO region (mainly into France), though the period of these imports is not specified.
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 . In Portugal the species is included in the list of Prohibited plants Decreto-Lei n.º 565/99 (http://www.silvaplus.com/fotos/editor2/LegislacaoPT/Floresta/dec_lei_565_99.pdf) . Otherwise, there are no restrictions for the trade of *P. stratiotes* within the EPPO region.
Has the pest already been intercepted on the pathway?	Yes because it is the commodity itself.
What is the most likely stage associated with the pathway?	Live plants both large and small, including seedlings (Appendix 3; Figure 7, will be associated with this pathway.
What are the important factors for association with the pathway?	*P. stratiotes* was found to be widely sold in shops in Germany (Hussner *et al.*, 2014b), and additionally it is frequently sold in online marketplaces such as ebay (www.ebay.com).
Is the pest likely to survive transport and storage in this pathway?	Yes. As an import for ornamental purposes, care would be taken to ensure plants survive during transportation.
Can the pest transfer from this pathway to a suitable habitat?	Only 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. Inappropriate disposal of aquarium contents have 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?	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 above.
Likelihood of entry	*Low* ☐ *Moderate* ☐ *High* X
Rating of uncertainty	*Low* X *Moderate* ☐ *High* ☐

Possible pathways (in order of importance)	***Pathway:* Contaminant of plants for planting**
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 *P. stratiotes* could contaminate shipments.
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.
What is the most likely stage associated with the pathway?	Juvenile plants, seeds and seedlings (Appendix 3; Figure 7).
What are the important factors for association with the pathway?	Potential to consolidate local or regional populations and establish new populations.
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?	Only 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. 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).
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 along this pathway would be low.
Likelihood of entry	*Low X* *Moderate ☐* *High ☐*
Rating of uncertainty	*Low X* *Moderate ☐* *High ☐*

Possible pathways (in order of importance)	***Pathway:* Leisure equipment**		
Short description explaining why it is considered as a pathway	Consideration can be given to river systems within the EPPO region which are connected to countries outside the EPPO region. It is possible that the use of recreational equipment (e.g. fishing or canoeing gear) could spread the species, particularly as seeds or seedlings, although this is not likely to be significant pathway at present given the rarity of the plant within the EPPO region.		
Is this pathway into the PRA area or within the PRA area or both?	Mainly within the EPPO region, but consideration can be given to river systems within the EPPO region which are connected to countries outside the EPPO region.		
Is the pathway prohibited in the PRA area?	No. However, there are 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?	Juvenile, seeds and seedlings (Appendix 3; Figure 7).		
What are the important factors for association with the pathway?	Potential to consolidate local or regional populations.		
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).		
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?	No. Within the EPPO region the current occurrence of *P. stratiotes* 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 ☐*

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

The plants withstand freezing air temperatures, as long as the water temperature does not drop below 10 °C, in a small flat winter form (Hussner *et al.*, 2014a). *P. stratiotes* is established in Morocco and Israel (Dufour-Dror, 2012) and southern France (Fried, pers.com.). *P. stratiotes* is able to become established in the climatic zones without frost events, for example Mediterranean and South-western European countries (e.g. Portugal, Spain, Italy, Greece) and in thermal waters in e.g. Slovenia, Germany or Hungary.

According to climate modelling (See appendix 1), *P. stratiotes* is capable of establishing in the Mediterranean biogeographical region. The species is capable of limited establishment in small areas of the Black Sea, Anatolian and Atlantic biogeographical regions (See see appendix 1, Figure 5).

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

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

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

Pistia stratiotes is traded and normally established in protected (managed) 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

Pistia stratiotes spreads mainly asexually by production of daughter plants, which detach from the mother plant (Neuenschwander *et al*., 2009). Heidbüchel *et al*. (2016) reported that up to 10 000 plants per day during the summer and autumn were introduced into the River Rhine from one of its tributaries, the thermally abnormal River Erft from an established *P. stratiotes* population. Even though the production of viable seeds has been observed in several sites, there is no report of seed germination in the field within the EPPO region (Sajna *et al*., 2007; Hussner *et al*., 2014a). However, long distance dispersal of seeds by waterfowl was found to be high likely for other aquatic plants (Green, 2016). Between connecting waterbodies dispersal is via whole plants, though seed dispersal may be possible.

Human assisted spread

Intended and / or unintended movement of plants by people is the most significant pathway of human mediated spread in the EPPO region. *P. stratiotes* is widely cultivated in many botanical gardens in Europe and is widely sold in aquarium and garden shops and is very popular because of its attractive growth form (Hussner *et al*., 2014b). For example:

http://www.aquabase.org/plant/view.php3?id=36&desc=pistia-stratiotes

https://www.amazon.co.uk/Lettuce-Pistia-Stratiotes-Aquarium-Floating/dp/B00CPUXE2O

http://www.lilieswatergardens.co.uk/pistia-stratiotes-british-grown-raised-loose-plants-p-1315.html

The spread of plants and seeds attached to water sports equipment seems possible, but evidence is lacking within the EPPO region. But this transport pathway was identified as a potential pathway for other aquatic plants (Barnes *et al*., 2013; Bruckerhoff *et al.*, 2015). The likelihood of a species to spread via boats and trailers largely depends on its resistance to desiccation (Barnes *et al.*, 2013).

In Belgium an awareness campaign was set up within the LIFE Alterias project where alternative plants are recommended instead of invasive plants to reduce human assisted spread. *P. stratiotes* was specifically envisaged in this campaign (see: http://www.alterias.be/en/list-of-invasive-and-alternative-plants/alternative-plants and Halford *et al*. 2014).

A moderate rating of magnitude of spread has been given as potentially spread through irrigation and river systems may act to facilitate spread nationally and regionally. However, this has not been seen as yet in the EPPO region and therefore a uncertainty rating of moderate is given.

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

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). This species can completely transform and alter trophic dynamics resulting in long-term changes.

Dense mats of *P. stratiotes* block sunlight, reducing primary production, decreasing water turbidity (Cai 2006 in Neuenschwander *et al*., 2009). Furthermore, the water shaded by *Pistia* shows decreased levels of oxygen and increased levels of nitrate, ammonium and phosphorus (Neuenschwander *et al*., 2009). As a result of the altered habitat, submerged vegetation decreased under dense mats along the river Erft in western Germany (Hussner 2014). Cilliers *et al*. (1996) reported that *P. stratiotes* threatens indigenous flora and fauna in South Africa, while increased mortality rates of fish and macroinvertebrates were reported from the USA (Dray & Center, 2002). In addition, the presence of *P. stratiotes* can increase the rates of siltation which can act to smother and degrade fish spawning sites (Dray and Center, 2002). Besides the blocking of sunlight, the *Pistia* mats limit the wind induced mixing of the water column, and thus the water beneath the *Pistia* mats can become thermally stratified (Sculthorpe, 1967; Attionu, 1976), with reduced dissolved oxygen levels and increased alkalinity (Yount, 1963; Attionu, 1976; Sridhar and Sharma, 1985). Finally, Sharma (1984) reported that the evapotranspiration rate over a *P. stratiotes* mat in one African lake was ten-fold greater than the evaporation rate over open water (but see the discussion on this topic and common misconceptions in Allen *et al*., 1997).

According to the available information, to-date there are no impacts recorded on red list species and species listed in the Birds and Habitats Directives.

Control methods
Pistia stratiotes can be controlled using chemical, physical/mechanical and biological means (reviewed in Global Invasive Species Database, 2005 and CABI, 2016).

Manual and physical control
As for all aquatic plants, removal by hand is recommended for early infestations and small areas in particular. Weed harvesters can be used for the biomass reduction of large infestations, but eradication is only achievable in combination with other control options (e.g. hand removal, chemical control). All hand or physical removal should be carried out before the plants starts to produce viable seeds to limit the risk of plant regrowth (Biosecurity Queensland, 2013).

The biological characteristic that allows for its persistence after mechanical control is that it can reproduce vegetatively from plant fragments that remain in situ after treatment. Seeds, if present and able to germinate, may persist in an area subject to control by either approach, requiring continued control over a number of years to increase the probability of achieving eradication (Millane and Caffrey, 2014).

Chemical control

This section details the chemical control options utilised throughout the introduced range. Any detail of a product does not imply the product is legal or safe to use in the EPPO region.

Chemical control of *P. stratiotes* is carried out using various herbicides with different levels of efficacy. Glyphosate, diquat, bispyribac-sodium, flumioxazin and imazamox caused up to >99% biomass reduction (Martins *et al*., 2002; Emerine *et al*., 2010; Glomski & Mudge, 2013; Mudge & Haller, 2012; Glomski & Netherland, 2013). Chemical control has also been used in combination with biological control (Cilliers *et al*., 1996). Repeated applications would be needed to effectively eradicate large populations but eradications of small populations would be feasible. Reinfestation is possible from untreated plants and regeneration from seeds.

Based on annual costs in Florida, associated with controlling *P. stratiotes* on at least 4 000 ha of public waterways, total expenditures exceed $2-million (Center 1994). Other States in the eastern USA spend a combined total less than $100 000 per year on *P. stratiotes* control (Center, 1994). In Florida, the combined total to [maintenance] control *P. stratiotes* and *Eichhornia crassipes* equates to $4 – 5 million a year, over the last 40 years.

Biological control

To date, 46 species of phytophagous insects have been recorded on *P. stratiotes* (South America: 25 species, Asia: 13 species, Africa: 8 species) (Cordo and Sosa, 2000). Most of these species are generalist that are not suitable for biological control, but 11 weevils species, belonging to the genera *Neohydronomus*, *Pistiacola*, and *Argentinorhynchus*, are assumed to be monophagous. Overall, only two species, a weevil, *Neohydronomus affinis* and a noctuid moth, *Spodoptera (Epipsammea) pectinicornis* (Hampson) have been given special attention as possible biological control agents. The moth was released in the USA, but failed to establish (Neuenschwader *et al* 2009). *N. affinis* has been released in 18 countries around the world where it has resulted in excellent control of *P. stratiotes* (Cilliers *et al* 2003), for example bringing *P. stratiotes* under complete control in Senegal in 18 months (Diop *et al* 2010). Recently the weevil has been released and established in Morocco with promising results (Hill 2013). The cost of developing and maintaining the biological control programme in South Africa (1985 to 2015) was approximately Euro 300 000 (Martin Hill pers comm, 2016.).

Rating of the magnitude of impact in the current area of distribution	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* X	*Moderate* ☐	*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	*P. stratiotes* can alter water quality, and limit water availability in arid zones. The species can dominate rice paddies.	Dray & Center, 2002
Regulating	Yes	*P. stratiotes* can increase the mortality of fish and macroinvertebrates. The species can displace submerged native plant species.	Dray & Center, 2002; Hussner 2014a
Supporting	Yes	*P. stratiotes* can alter the chemical composition of the water column which changes the habitat, and influencing the species within.	Dray & Center, 2002; Neuenschwander *et al*. 2009; Chamier *et al*., 2012
Cultural	Yes	*P. stratiotes* can restrict access for recreation and tourism. The species can degrade habitats making them less appealing to the general public and block waterways restricting the transportation of leisure boating. Dense mats restrict access to angling waters.	Chamier *et al*., 2012

Negative impacts on ecosystem services are hard to assess, given that many descriptions in the literature relate to potential impacts or impacts of sprawling emergent weeds with a similar native range such as *A. philoxeroides* and *Myriophyllum aquaticum* (e.g., Dugdale & Champion, 2012; Hussner & Champion, 2012). However, as an aquatic plant species that can form smothering mats impacts on ecosystem services can be potentially significant. The risk assessment for ecosystem services is therefore given a high rating of magnitude with a low level of uncertainty is given.

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

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

Economic impact

There are references onto the impact of the species in rice paddies where it is documented as a serious weed (Suasa-Ard, 1979 in Dray & Center, 2002), however, also it is documented as having a positive value on rice yields when used as a soil conditioner (Roger and Watanabe, 1984). Although no accurate measurement is available of the loss of water needed for agriculture through transpiration from beds of *P. stratiotes*, losses are believed to be considerable (Holm *et al*. 1977)". *P. stratiotes* can reduce water flow in drainage and irrigation systems and flood control canals (Dray & Center, 2002), and increase the water loss by evapotranspiration (Sharma 1984, but see Allen *et al*., 1997 in Neuenschwander *et al*., 2009 for contrasting results). *P. stratiotes* mats also block water flow and reduce hydropower production (Dray & Center, 2002).

Pistia stratiotes may have serious negative effects on the multifunctional human use of water bodies. These harmful effects include impediment of the transport of irrigation and drainage water, interference with hydro-electric schemes from artificial lakes, hindering navigation and fishing and the creation of habitats favourable for the transmittance of water-borne diseases (Mbati and Neuenschwander, 2005).

The dense mats of *P. stratiotes* can provide a suitable habitat for disease-carrying mosquitoes such as *Culex*, *Anopheles* and *Mansonia* species (Lounibos & Dewald, 1989). This has serious human health implications. Gangstad and Cardarelli (1990) notes that larvae of *Mansonia* mosquitos may directly obtain oxygen from the roots of *P. stratiotes*

The covering of water surfaces interacts with recreational water sports activities, like boating, fishing and swimming. 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 euros a year (low estimate) (Chas & Wittmann, 2015). The annual cost of just one such species, *Hydrocotyle ranunculoides* L., to the British economy alone was estimated at €33-million (Williams *et al*., 2010).

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

13. Potential impact in the PRA area

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

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. Ecological impacts occur within the PRA area on flora and fauna, specifically documented for the former in the River Erft in Germany, where floating mats shade out native submerged vegetation.

The potential economic impact of *P. stratiotes* in the EPPO region could be 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 indigenous 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.

Even though the EWG considers the magnitude of impacts to remain the same, uncertainty will increase for all categories (impact on biodiversity, impact on ecosystem services and socio-economic impact. This is mainly due to the fact that impacts have not been measured in the PRA area.

In the PRA area, *P. stratiotes* 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 and affects most threatened aquatic plant species (Bilz et al., 2011).

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

Impact on biodiversity

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

Impacts on ecosystem services

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

Socio-economic impacts

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

14. Identification of the endangered area

Pistia stratiotes is a frost sensitive free-floating species. The southern countries within the EPPO region provide suitable climatic conditions for *P. stratiotes*. All water bodies not enclosed in freezing during the winter months, including thermally abnormal waters in other EPPO countries, provide potential habitats for *P. stratiotes*

Pistia stratiotes is capable of establishing in the Mediterranean biogeographical region. The species is capable of limited establishment in small areas of the Black Sea, Anatolian and Atlantic biogeographical regions (see appendix 1, Figure 5 and Appendix 2, Figure 1).

Significant impact could is 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)**

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 **(no)**	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 pathways will not change.	Hussner *et al*., 2014b
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 in some countries will increase with increasing temperature where frost events currently hinder *P. stratiotes* establishment. With projected climate change it is predicted (using the scenario RCP 8.5: 2070) that the species will be capable of establishing throughout the Atlantic zone, Western Continental Europe, and is likely to increase its potential distribution in North Africa (see appendix 1, Figure 6). The overall rating given in section 9 and 10 will not change.	See appendix 1. Pieterse *et al*., 1981; Sajna *et al*., 2007 ; Hussner *et al*., 2014a
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 *P. stratiotes* to become established, will increase with increasing temperature. Increased flood events resultant of climate change could facilitate the spread of the species into new regions (see appendix 1, Figure 6). The risk of spread will remain as moderate but the level of uncertainty could be reduced from moderate to low.	Pieterse *et al*., 1981; Sajna *et al*., 2007 ; Hussner *et al*., 2014a
Will **impacts** change due to climate change? **(If yes, provide a new risk and uncertainty score)**	**Reference**
With increasing temperature, the impacts of *P. stratiotes* 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. The overall rating given in section 12 will not change.	Pieterse *et al*., 1981; Sajna *et al*., 2007 ; Hussner *et al*., 2014a

16. Overall assessment of risk

The overall likelihood of *P. stratiotes* entering into the EPPO region is high. The plant is imported into the EPPO region under its proper name and sold for aquarium and garden ponds. In addition, it is grown and traded within the EPPO region.

In view of risk of entry, risk of establishment and risk of spread, it is surprising, despite the long history of trade as an ornamental, and the climatic match with the Mediterranean, it is not yet widely established. However, where it has become established in Morocco it is a serious pest.

Pistia stratiotes has already been reported as a casual in Austria, Belgium, Czech Republic, France, Germany, Hungary, Norway, Italy, The Netherlands, Portugal, Romania, Russia, Slovenia, Spain and the United Kingdom. In addition, the species is established in Morocco and Israel. The species is established in Germany, Russia and Slovenia in thermally abnormal waters. At least one established population in southern France shows an invasive behaviour with a canal colonized with 100% cover on nearly 1 km.

Pathways for entry:

Plant for Planting

Likelihood of entry plants for planting	*Low* ☐	*Moderate* ☐	*High* **X**
Rating of uncertainty	*Low* **X**	*Moderate* ☐	*High* ☐

Contaminant of plants for planting

Likelihood of entry contaminant plants for planting	*Low* **X**	*Moderate* ☐	*High*
Rating of uncertainty	*Low* **X**	*Moderate* ☐	*High* ☐

Leisure equipment

Likelihood of entry 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* ☐

Spread in the PRA area

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

Impacts

Impacts on biodiversity

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

Impacts on 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* **X**	*Moderate* ☐	*High* ☐

Economic impacts

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

Impacts in the PRA area

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

Impact on biodiversity

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

Impacts on ecosystem services

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

Socio-economic impacts

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

Stage 3. Pest risk management

17. Phytosanitary measures

The results of this PRA show that *P. stratiotes* poses an unacceptable risk to the endangered area (Mediterranean biogeographical region) with a low uncertainty.

The major pathway being considered is:

Plants for planting

Given the significant impact of the species in other parts of the world and the identified risk to the PRA area, the expert working group recommends the following measures for the endangered area:

International measures:

For the pathway plant for planting:

- Prohibition of import into and within the countries, of plants labeled or otherwise identified as *P. stratiotes*,

- Recommend that *P. stratiotes* is banned from sale within the endangered area,

- *P. stratiotes* should be recommended as a quarantine pest within the endangered area.

National measures:

National prevention measures on the sale of *P. stratiotes* already exist in Spain and Portugal. The expert working group recommends similar measures are adopted by countries identified as at risk of invasion within this PRA.

Pistia stratiotes should be monitored and eradicated, contained or controlled where it occurs in the environment. The species should be discouraged from being used in phytoremediation. In addition, public awareness campaigns to prevent spread from existing populations or from botanic gardens in countries at high risk are necessary. If these measures are not implemented by all countries, they will not be effective since the species could spread from one country to another. National measures should be combined with international measures, and international coordination of management of the species between countries is recommended.

The expert working group recommends the prohibition of selling, planting, movement, and causing to grow in the environment, combined with management plans for early warning; obligation to report findings; eradication and containment plans; public awareness campaigns.

Containment and control of the species in the PRA area
Eradication measures should be promoted where feasible with a planned strategy to include surveillance, containment, treatment and follow-up measures to assess the success of such actions. As highlighted by EPPO (2014), regional cooperation is essential to promote phytosanitary measures and information exchange in identification and management methods. Eradication may only be feasible in the initial stages of infestation, and this should be a priority. The expert working group considers that this is possible at the current level of occurrence the species has in the EPPO region.

General considerations should be taken into account for all potential pathways, where, as detailed in EPPO (2014), these measures should involve awareness raising, monitoring, containment and eradication measures. NPPO's should facilitate collaboration with all sectors to enable early identification including education measures to promote citizen science and linking with universities, land managers and government departments. The funding of awareness campaigns, targeting specific sectors of society, i.e. anglers, and the water based leisure trade will facilitate targeting groups most prone to spread.

Import for (aquatic) plant trade: Prohibition of the import, selling, planting, and movement of the plant in the endangered area.

Unintended release into the environment: The species should be placed on NPPO's alert lists and a ban from sale would be recommended in countries most prone to invasion. Export of the plant should be prohibited within the EPPO region. Management measures would be recommended to include an integrated management plan to control existing populations including manual and mechanical techniques, targeted herbicides and proven biological control techniques. Monitoring and surveillance including early detection for countries most prone to risk. NPPO's should report any finding in the whole EPPO region in particular the Mediterranean area.

Intentional release into the environment: Prohibition on planting the species or allowing the plant to grow in the environment.

Natural spread (method of spread within the EPPO region): Increase surveillance in areas where there is a high risk the species may invade. NPPO's should provide land managers and stakeholders with identification guides and facilitate regional cooperation, including information on site specific studies of the plant, control techniques and management.

See Standard PM3/67 'Guidelines for the management of invasive alien plants or potentially invasive alien plants which are intended for import or have been intentionally imported' (EPPO, 2006).

See Standard PM9/19 (1) 'Invasive alien aquatic plants' (EPPO, 2014).

See Standard PP 3/74(1) 'EPPO guidelines on the development of a code of conduct on horticulture and invasive alien plants' (EPPO, 2009).

17.01 Management measures for eradication, containment and control

Biological control using *Neohydronomus affinis* is considered as the most effective control method (Hill 2003). But this biological control agent requires a certain temperature regime, and thus the use of *N. affinis* seems not to be an option within most parts of the EPPO region. Chemical control of aquatic plants, which is common in the USA or New Zealand is prohibited in most EPPO countries. Consequently, harvesting by boats (large populations) and hand removal (small and early infestations) are considered as the most effective control methods. The spread of this floating species can be controlled by barriers and nets, which must be used to prevent the spread of *Pistia* within connected water systems.

Manual and physical control

As for all aquatic plants, removal by hand is recommended for early infestations and small areas only. Weed harvesters can be used for the biomass reduction of large infestations, but eradication is only achievable in combination with other control options (e.g. hand removal, chemical control). All hand or physical removal should be carried out before the plants starts to produce viable seeds to limit the risk of plant regrowth (Biosecurity Queensland, 2013).

The biological characteristic that allows for its persistence after mechanical control is that it can reproduce vegetatively from small daughter plants that remain in situ after treatment. Seeds, if present and able to germinate, may persist in an area subject to control by either approach, requiring continued control over a number of years to increase the probability of achieving eradication (Millane and Caffrey, 2014).

Chemical control

This section details the chemical control options utilised throughout the introduced range. Any detail of a product does not imply the product is legal or safe to use in the EPPO region.

Chemical control of *P. stratiotes* is carried out using various herbicides with different levels of efficacy. Glyphosate, diquat, bispyribac-sodium, flumioxazin and imazamox caused up to >99% biomass reduction (Martins *et al*., 2002; Emerine *et al*., 2010; Glomski & Mudge, 2013; Mudge & Haller, 2012; Glomski & Netherland, 2013). Chemical control has also been used in combination with biological control (Cilliers *et al*., 1996). Repeated applications would be needed to effectively eradicate populations though this is often unfeasible. Reinfestation is possible from untreated plants and regeneration from seeds.

Based on annual costs in Florida, associated with controlling *P. stratiotes* on at least 4 000 ha of public waterways, total expenditures exceed $2-million (Center 1994). Other States in the eastern USA spend a combined total less than $100 000 per year on *P. stratiotes* control (Center, 1994). In Florida, the combined total to [maintenance] control *P. stratiotes* and *Eichhornia crassipes* equates to $4 – 5 million a year, over the last 40 years.

Biological control

To date, 46 species of phytophagous insects have been recorded on *P. stratiotes* (South America: 25 species, Asia: 13 species, Africa: 8 species) (Cordo and Sosa, 2000). Most of these species are generalist that are not suitable for biological control, but 11 weevils species, belonging to the genera *Neohydronomus*, *Pistiacola*, and *Argentinorhynchus*, are assumed to be monophagous. Overall, only two species, a weevil, *Neohydronomus affinis* and a noctuid moth, *Spodoptera (Epipsammea) pectinicornis* (Hampson) have been given special attention as possible biological control agents. The moth was released in the USA, but failed to establish (Neuenschwader *et al* 2009). *N. affinis* has been released in 18 countries around the world where it has resulted in excellent control of *P. stratiotes* (Cilliers *et al* 2003), for example bringing *P. stratiotes* under complete control in Senegal in 18 months (Diop *et al* 2010). Recently the weevil has been released and has established in Morocco with promising results (Hill 2013). The cost of developing and maintaining the biological control programme in South Africa (1985 to 2015) was approximately Euro 300 000 (M.Hill pers comm.).

18. Uncertainty

Overall uncertainty for the PRA: Low

Currently the species is not invasive in natural habitats in the PRA area, apart from Morocco. However, in view of the overwhelming evidence from elsewhere in the world it is likely to exhibit a similar behaviour in the endangered area.

Uncertainty should also be considered in the context of species distribution modelling (SDM). Here records for *P. stratiotes* 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 *P. stratiotes* 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.

Level of uncertainty per sections:

Pathway for entry: Low

Likelihood of establishment:

Establishment in natural areas: Moderate

Establishment in managed areas: Low

Spread: Moderate

Impacts: Low

Potential impacts in PRA area: Low

19. Remarks

Other recommendations:

Inform EPPO or IPPC or EU

- Inform NPPO's, that surveys are needed to confirm the distribution of the plant, in particular in the area where the plant is present 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

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Appendix 1. Projection of climatic suitability for *P. stratiotes* establishment

Aim

To project the suitability for potential establishment of *Pistia stratiotes* 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 *P. stratiotes*.
- Mean minimum temperature of the coldest month (Bio6 °C) reflecting exposure to frost. *Pistia stratiotes* 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.

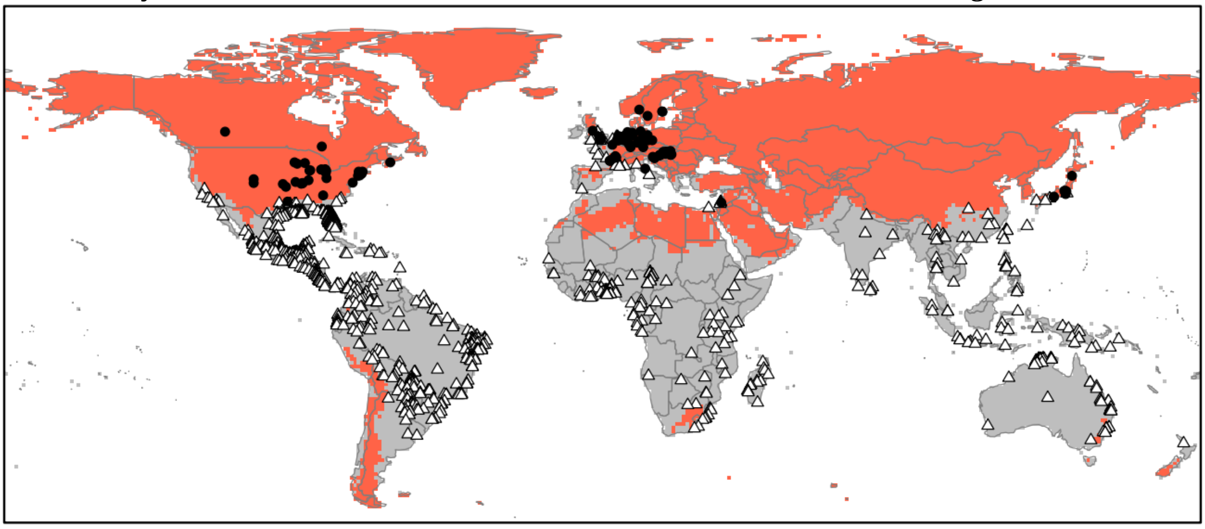
Species occurrences were obtained from the Global Biodiversity Information Facility (www.gbif.org), supplemented with data from the literature and the Expert Working Group. Occurrence records with insufficient spatial precision, potential errors or that were outside of the coverage of the predictor layers (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 1087 grid cells with recorded occurrence of *P. stratiotes* available for the modelling and a further 99 records from regions considered unsuitable and excluded (Figure 1).

Figure 1. Map with points showing the occurrence records obtained for *Pistia stratiotes*. The background shading indicates regions considered highly unsuited to *P. stratiotes*. 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.



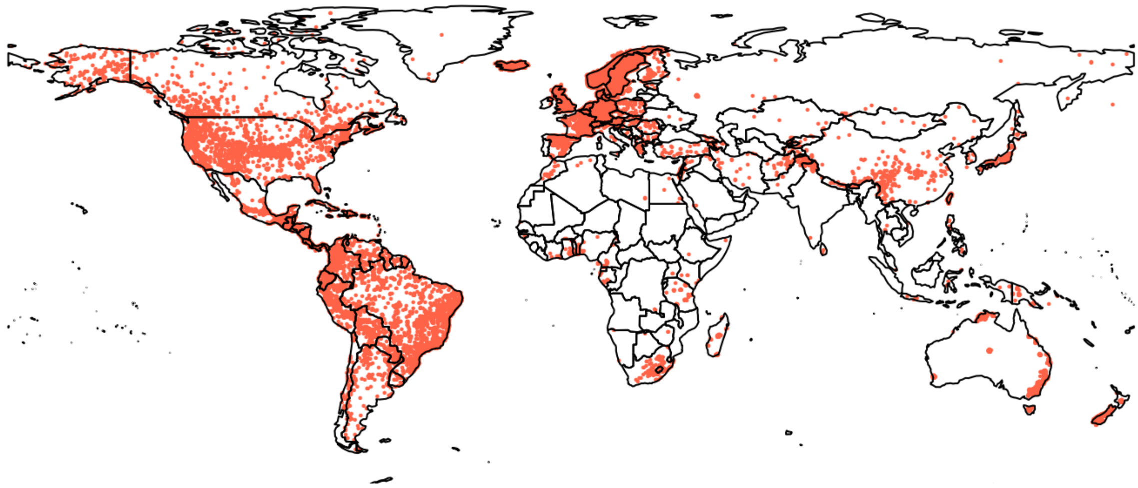
Species distribution model
A presence-background (presence-only) ensemble modelling strategy was employed using the BIOMOD2 R package v3.3-7 (https://cran.r-project.org/web/packages/biomod2/index.html). These models contrast the environment at the species' occurrence locations against a random sample 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 *P. stratiotes*, for which the species is likely to have had sufficient time to cross all biogeographical barriers. Although there is some debate about the precise native range, the consensus view of the Expert Working Group was that South America should be used as the native continent; 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 *Pistia stratiotes*.



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.

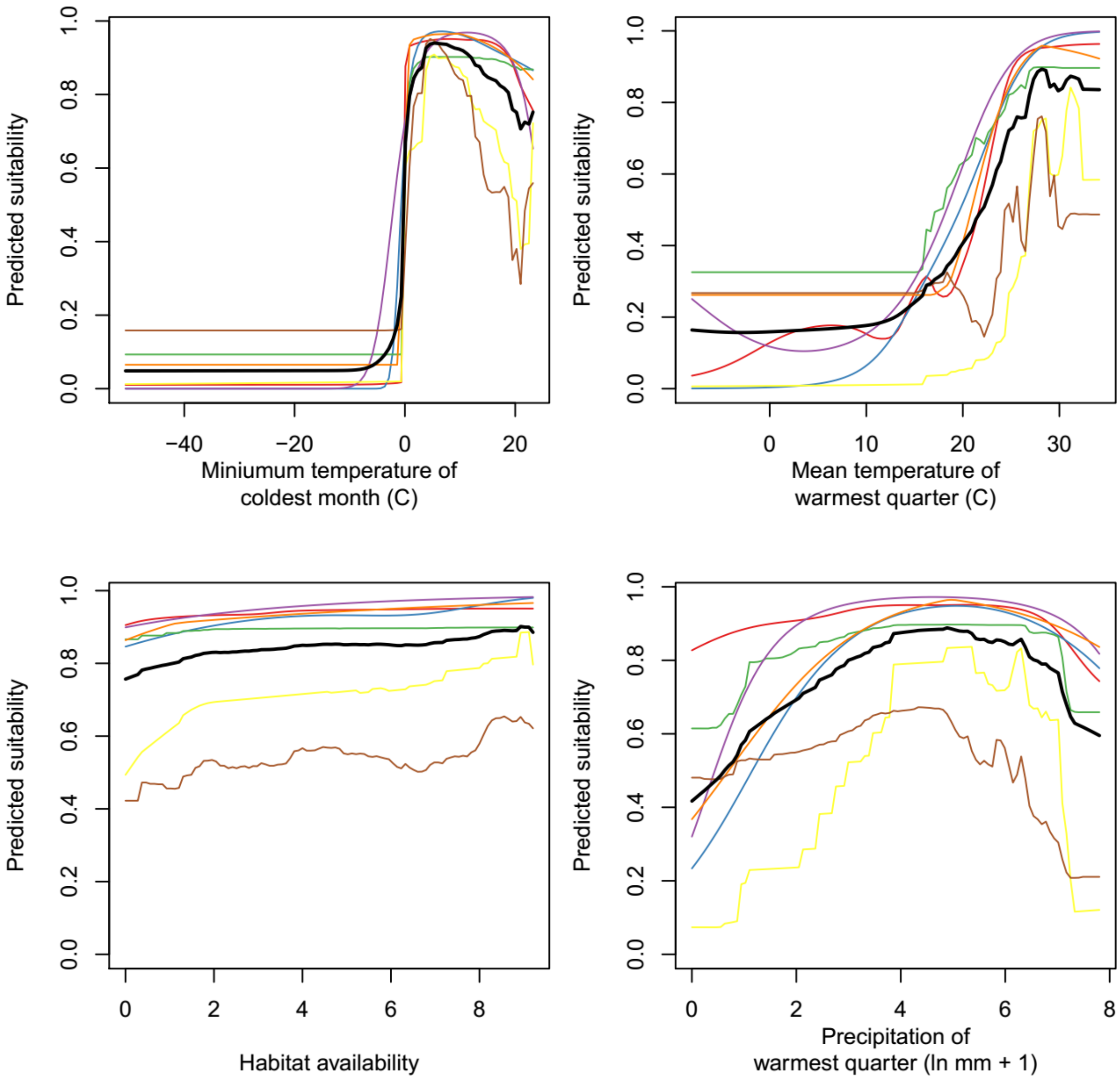
Results

The ensemble model had a better predictive ability than any individual algorithm and suggested that suitability for *P. stratiotes* 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).

Table 1. Summary of the cross-validation predictive performance (AUC) and variable importance 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	0.9548	43.8%	51.5%	2.0%	2.7%
GBM	0.9598	68.6%	28.1%	1.1%	2.2%
GAM	0.9574	58.0%	38.2%	2.0%	1.7%
CTA	0.9262	66.6%	29.6%	1.3%	2.5%
ANN	0.9574	56.3%	37.1%	2.5%	4.1%
FDA	0.9508	8.8%	88.6%	1.8%	0.9%
MARS	0.9588	60.3%	36.1%	1.9%	1.7%
RF	0.9542	46.8%	37.0%	8.5%	7.7%
MaxEnt	0.9566	42.0%	50.1%	4.2%	3.7%
MEMLR	0.9076	81.8%	0.1%	12.3%	5.8%
Ensemble	0.9618	53.7%	39.7%	3.2%	3.4%

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 tropical and subtropical parts of the world (Fig. 4). This was consistent with the observed occurrences of the species in its native and non-native ranges.

In Europe and the Mediterranean, areas projected as currently moderately suitable for establishment included southern Spain and Portugal and the coastal fringes of Morocco, Algeria and Tunisia (Fig. 5). There were also pockets of projected suitability around the coastlines of the Mediterranean and southern Caspian Sea. Occurrences of the species in western Europe that were not excluded from the modelling were projected as being in moderately unsuitable conditions. The status of these populations is unclear but it is likely that they are casual rather than fully established.

By the 2070s, under climate change scenario RCP8.5, the projected suitability for *P. stratiotes* in Europe and the Mediterranean increased substantially. The model suggested that in this climate, much of Mediterranean, western and Pannonian Europe could become suitable for invasion, and suitability also increases around the coasts of the Black Sea and Caspian Sea. Therefore, the model suggests climate change could facilitate a major expansion of the species in Europe.

Figure 4. Global projected suitability for *Pistia stratiotes* 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.

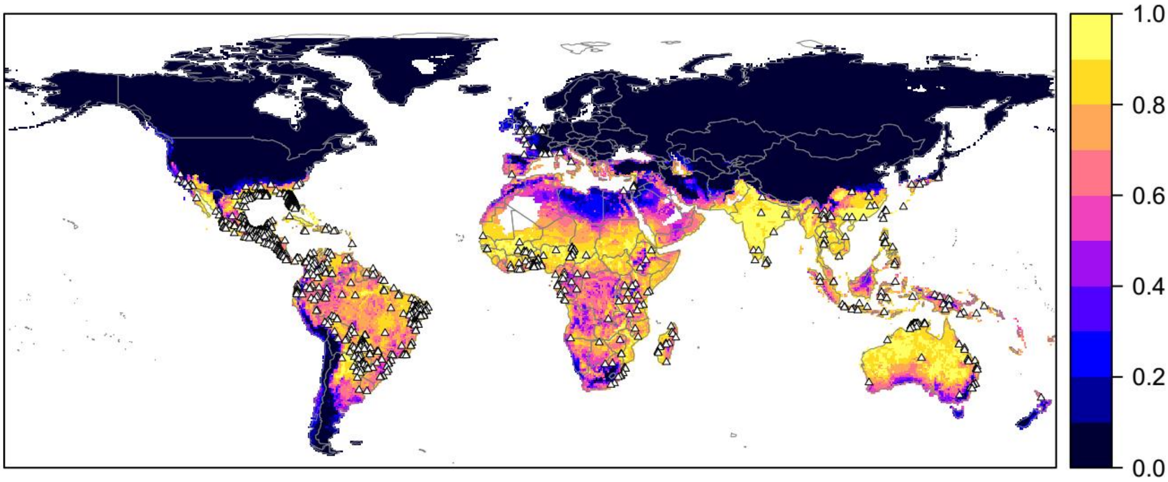


Figure 5. Projected current suitability for *Pistia stratiotes* establishment in Europe and the Mediterranean region. To aid visualisation, the projected suitability has been smoothed with a Gaussian filter with standard deviation of 0.1 degrees longitude/latitude. The white areas have climatic conditions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

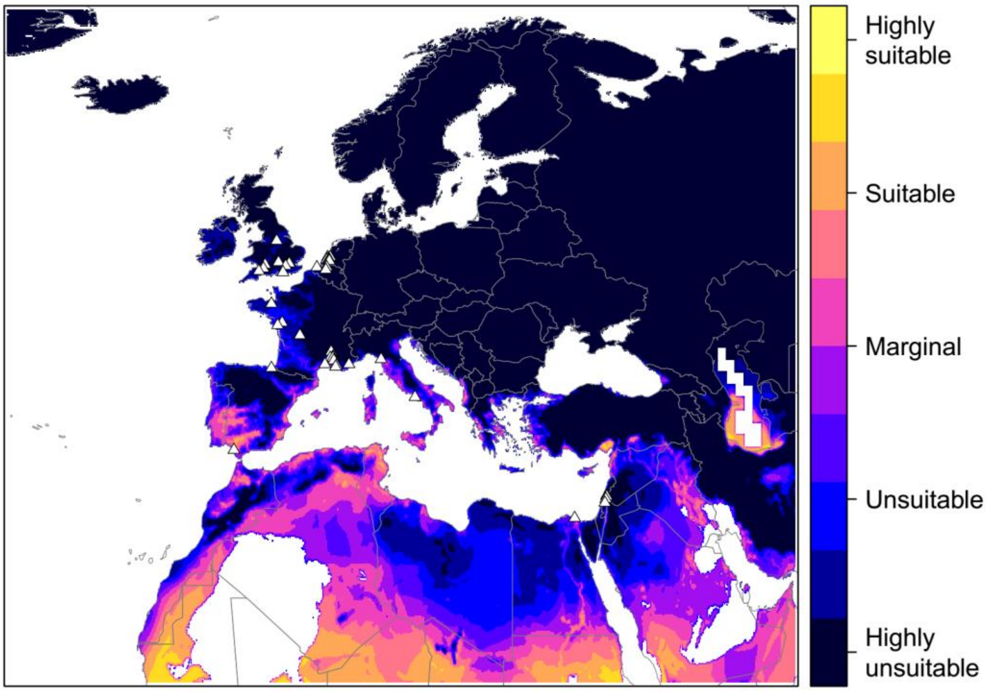
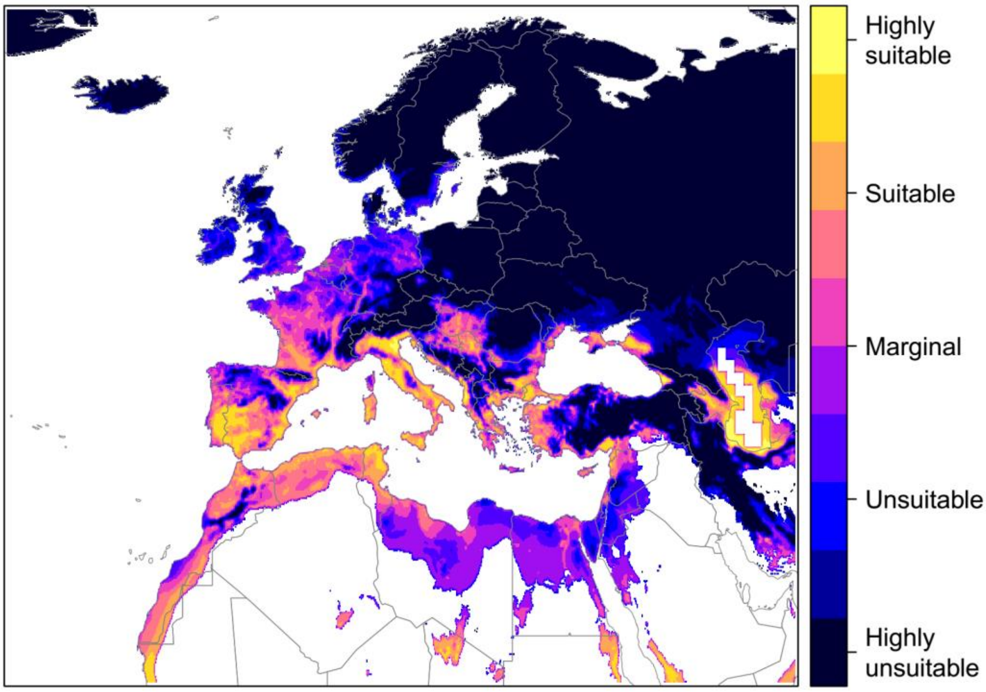


Figure 6. Projected suitability for *Pistia stratiotes* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP8.5, equivalent to Fig. 5.



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:

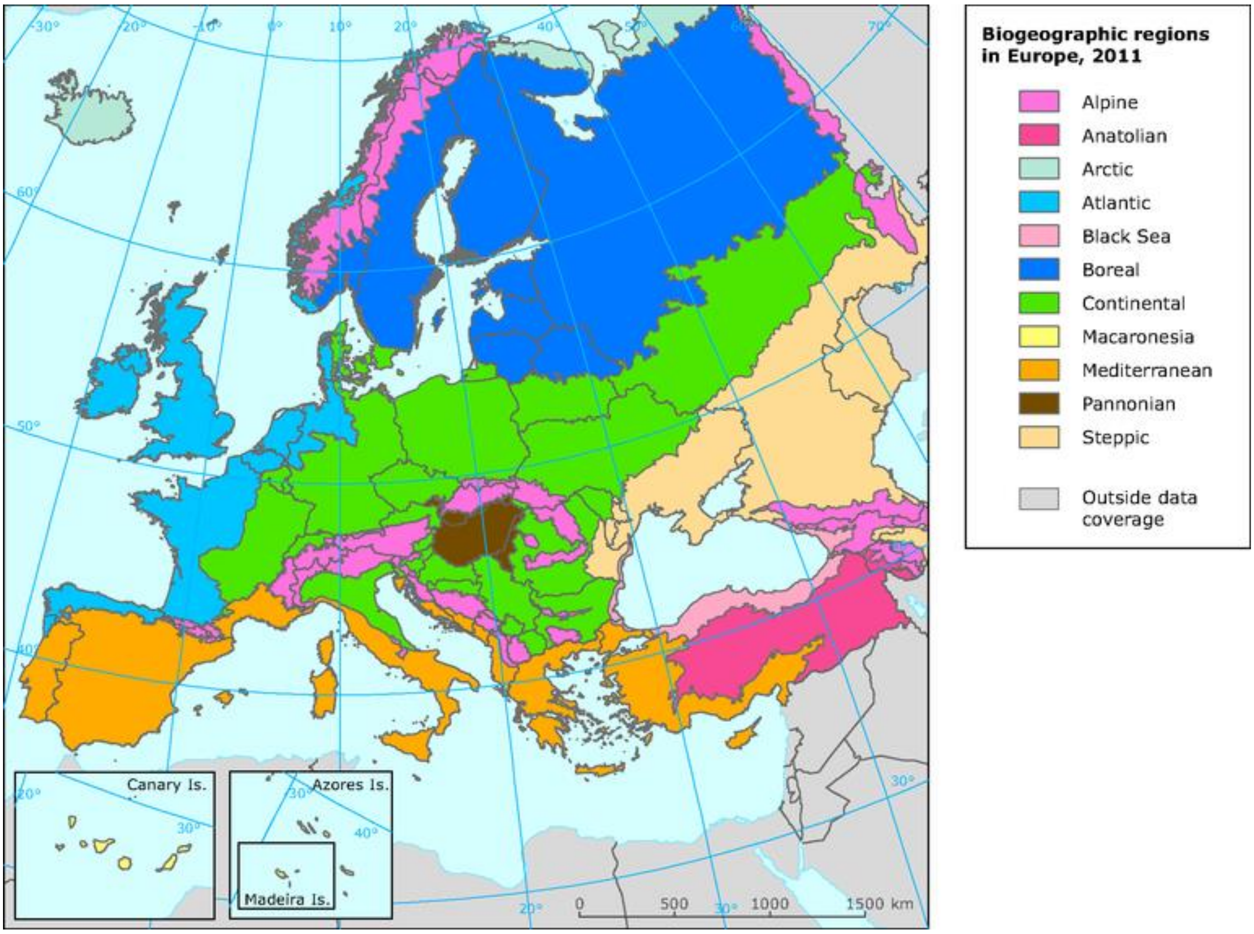
- The GBIF API query used to did not appear to give completely accurate results. For example, in a small number of cases, GBIF indicated no Tracheophyte records in grid cells in which it also yielded records of the focal species.
- We located additional data sources to GBIF, which may have been from 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 caused 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 Biogeographical regions in Europe



Appendix 3. Relevant illustrative pictures (for information)

Figure 1. *P. stratiotes* showing damage from frost

Figure 2. *P. stratiotes* surviving cold conditions in Europe.

Figure 3. *P. stratiotes*. (Drawn by G. Condy, first published in Henderson *et al*. (1987).

Figure 4. *P. stratiotes* seeds

Figure 5. Monoculture of *P. stratiotes* in Germany

Figure 6. Dense floating mat of *P. stratiotes* in Germany

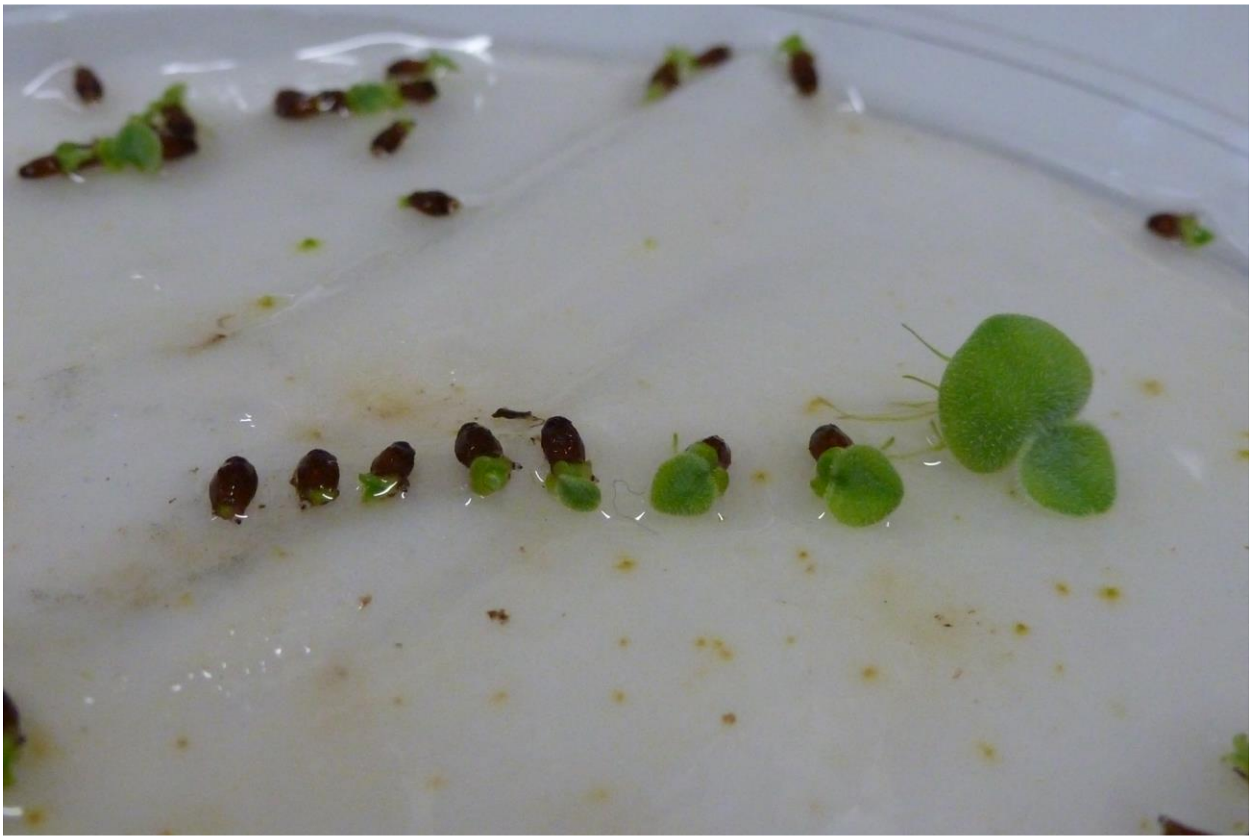


Figure 7. *P. stratiotes* seedlings

Appendix 4. Distribution maps of *P. stratiotes*

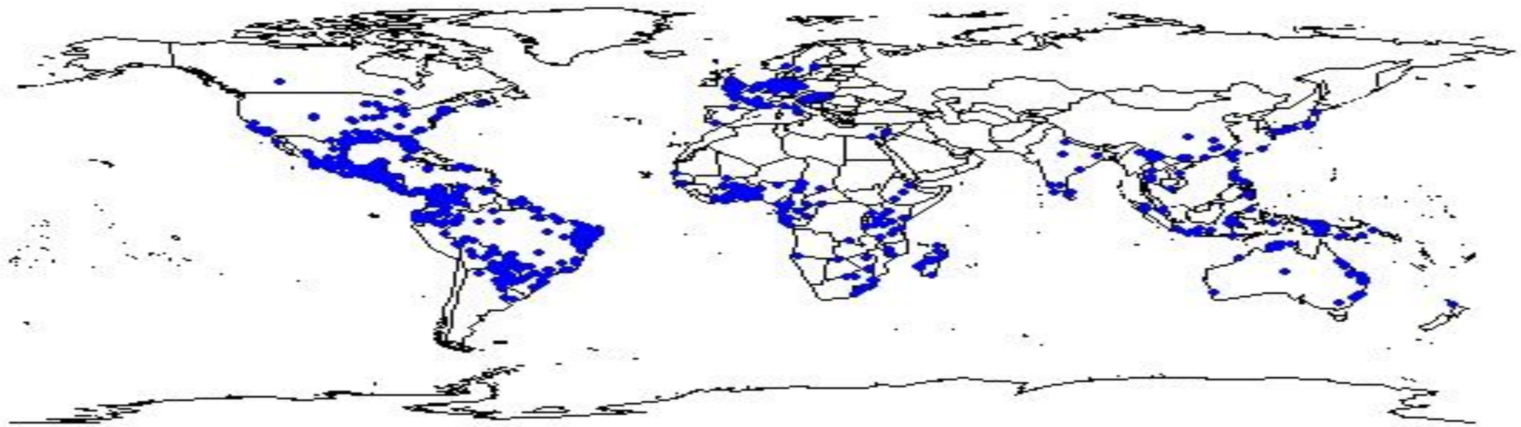


Figure 1 Global distribution of *P. stratiotes*

Figure 2 Distribution of *P. stratiotes* in Africa

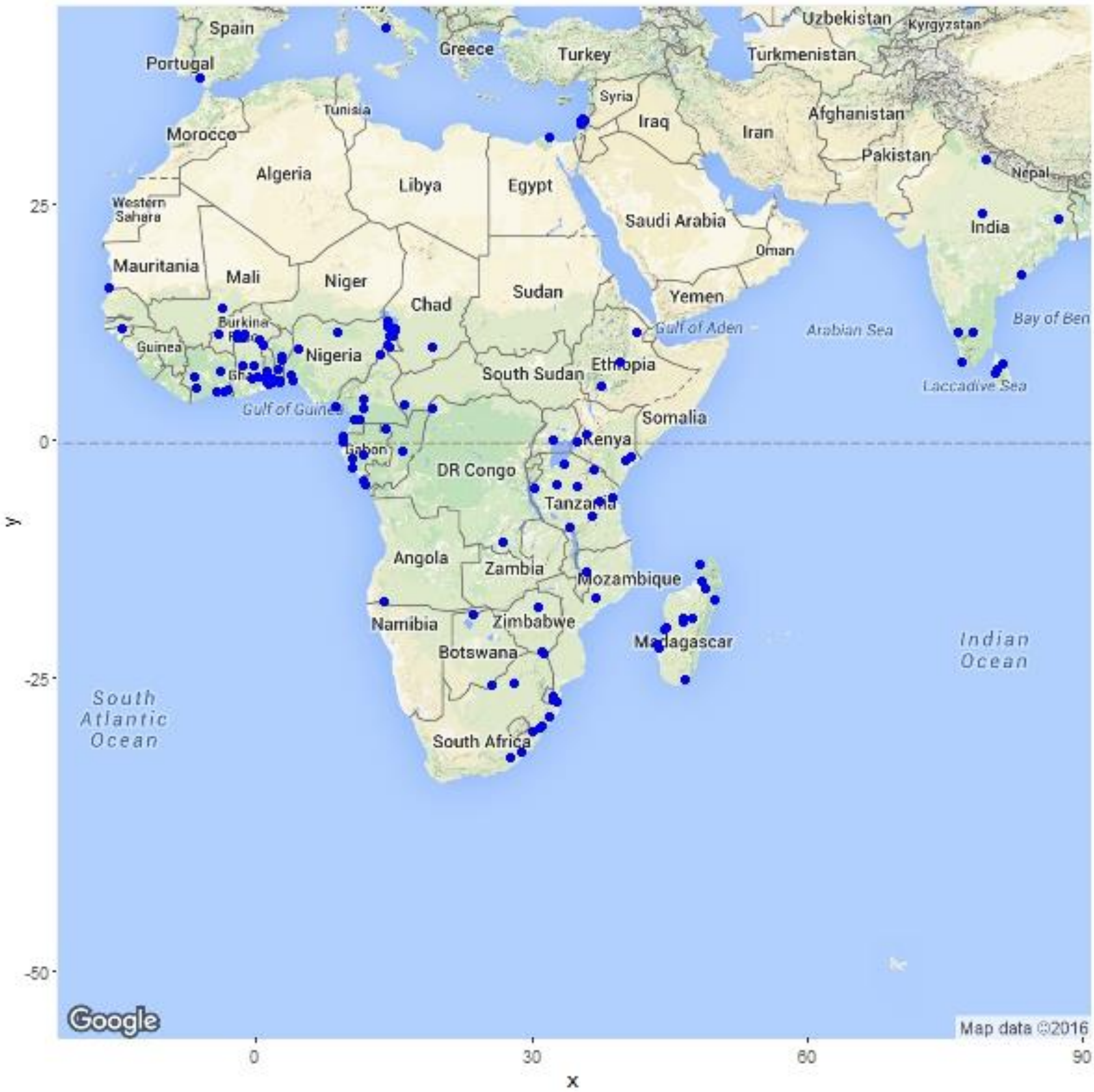


Figure 3 Distribution of *P. stratiotes* in Asia

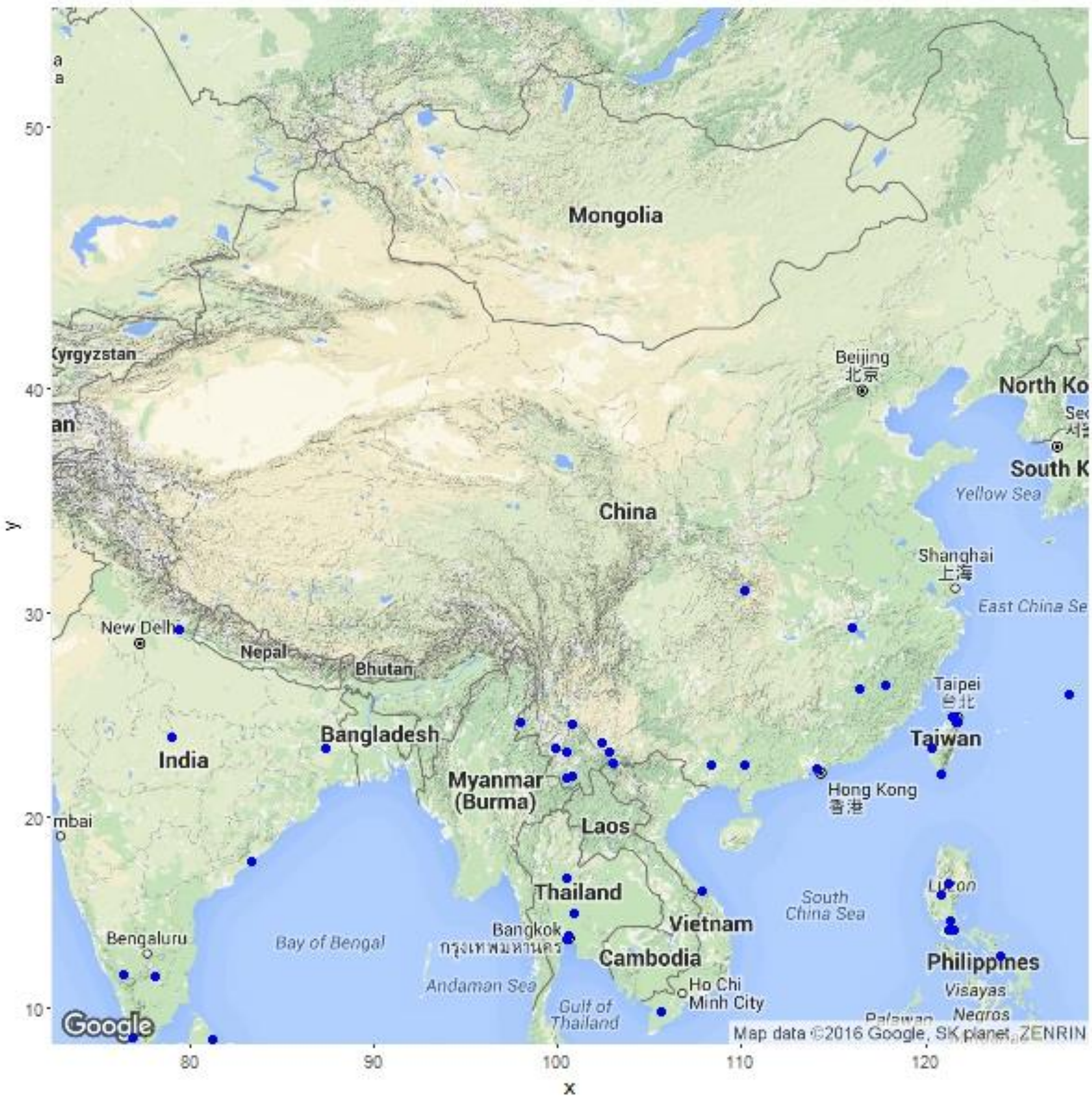


Figure 4 Distribution of *P. stratiotes* in North America

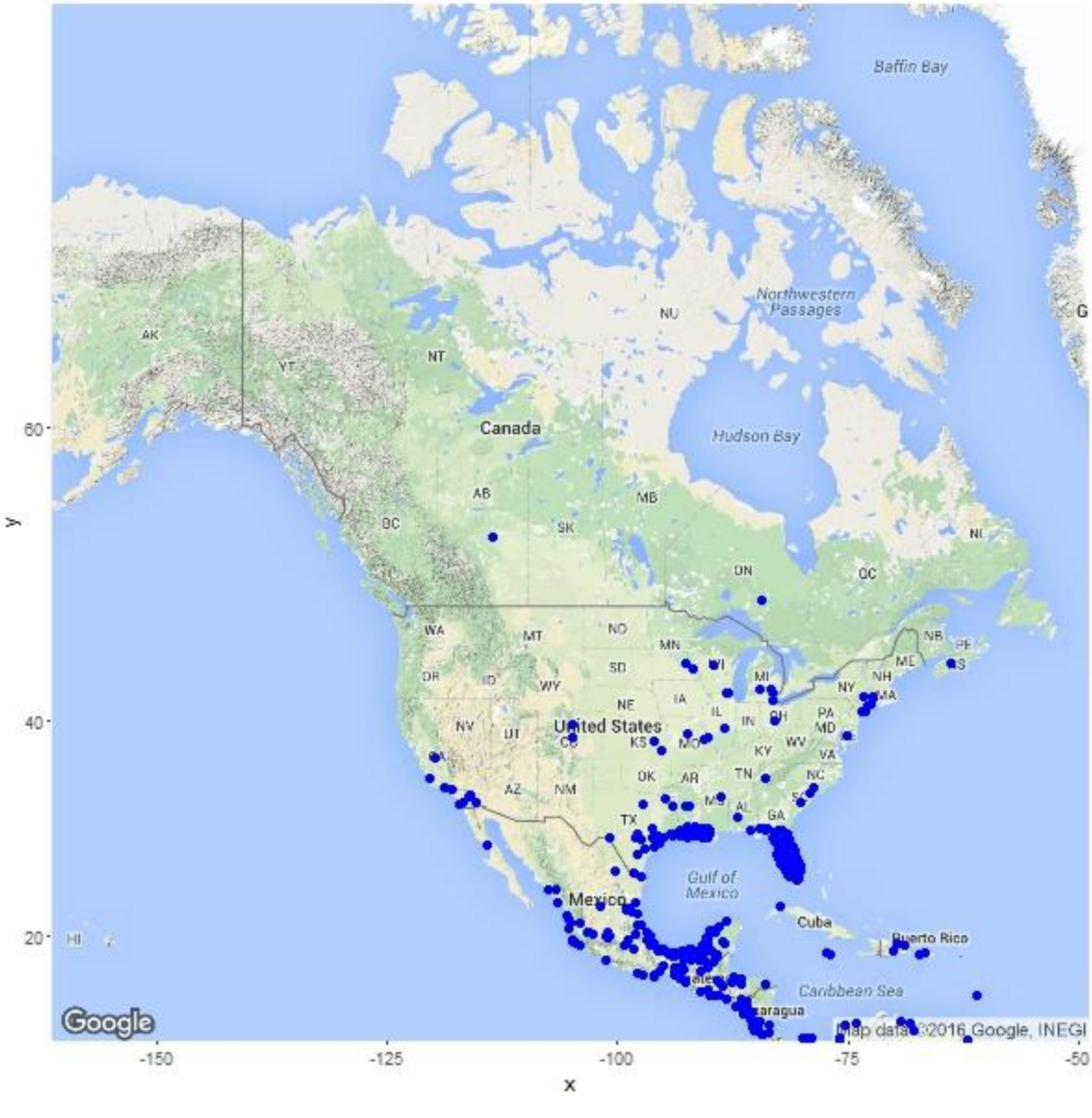


Figure 5 Distribution of *P. stratiotes* in South America

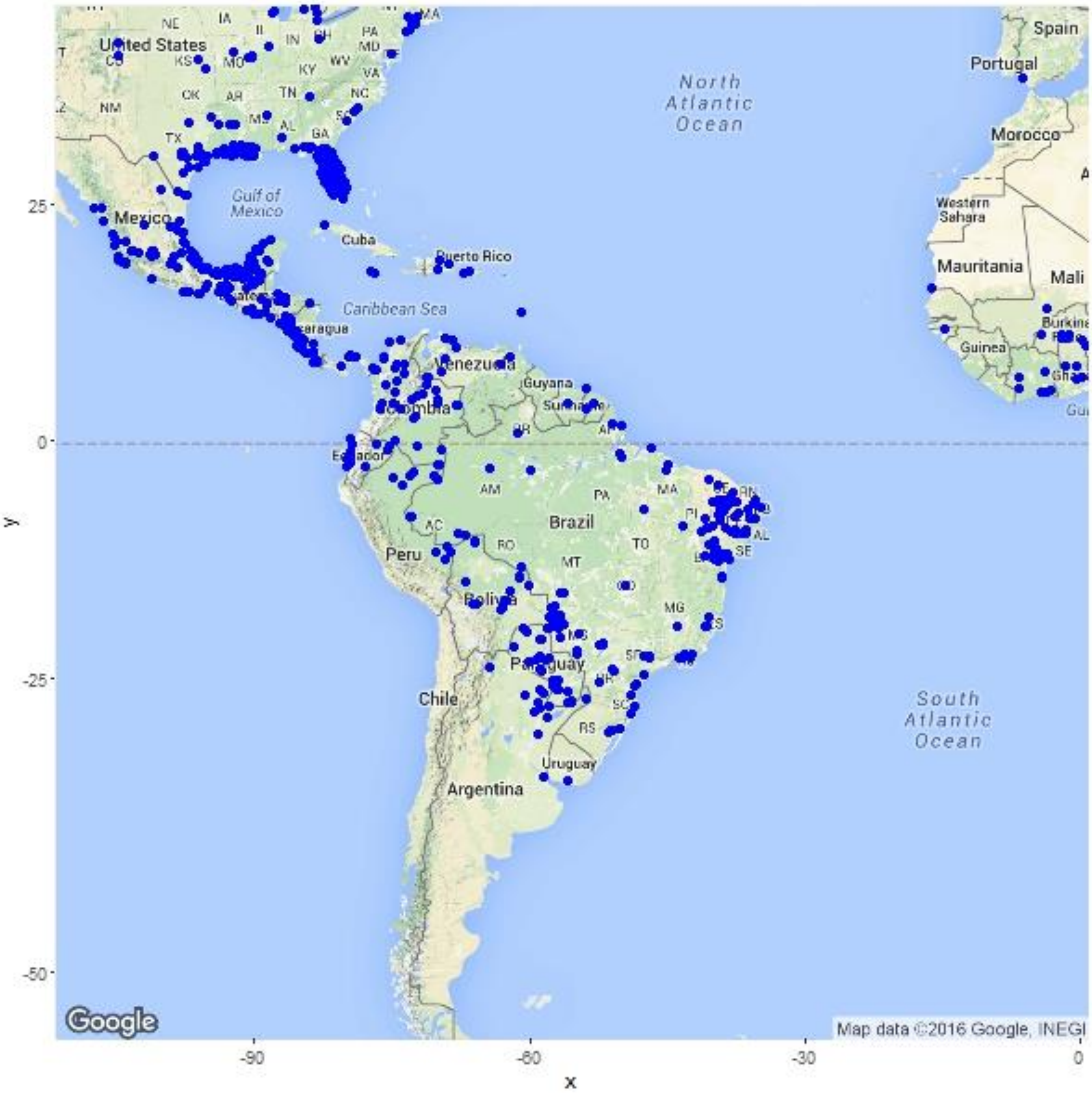


Figure 6 Distribution of *P. stratiotes* in Oceania

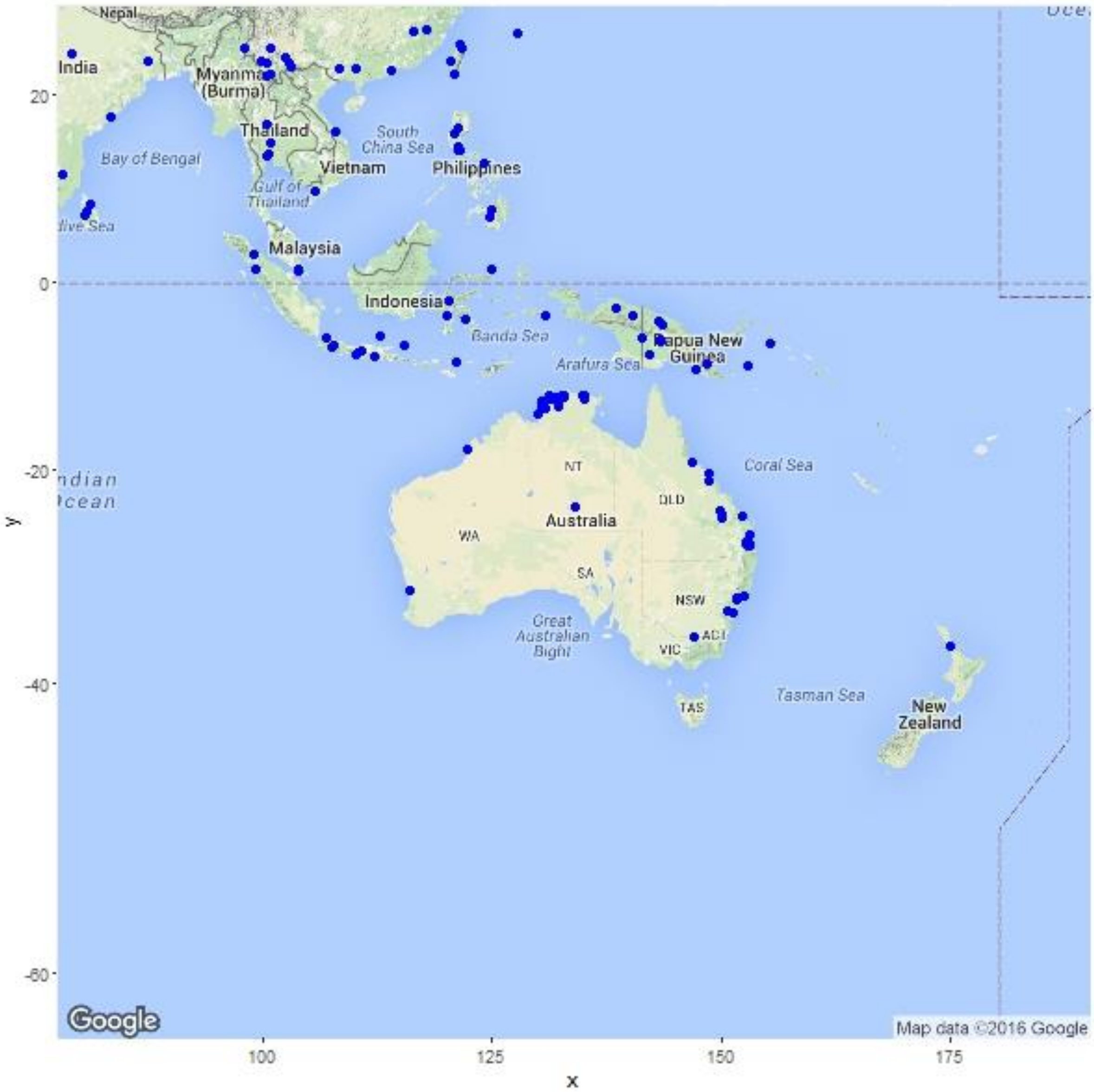


Figure 7 Distribution of *P. stratiotes* in Europe