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Pest Risk Analysis for

Myriophyllum heterophyllum

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This risk assessment follows the EPPO Standard PM PM 5/5(1) *Decision-Support Scheme for an Express Pest Risk Analysis* (available at http://archives.eppo.int/EPPOStandards/pra.htm) and uses the terminology defined in ISPM 5 *Glossary of Phytosanitary Terms* (available at https://www.ippc.int/index.php).
This document was first elaborated by an Expert Working Group and then reviewed by the Panel on Invasive Alien Plants and if relevant other EPPO bodies.

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Photo: *Myriophyllum heterophyllum*.Courtesy: Andreas Hussner, Institut für Botanik (DE)

Pest Risk Analysis for *Myriophyllum heterophyllum* Michaux

This PRA follows EPPO Standard PM 5/5 *Decision-Support Scheme for an Express Pest Risk Analysis*.

PRA area: EPPO region
Prepared by: EWG on *Alternanthera philoxeroides* and *Myriophyllum heterophyllum*
Date: 2015-04-20/24

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The PRA was reviewed by the Panel on Invasive Alien Plants on 2015-05-05/07.

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Describe the endangered area:
Habitats within the endangered area include; riparian systems, slow moving rivers, canals, irrigation canals, lakes, reservoirs and semi-aquatic systems, including wetlands. Establishment is likely in the temperate climate regions within the EPPO region. Climate is not such a strictly limiting factor for submerged aquatic plants as it is for terrestrial plant species. The Expert Working Group considers that Tundra and Taiga biomes in Scandinavia and Asia are unlikely to be invaded.

Main conclusions
Myriophyllum heterophyllum presents an overall high phytosanitary risk for the EPPO region with a low uncertainty rating. The overall likelihood of *M. heterophyllum* continuing to enter the EPPO region is high. The plant is imported into the EPPO region as a misidentified aquatic species for aquaria and ponds and is already established in Austria, Belgium, France, Germany, Hungary, the Netherlands, Spain and Switzerland. The risk of entry into other EPPO countries through import is considered high. The risk of the species establishing in additional countries is high as movement through irrigation and river systems acts to connect countries, facilitating spread regionally. Spread may be accelerated by recreational activities in water bodies invaded by the weed. Impacts of the species within the EPPO region are likely to be severe (high score rating), including aquatic plant species displacement, habitat dominance and effects on other aquatic organisms.

Entry and establishment
Entry into the EPPO region is through the aquatic plant trade pathway, often misidentified as other *Myriophyllum* species. It's already established in 8 countries within the EPPO region and conditions for further establishment exist in temperate climatic EPPO regions.

Impacts on biodiversity and the environment
Dense mono-specific growth of any aquatic plant species can incur impacts on native plant communities and other aquatic organisms such as invertebrates and fish. *M. heterophyllum* has both environmental and economic impacts in the EPPO region. The species has impacts on ecosystem services, as seen in other regions where it is present.
Dense mats of *M. heterophyllum* reduce light to other submerged plants and can affect water quality by reducing oxygen levels resulting in fish avoiding the infested area. Many rivers and lakes with the PRA area are either protected areas or contain protected species that may be adversely affected by dense mats of *M. heterophyllum*. The presence of *M. heterophyllum* in rivers and lakes in the EPPO region can act to degrade such habitats reducing the ecological status of water bodies.

Economic impacts within the EPPO region
M. heterophyllum blocks canals and water control systems and management options need to be applied to remove the species from these areas. The species could have impacts if invading agricultural irrigation systems. Potential impacts may be incurred to recreation if the species invades water bodies used for boating, swimming, fishing and diving. Consequential costs, through loss of earnings by companies that organise recreational activities, plus reduced earnings for the wider region, may be incurred.

Phytosanitary measures:

The result of this PRA shows that *M. heterophyllum* poses an unacceptable risk in the EPPO region. It is recommended that *M. heterophyllum* is included in the list of quarantine pests.

Identified pathways are: **Plants for planting**

International measures:
(1) Prohibition of import into and within the EPPO region. Because many species are imported under incorrect names it is necessary to screen imported aquatic plants for the presence of *M. heterophyllum*.
M. heterophyllum should be recommended as a quarantine pest within the EPPO region.
Techniques for confirmation of exact species identification, including molecular methods are available (Ghahramanzadeh *et al*., 2013).
(2) In addition to the existing requirement for a phytosanitary certificate (PC) by the exporting country, confirmation of the correct identification and labelling of the species should be required (see EPPO Standard PM 1/1(2) Use of phytosanitary certificates).

National measures:
Prohibition of selling, planting, holding, moving, and causing to grow in the wild of the plant in the EPPO region is necessary. Moreover, the plant has to be surveyed and eradicated, or contained, or controlled if this is not possible where it occurs. In addition, public awareness campaigns to prevent spread from existing populations 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 have to be combined with international measures, and international coordination of management of the species between countries is necessary.

Containment and control of the species in unintended habitats
General considerations should be taken into account for the pathway under consideration, 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 water based recreational activities will facilitate targeting groups most prone to spreading *M. heterophyllum.*
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. This may be possible with the current level of occurrence the species has in the EPPO region. Coordination of all stakeholders is required and should be easy to achieve, especially since the distribution is limited.

Import for (aquatic) plant trade: Prohibition of the import, selling, planting, holding and movement of the plant within the EPPO region.

Transportation through recreational activities (method of spread within the EPPO region): Raise awareness on the species, including publicity regarding its identification and its impacts to the sector in question.

Natural spread (method of spread within the EPPO region): Increase surveillance in protected areas where there is a high risk the species may invade. NPPO's to 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.

Phytosanitary risk for the *endangered area*	High ☒	Moderate ☐	Low ☐
Level of uncertainty of assessment Pathways for entry – Low Likelihood of establishment outdoors in the PRA area – Low Likelihood of establishment in protected conditions in the PRA area – Low Spread in the PRA area – Low Impact in the current area of distribution – Moderate Potential impact in the PRA area – Low	High ☐	Moderate ☐	Low ☒

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 DG Environment on the eligibility of the species for inclusion on the list of IAS of EU concern.
- ***Inform industry, other stakeholders***
  Inform on the need for correct identification and labelling of the species and on the risk the species present

Express Pest Risk Analysis: *Myriophyllum heterophyllum*

Stage 1. Initiation

Reason for performing the PRA:
Myriophyllum heterophyllum Michaux currently has a limited distribution in Europe. The species is present in the wild in the EPPO region. Further spread is predicted as the species is traded and used in aquaria within the EPPO region. In Europe *M. heterophyllum* is established in Austria, Belgium, France, Germany, Hungary, the Netherlands, Spain and Switzerland. *M. heterophyllum* has shown a fast rate of spread in western parts of Europe (Hussner, 2012). There appears to be no climatic restriction for the spread of this species throughout temperate Europe. We expect high levels of shading and low dissolved oxygen below the very dense mono-specific canopy, which will impact submerged macrophyte communities and associated invertebrate and fish communities.

Two PRA currently exist for this species:
A PRA (07-13662) was specifically carried out for Germany (Ahlburg *et al.*, 2009) and a rapid risk assessment was carried out on behalf of the Animal and Plant Health Authority (APHA) specifically for the UK (Newman, 2014). This PRA has been conducted as both of the above have a limited (geographical) focus and were not conducted following the most recent EPPO DSS.

PRA area: The EPPO region

Stage 2. Pest risk assessment

1. Taxonomy:

Myriophyllum heterophyllum Michaux **(**Kingdom Plantae; Phylum Spermatophyta; Subphylum Angiospermae; Class Dicotyledoneae; Order Haloragidales; Family Haloragaceae; Genus *Myriophyllum*)

EPPO Code: MYPHE

Syn: None

Common names: Variable-leaf water milfoil, Two-leaf water milfoil, and sometimes broadleaf water milfoil.

German name: Verschiedenblättriges Tausendblatt, **French name:** Myriophylle hétérophylle, **Dutch name:** Ongelijkbladig vederkruid

Plant type: Aquatic evergreen perennial (submerged species)

Related species in the EPPO region:

Native species: *Myriophyllum alterniflorum* DC., *Myriophyllum spicatum* L., *Myriophyllum verticillatum* L. (Royal Botanic Garden Edinburgh, 2001).

Non-native species: *Myriophyllum aquaticum* (Vell.) Verdc.

Van Valkenburg and Boer (2014) list *M. hippuroides, M. propinquum* and *M. scabratum* as mis-applied names for *M. heterophyllum* in trade in the Netherlands.

2. Pest overview

Introduction

Myriophyllum heterophyllum is an aquatic plant native to the eastern United States where it often forms dense stands (Brown *et al.*, 2014). In the USA the plant is regarded as an invasive alien species in New Hampshire and Maine (Thum & Lennon, 2006). *M. heterophyllum* is present as an alien species in eight European countries and in southern China. The species is sold as an ornamental aquatic plant in some regions of the PRA area, however, the species is often mislabelled as other species (see above section). *M. heterophyllum* was included in the EPPO alert list in 2009 and subsequently transferred to the List of Invasive Alien Plants in 2012 (EPPO 2012). Within the EPPO region the species has shown it has the capacity to become established in water-bodies from different climatic regions. The species shows strong resistance to different management practices within the PRA area.

Environmental requirements

Myriophyllum heterophyllum can grow in a wide range of physical and chemical conditions (Brown *et al*., 2014). It can tolerate high summer temperatures as well as cold winter temperatures where it can be covered by ice during the winter months (Brunel *et al.*, 2010). There are few data on the exact temperature requirements for this species within the EPPO region. The optimum temperature for *M. heterophyllum* is about 20 ^{o}C and plants grow best under high carbon dioxide availabilities even though the species can use bicarbonate as an additional carbon source for photosynthesis (Hussner & Jahns, 2015). The light saturation point for *M. heterophyllum* is between 200 and 300µmol m^{-2} s^{-1} (Hussner, 2008), which is quite low but in the normal range for submerged aquatic plants, indicating shade tolerance.

M. heterophyllum grows in slow moving rivers, irrigation channels, ponds, lakes, canals and damp ditches (Peters, 2004; Hussner *et al*., 2005; De Beer & De Vlaeminck, 2008; Valkenburg, 2011; Brown *et al*., 2014). A semi-terrestrial form can be found between the interface of the aquatic and terrestrial environment on mudflats and boggy land (CABI, 2015), but this is a survival strategy rather than a preferred growth form when water levels drop. *M. heterophyllum* is able to grow in water up to 9.5 m in depth (Hussner *et al*., 2005; personal communication Hussner, 2015).

Identification

Myriophyllum heterophyllum is a perennial evergreen submerged aquatic herb, having both submerged and emergent leaf forms. Submerged leaves are feather-like and pinnate (2-5 cm long and 2-4 cm wide) (Fig. 1, Appendix 1). Each leaf has 4-10 pinnae. Emergent leaves can take two forms, either a terrestrial form (pinnately dissected) which is expressed when growing on damp mud (Fig. 2, Appendix 1), or an emergent leaf form (entire toothed) on a stem on which flowers are produced. Emergent leaves are variable both in shape and structure – 0.4-3 cm in length and 1.5-3 mm wide - and stiff in texture (Fig. 3, Appendix 1). Flowering is rarely observed throughout its native and invasive range (Global Invasive Species Database, 2011) but when it does, female flowers are small, and red in colour (Fig. 3, Appendix 1) and appear from the nodes along the stems of specialised emergent leaves from May to October (Brown *et al*., 2014). Flowers are only produced on the emergent part of the stem which can often be exposed 10-15 cm above the water's surface. Like other submerged aquatic plants, *M. heterophyllum* readily produces fragments that are capable of dispersal and regeneration (Fig. 4, Appendix 1) (Hussner & Krause, 2007). Molecular DNA barcoding has been developed for *M. heterophyllum* (Ghahramanzadeh *et al*., 2013) to confirm the presence of the species in trade and from unidentified wild populations. The spread of *M. heterophyllum* occurs predominately via clonal reproduction and fragmentation.

Symptoms

Myriophyllum heterophyllum forms dense mats at the surface of the water body (Fig. 5 and 6, Appendix 1) reducing light penetration and dissolved oxygen below which can reduce suitable habitats for native plants (Bailey, 2007). The clogging of water bodies is likely to obstruct access for water based recreational activities. The plant has been shown to reduce property values when it invades lake shores close to properties in the USA. Flood risk is increased as the species can increase sedimentation and reduce flow in water-bodies. Thus the species can impact on a number of ecosystem services including supporting, regulating, provisioning and cultural services

3. Is the pest a vector? No

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

No vector is needed for *M. heterophyllum* spread or entry into the PRA area.

5. Regulatory status of the pest

Europe: *M. heterophyllum* was added to the EPPO alert list in 2009 and moved to the EPPO List of Invasive Alien Plants in 2012 (EPPO, 2014).

In a Code of Conduct from the Netherlands all major growers and retail chains have agreed not to sell it after 2013 (Verbrugge *et al*., 2014).

In Belgium, different initiatives regarding regulation are in preparation or under application. At the federal level there is a Royal Decree in preparation to prohibit the import, export and transit of *M. heterophyllum.* In Wallonia, the Circulaire Wallonne (Version 2013) prohibits the use of *M. heterophyllum*. In a Code of Conduct there is a so called 'consensus species list' that horticulture professionals agreed on to withdraw from sales or plantations (Halford *et al*., 2011). *M. heterophyllum* appears on that list. *M. heterophyllum* is assigned to the black list and classified as an A1 species (isolated populations but with a high environmental risk).

In Germany, *M. heterophyllum* is included on the Black List/Action List of the invasive alien plants in Germany (Seitz *et al*., 2013). According to paragraph 40 (BNatSchG, 2010), these species that are on the action list should be targeted by the local authorities. A PRA record was produced specifically for Germany (Ahlburg *et al*., 2009).

In the UK, *M. heterophyllum* would probably be subject to Schedule 23 of the Infrastructure Act 2015 (http://www.legislation.gov.uk/ukpga/2015/7/contents), which imposes species control and orders on invasive non-native species. A Rapid Risk Assessment was has been produced for the GB Non-Native Species Secretariat (Newman, 2014).

North America: *M. heterophyllum* has legal status in 7 States (USDA, 2015). Threatened and Endangered: In Kentucky it is regarded with special concern whereas in Ohio and Pennsylvania the species is endangered. Noxious Weed (to the north east of the range): In Connecticut the species is regarded as invasive and is banned. In Maine the species is regarded as an invasive species. In Massachusetts the species is prohibited and in Vermont the species is classed as a Class A noxious weed (USDA, 2015).

6. Distribution

Continent	*Distribution*	*Comments*	*Reference*
Asia	China (Guangdong Province)	Present, introduced	Yu *et al*., 2003
North America	**Present in:** Canada (British Columbia, New Brunswick, Ontario, Quebec), Mexico, USA (Alabama, Arkansas, Connecticut, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Maryland, Michigan, Minnesota, Mississippi, Missouri, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Virginia, Washington, West Virginia, Wisconsin).	Native, Shows invasive tendencies in the north east of its range.	(USDA, 2015)
Central and South America	Guatemala	Present	(EPPO, 2014)
Europe	Austria, Belgium, France, Germany, Hungary, Netherlands, Spain, Switzerland	Introduced, established and locally invasive and still spreading.	(Aquatische Neobiota in Österreich 2013; Casper & Krausch, 1981; Cirujano *et al.*, 1997; De Beer & De Vlaeminck, 2008; Hussner, 2008; Lafontaine *et al*., 2013; Lebreton, 2013; Lukács *et al.*, 2014 Pietsch & Jentsch, 1984; www.infoflora.ch)

Introduction:
M. heterophyllum is found in the USA, China, Central America and Europe (Fig. 7, Appendix 2). It should be noted that there is no consensus on the native distribution of *M. heterophyllum* in eastern North America. Thum *et al.* (2011) have identified three distinct lineages within populations in the USA; one lineage of a hybrid population *M. heterophyllum* x *Myriophyllum laxum* Schuttlew ex Chapm. and two distinct pure lineages.

North America:
It is generally regarded that in North America, *M. heterophyllum* is native to the eastern United States with a distribution throughout the southern region, and in the north, westwards to North Dakota (ENSR International, 2005) (Fig. 8, Appendix 2). The species is considered invasive in much of the northeast (New England region)) (www.invasive.org).

Europe:
In Europe *M. heterophyllum* is established in Austria, Belgium, France, Germany, Hungary, the Netherlands, Spain and Switzerland (Fig. 9, Appendix 2). In the UK, *M. heterophyllum* has not been recorded since 1969 (BSBI, 2012), although efforts are being made to confirm the absence in 2015. In Belgium, the species was first observed in 1993 (Bouxin & Lambinon, 1996). The species appears to be established in several localities but does not seem to spread in an invasive way. Its current distribution is the Kempen region of Belgium (ias.biodiversity.be, 2015). In France *M. heterophyllum* was found in 2011 in a large covered private pond in Saint-Sylvestre in the Haute-Vienne French department (Lebreton, 2013). The species is also known from Landes, Rhone and Pyrénées-Atlantiques departments in France (Lebreton, 2013). *M. heterophyllum* was found in East Germany in 1960s (Stricker, 1962). In West Germany (Nordrhein-Westfalen) *M. heterophyllum* arrived in 1979 (Spangehl & Scharrenberg, 1985). In Germany there has been little spread but the current populations are stable and dominant within the submerged vegetation.

The first record of *M. heterophyllum* in the Netherlands was in 1999 (van Valkenburg, 2011). In 2007, in a canal in Orvelte, *M. heterophyllum* was observed dominating the canal. In 2008, the plant was found in Loosdrecht and Maasbracht (inland harbour). In 2010, *M. heterophyllum* was recorded in Leeuwarden again in urban canals. At present the species can be found throughout the south east and central parts of the Netherlands (http://www.verspreidingsatlas.nl/5500).

7. Habitats and their distribution in the PRA area

Habitats	**Presence in PRA area (Yes/No)**	**EUNIS http://eunis.eea.europa.eu/**	**Comments**	***Reference***
Freshwater bodies such as canals, rivers (slow moving), ponds, irrigation channels, estuaries, reservoirs and lakes	Yes	C1 : Surface standing waters C2 : Surface running waters	Major habitat(s) within the PRA area and the habitat(s) at the highest risk of invasion	Peters, 2004; Hussner *et al.*, 2005; De Beer & De Vlaeminck, 2008; Valkenburg, 2011; Brown *et al*., 2014
Wetlands	Yes	C3 : Littoral zone of inland surface waterbodies	Major habitats within the PRA area.	(EPPO, 2012)

8. Pathways for entry

Possible pathways	**Short description explaining why it is considered as a pathway**	Existing legislation?	Pest already intercepted on the pathway? Yes*
Plants for planting (either as an intentional import as an ornamental species or a case of misidentification).	*Myriophyllum heterophyllum* is used in aquaria and as an ornamental plant in outdoor ponds. The plant is sold throughout the PRA area as an ornamental aquatic species but never under its proper name. Often traded as *M. scabratum*, *M. propinquum* and *M. hippuroides*	Yes	Under mis-applied names EPPO region, Yes (van Valkenburg 2015; Brunel 2010; Hussner *et al.*, 2014)

Van Valkenburg (2011) reports that there are no records of *M. heterophyllum* in the aquatic plant trade in the Netherlands under its proper name. Van Valkenburg and Boer (2015) lists *M. hippuroides, M. propinquum* and *M. scabratum* as mis-applied or mistakenly used names for *M. heterophyllum* in trade in the Netherlands.

Plants labelled as *M. heterophyllum* can be purchased from a number of internet-suppliers (worldwide). For example:

www.aquabase.org.
http://www.aquariumplants.com/Myrio_Red_Myriophyllum_heterophyllum_p/bp025.htm
http://shop.plantedaquariumscentral.com/Foxtail-RED-Myriophyllum-heterophyllum-fish-fry-saver_p_52.html
http://www.liveaquaria.com/product/prod_display.cfm?c=768+2546&pcatid=2546

Rating of the likelihood of entry	*Low* ☐	*Moderate* ☐	*High*
Rating of uncertainty	*Low*	*Moderate* ☐	*High* ☐

9. Likelihood of establishment outdoors in the PRA area

Climatic suitability risk mapping decision support scheme.

Based on the area of potential establishment already identified, how similar are the climatic conditions that would affect pest establishment to those in the current area of distribution?

Answer: **largely similar**, Level of uncertainty: **Low**

Stage 1: Is it appropriate to map climatic suitability?

1.1 Based on the response to the above, is there low uncertainty that the climate in the area suitable for establishment is completely or largely similar to the climate where the pest is currently present?

Yes – The present occurrence of *M. heterophyllum* within the PRA area confirm that the climate is largely similar to that of the current area of distribution.

1.3 Does the species spend a large part of its life cycle experiencing climatic conditions significantly different to those measured at weather stations?

Yes- The species is a submerged aquatic plant.

It is not appropriate to use climatic mapping for this species in the EPPO region.
M. heterophyllum is able to thrive in a wide variety of environmental conditions (Peters, 2004; Hussner *et al*., 2005; De Beer & De Vlaeminck, 2008; Valkenburg, 2011; Brown *et al*., 2014). Habitats suitable for the establishment of *M. heterophyllum* are found throughout the EPPO region. Climate is not such a strictly limiting factor for aquatic plants as it is for terrestrial plant species. The Expert Working Group considers that tundra and Taiga biomes in Scandinavia and Asia are unlikely to be invaded.

Habitats within the endangered area include; riparian systems, slow moving rivers, canals, irrigation canals, lakes, reservoirs and semi aquatic systems including wetlands.

As previously detailed, *M. heterophyllum* is established in a number of European countries: Austria, Belgium, France, Germany, Hungary, the Netherlands, Spain and Switzerland. These countries exhibit a wide range of climatic conditions which are obviously suitable for establishment.

The species occurs in clearly defined climatic zones in its native range, Cfa, Cfb, Dfa, Dfb, (based on the Geiger climate zones (Kottek *et al*., 2006) (Fig. 10, Appendix 3). These zones are present in the EPPO region.

Rating of the likelihood of establishment outdoors	*Low* ☐	*Moderate* ☐	*High*
Rating of uncertainty	*Low*	*Moderate* ☐	*High* ☐

10. Likelihood of establishment in protected conditions in the PRA area

A species in trade is normally established in protected conditions, for example under glass. The rating of the likelihood of establishment in protected areas along with the rating of uncertainty were not scored.

11. Spread in the PRA area

Natural spread: There is no seed production in the PRA area, thus there is no likelihood of dispersal by seed. Small stem fragments (less than 1 cm) that contain at least one node have a high capacity to regenerate new plants and thus could initiate new infestations. Regeneration is even possible from single leaves though this is generally unlikely. Compared with most other submersed macrophytes, stems of *M. heterophyllum* are more robust and tend to remain intact all year resulting in a low incidence of autofragment production. However, physical disturbance caused by human, fish and water bird activity can lead to production of allofragments. The allofragments usually regenerate through the production of new roots and the regeneration rate has been shown to be higher when fragments come in contact with the sediment (Hussner, 2008; Kuntz *et al.*, 2014). Activity of water birds is usually sufficiently vigorous to generate large fragments that often include roots. Natural spread is also influenced by the extent and type of connectivity of suitable habitats. For example, in the Netherlands where habitat connectivity is high, spread to new locations has been much more rapid compared to much slower spread between isolated sites in Germany.

Human assisted spread:
Spread via human activity is one of the main causes of dispersal for *M. heterophyllum* within and between lakes in the USA (Green Mountain Conservation Group, 2015). The potential for long-distance spread of *M. heterophyllum* is high because the species is very tolerant of desiccation (Barnes *et al.* 2013), meaning that hitch-hiker fragments are likely to remain viable for prolonged periods of time, allowing for introduction of viable fragments to new locations. Thus, motorized and non-motorized vessels, fishing equipment, and other water related paraphenalia or machines can all harbour and transport fragments of the plants as people move around (Eiswerth *et al*., 2000). Eurasian watermilfoil (*M. spicatum*), which is completely intolerant to desiccation (Barnes *et al.* 2013), has been shown to spread rapidly via boat movements (Eiswerth *et al*., 2000). These pathways for the spread of invasive species have prompted the "Check, Clean and Dry" Campaign in the UK (GB Non-native species secretariat, 2015) and other regional information portals (EUBARnet, 2013). Similar "Clean, Drain and Dry" campaigns have been employed in the U.S. and British Colombia to retard transport of aquatic invasive species (http://bcinvasives.ca/; Stop Aquatic Hitch hikers http://www.protectyourwaters.net/).

The use of *M. heterophyllum* (although not traded under the correct name) has been very popular with landscape designers, aqua-scape designers and gardeners because of its large size and emergent foliage. Dumping of aquaria by pouring the content into public waters is another possibility of stochastic spread.

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

12. Impact in the current area of distribution

Impacts on biodiversity and the environment
Throughout the introduced range, the impacts of *M. heterophyllum* are largely unknown due to the lack of research. In New Hampshire (USA) *M. heterophyllum* displaced native vegetation (Sheldon, 1994; Thum & Lennon 2009). In the invaded habitat in Europe, *M. heterophyllum* is most often the dominant species implying that there will be effects on native plants and communities. Evergreen submerged macrophyte species outcompete native seasonal species (Greulich & Bornette, 2003; Hussner, 2014) and thus similar effects are likely for *M. heterophyllum.*

Dense mats of *M. heterophyllum* reduce light to other submerged plants, killing them off, and can affect water quality by reducing oxygen levels resulting in fish avoiding the infested area, or even fish kills. Maximum dry weight recorded for this species is 4 kg m^{-2} in established infestations (pers. comm. Hussner, 2015). Additionally, pH within *M. heterophyllum* stands can vary between 7 and 10.5 on a daily basis, increasing stress for fish populations and excluding available habitat for other macrophyte species.

M. heterophyllum is known to hybridise with *M. laxum* and *M. hippuroides*, both very closely related species (Moody & Les, 2002). Although as detailed by Newman (2014), , closely related species from the Spondylium subsection do not occur in the EPPO region and therefore hybridisation seems unlikely. However, in the USA, *M. heterophyllum* has the potential to hybridise with the native *M. pinnatum* forming *Myriophyllum heterophyllum x pinnatum* which is a more aggressive hybrid and considering the number of *Myriophyllum* 'species' in trade hybridization in future may result in more aggressive invasive species (Moody & Les, 2002; Thum & Lennon, 2006; Tavalire *et al*., 2012).

The decay of large plant masses results in elevated levels of dissolved and suspended organic matter into the water column (Carpenter & Lodge, 1986). Furthermore large populations act to increase sedimentation (Carpenter & Lodge, 1986). Mono-specific stands can negatively affect wildlife (predator/prey relationship among fish, impede predation, shelter prey fish, cover spawning areas).

M. heterophyllum can reduce the aesthetic value of water bodies and restrict water related recreation activities including fishing, swimming and boating.

Economic impacts

In the USA, *M. heterophyllum* has been recorded as reducing house price values by 20-40 % when the species grows along lake shores (Halstead *et al.*, 2003). Invasive aquatic weeds can cause high economic impacts to areas where they invade, both in terms of management and loss of earnings through degrading the areas (Williams *et al.*, 2010). In drainage and irrigation systems the presence of the species reduces water availability and flow. Hydropower and drinking water resources can be affected as the plant clogs up waterbodies.

Impacts on human activities

Human activities on water bodies infested with *M. heterophyllum* can become restricted. *M. heterophyllum* can choke channels and restrict recreational activities such as fishing, swimming and boating.

Control methods

Manual and physical control

In a study in Maine, USA, three physical control methods (hand removal, cutting and benthic mats) were assessed for *M. heterophyllum* (Bailey & Calhoun, 2008). All three methods significantly lowered regrowth though the cost of both hand pulling and cutting was one-third the cost of benthic mats. Benthic mats can only be applied in the case of small infestations.

Washing out plant stands using a hydro-venturi system has been practiced in the Netherlands for the management of both *M. heterophyllum* and *Cabomba caroliniana*. The system removes both the root system and foliage resulting in long term control (van Valkenburg *et al*., 2011). Costs of hydro-venturi system, when taking into account all preparatory work and aftercare, can be in the region of € 1.35-2.05m^2 (pers. comm. van Valkenburg, 2015). This depends in dimensions of the waterways, sediment types etc. (van Valkenburg *et al*., 2011).

Small, recently detected infestations may be successfully eradicated through careful and thorough hand-pulling or using a tarpaulin. Great care should be taken with such methods since they cause fragmentation of the plant and therefore increase potential spread.

Benthic barriers may be used in small areas (swimming beaches, boating lanes, around docks) to restrict light and upward growth. Nevertheless, barriers can have a negative impact on benthic organisms and need to be properly maintained.

Dense stands occurring in shallow lakes in the vicinity of Dusseldorf (North- Rhine Westfalia, Germany) have been regularly cut in summer using a weed cutting boat without any long term effect (Hussner *et al* 2005; Hussner & Krause, 2007). Mechanical control of *M. heterophyllum* in these lakes, where 190 tonnes of fresh weight was removed, cost in the region of 45,000 € (Hussner & Krause, 2007).

Again, since the 1990s, repeated cutting in a lake in the Ville area has not decreased the population in the long term. However, mechanical control options may be better practiced during the winter time, when the plant is less active and regrowth is less likely, to reduce the effect on native vegetation and to reduce the competitive advantage of *M. heterophyllum* in spring.

Drawdown can also be used to control *M. heterophyllum* where applicable, if it is extensive enough to prevent re-growth but this control method could have a negative impact on native plants and animals (fish, reptiles, amphibians, etc.).

Chemical

Herbicide control (e.g. diquat-dibromide and 2,4-D) is recommended in some States of USA to manage this species (Getsinger *et al*., 2003). Triclopyr is effective against *M. heterophyllum* over a wide range of concentrations and exposure times. Carfentrazone-ethyl has been shown to be effective against *M. heterophyllum* (Glomski & Netherland, 2007). Diquat applied at 370 µg ai L^{-1} for 30 hours provided good control (85%) and carfentrazone significantly reduced *M. heterophyllum* biomass. Fluridone and penoxsulam are also reported to control *M. heterophyllum* at rates as low as 5 and 10 µg ai $^{L-1}$ respectively (Glomski & Netherland, 2008). None of the active ingredients are currently approved for use in the EU.

Biological control:

The following insects have been observed to feed on emergent or submerged leaves, petioles and stems of *M. heterophyllum*: *Donacia cincticornis* Newman (Coleoptera, Chrysomelidae) *Perenthis vestitus* Dietz (Coleoptera, Curculonidae) *Mystacoides longicornis* L., *Oecetis cinerascens* Hagen, *Triaenodes injusta* Hagen, *Triaenodes marginata* Sibley, *Triaenodes* spp (Trichoptera, Leptocertidae) (McGaha, 1952). In the USA (New Hampshire), initial surveys of nematode communities that occur where *M. heterophyllum* is present have been conducted (University of New Hampshire, 2008).

Grass carp (*Ctenopharyngodon idella*) have been used in Dusseldorf (Germany), after the failure of mechanical control, but they have not eradicated the species. In the USA, Hanlon *et al*. (2000) showed a reduction in cover in 6 years from 54 to 24% when grass carp were present.

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

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

Ecosystem services

Ecosystem service	**Does the IAS impact on this Ecosystem service?** Yes/No	**Short description of impact**	**Reference**
Provisioning	Yes	Hybridises with closely related species reducing genetic diversity	(Moody & Les, 2002)
Regulating	Yes	Degrades biological diversity and displaces native plant species	(Greulich & Bornette, 2003; Hussner, 2014; Sheldon, 1994; Thum & Lennon 2009)

Ecosystem service	Does the IAS impact on this Ecosystem service? Yes/No	Short description of impact	Reference
Supporting	Yes	Alters chemical composition of water bodies and increases sedimentation rates	(Carpenter & Lodge, 1986)
Cultural	Yes	Invades scenic areas; restricts access for recreation and tourism. Decreases property values.	(Halstead *et al*., 2003; pers. Comm. Hussner, 2015)

13. Potential impact in the PRA area

Impacts on biodiversity and the environment
Dense mono-specific growth of any aquatic plant species can incur impacts on native plant communities and other aquatic organisms such as invertebrates and fish (Carpenter and Lodge, 1986). *Myriophyllum heterophyllum* has both environmental and economic impacts in the EPPO region. The species has impacts on ecosystem services, as seen in other regions where it is present.

Dense mats of *M. heterophyllum* reduce light to other submerged plants and can affect water quality by reducing oxygen levels resulting in fish avoiding the infested area. Maximum dry weight recorded for this species is very high, measured at 4 kg m^{-2} in old infestations (pers. Comm. Hussner, 2015). Additionally, the pH within *M. heterophyllum* stands can vary between 7 and 10.5 on a daily basis, increasing stress for fish populations and reducing available habitat for other macrophyte species. On the Oranjekanaal in the province of Drenthe (Netherlands) the turbidity of the water decreased greatly when *M. heterophyllum* invaded the canal (Matthews *et al*., 2013). Retention of sediments can act to impede the lifecycle of high trophic levels by smothering spawning grounds for fish.

Many rivers and lakes with the PRA area are either protected areas or contain protected species that may be adversely affected by dense mats of *M. heterophyllum*. The presence of *M. heterophyllum* in rivers and lakes in the EU can act to degrade such habitats reducing the ecological status of water bodies. In Belgium, the species grows alongside several rare and vulnerable aquatic native species including *Luronium natans,* a Red List Species. In Germany, in some nature reserves the species occurs as the dominant species with up to 95% coverage of the whole water body.

Human health impacts within the EPPO region
There are no human health impacts associated with this species in the wider invasive range and therefore none are envisaged for the EPPO region.

Economic impacts within the EPPO region
M. heterophyllum blocks canals and water control systems and management options need to be applied to remove the species from these areas. The species could have potential impacts if invading agricultural irrigation systems. Potential impacts may be incurred to recreation if the species invades water bodies used for boating, swimming, fishing and diving. Consequential costs, through loss of earnings by the companies that organise recreational activities, plus reduced earnings for the wider region, may be incurred.

Will impacts be largely the same as in the current area of distribution? Yes /No

If No

Rating of the magnitude of impact in the area of potential establishment	*Low* ☐	*Moderate* ☐	*High*
Rating of uncertainty	*Low*	*Moderate* ☐	*High* ☐

14. Identification of the endangered area

The EPPO region - where suitable climates and habitats overlap. Climate is not such a strictly limiting factor for aquatic plants as it is for terrestrial plant species. The Expert Working Group considers that Tundra and Taiga biomes in Scandinavia and Asia are unlikely to be invaded.

Habitats within the endangered area include; riparian systems, slow moving rivers, canals, irrigation canals, lakes, reservoirs and semi-aquatic systems, including wetlands.

15. Climate change
Climate projection: **2050**

Which component of climate change do you think is most relevant for this organism?

Temperature ***$C0_2$ levels***

*Are the **introduction pathways** likely to change due to climate change and will the overall risk and uncertainly score change due to climate change? (If yes provide new score)*	**Reference**
The introduction pathways are unlikely to change as a result of climate change as the species enters the EPPO region as a result of the horticultural trade. The overall rating for introduction will not change.	EPPO region, Yes (van Valkenburg 2015; Brunel 2010; Hussner *et al.*, 2014)
*Is the **risk of establishment** likely to change due to climate change and will the overall risk and uncertainly score change due to climate change? (If yes provide new score)*	**Reference**
The risk of establishment may potentially increase with temperature increases. Those areas which are currently unsuitable for the occurrence of *M. heterophyllum* may become more suitable with increased number of day degrees. Extreme weather events, flooding etc., may increase the occurrence and potential areas of establishment for the plant. The overall rating for establishment will not change.	Newman (2014)
*Is the **risk of spread** likely to change due to climate change and will the overall risk and uncertainly score change due to climate change? (If yes provide new score)*	**Reference**
The risk of spread is likely to increase within the EPPO region as established populations build and become more invasive. An increase in extreme natural events, such as increased flooding may act to facilitate movement of the species between isolated populations. *M. heterophyllum* has been shown to increase in growth and vigour at elevated C02 levels. The overall rating for the risk of spread will not change.	(Newman, 2014 ; Hussner *et al.*, 2015)
***Will impacts change** due to climate change and will the overall risk and uncertainly score change due to climate change? (If yes provide new score)*	**Reference**
With increased temperature, C02 levels and nitrogen deposition, the impacts of *M. heterophyllum* may be more profound within native plant communities. *M. heterophyllum* has high phenotypic plasticity which will enable the species to persist and outcompete species with restricted habitat requirements. The overall rating for the risk of spread will not change.	(Hussner *et al.*, 2015)

16. Overall assessment of risk

The overall likelihood of *M. heterophyllum* entering into the EPPO region is high. The plant is imported into the EPPO region as a misidentified aquatic species for aquaria and ponds and is already established in Austria, Belgium, France, Germany, Hungary, the Netherlands, Spain and Switzerland. The risk of entry into other EPPO countries through import is considered high. The risk of the species establishing in additional countries is high as movement through irrigation and river systems acts to connect countries, facilitating spread regionally. Spread may be accelerated by recreational activities in water bodies invaded by the weed. The potential impact of the species within the EPPO region would be considered similar to what is seen in other countries where the species has invaded and become establish; *i.e.* parts of the USA. In the Netherlands, Belgium and Germany *M. heterophyllum* is causing both ecological and economic impacts.

Pathways for entry

Rating of the likelihood of entry	*Low* ☐	*Moderate* ☐	*High*
Rating of uncertainty	*Low*	*Moderate* ☐	*High* ☐

Likelihood of establishment outdoors in the PRA area

Rating of the likelihood of establishment outdoors	*Low* ☐	*Moderate* ☐	*High*
Rating of uncertainty	*Low*	*Moderate* ☐	*High* ☐

Spread in the PRA area

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

Impact in current area of distribution

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

Impact in the area of potential establishment

Rating of the magnitude of impact in the area of potential establishment	*Low* ☐	*Moderate* ☐	*High*
Rating of uncertainty	*Low*	*Moderate* ☐	*High* ☐

This species poses an unacceptable risk to the EPPO region

17. Stage 3. Pest risk management

The pathway being consider is:

(1) Plants for planting

International measures:
(1) Prohibition of import into and within the EPPO region. Because many species are imported under incorrect names it is necessary to screen imported aquatic plants for the presence of *M. heterophyllum*.

M. heterophyllum should be recommended as a quarantine pest within the EPPO region.

Techniques for confirmation of exact species identification, including molecular methods are available (Van Valkenburg & Boer, 2015; (Ghahramanzadeh *et al*., 2013).

(2) In addition to the existing requirement for a phytosanitary certificate (PC) by the exporting country, confirmation of the correct identification and labelling of the species should be required (see EPPO Standard PM 1/1(2) Use of phytosanitary certificates).

National measures:
Prohibition of selling, planting, holding, moving, and causing to grow in the wild of the plant in the EPPO region is necessary. Moreover, the plant has to be surveyed and eradicated, or contained or controlled if this is not possible where it occurs. In addition, public awareness campaigns to prevent spread from existing populations 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 have to be combined with international measures, and international coordination of management of the species between countries is necessary.

Containment and control of the species in unintended habitats
General considerations should be taken into account for the pathway under consideration, 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 water based recreational activities will facilitate targeting groups most prone to spread *M. heterophyllum.*

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. This is possible with the current level of occurrence the species has in the EPPO region. Coordination of all stakeholders is required and should be easy to achieve, especially since the distribution is limited.

Import for (aquatic) plant trade: Prohibition of the import, selling, planting, holding and movement of the plant within the EPPO region.

Transportation through recreational activities (method of spread within the EPPO region): Raise awareness on the species, including publicity regarding its identification and its impacts to the sector in question.

Natural spread (method of spread within the EPPO region): Increase surveillance in protected areas where there is a high risk the species may invade. NPPO's to 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).

18. Uncertainty

Pathways for entry – Low

Justification for uncertainty score: The fact that *M. heterophyllum* is already present within the EPPO region highlights that potential pathways for the entry of this species are already present. In addition, the species has been proven to be traded, although not under its proper name within the EPPO region.

Likelihood of establishment outdoors in the PRA area – Low

Justification for uncertainty score: The presence and establishment of the plant within the EPPO region justify the low uncertainty score for this category. Eco-climatic conditions and habitats suitable for this species are widespread in the PRA area.

Likelihood of establishment in protected conditions in the PRA area – No score assigned

Justification: A species in trade is normally established in protected conditions. The rating of the likelihood of establishment in protected areas along with the rating of uncertainty were not scored

Spread in the PRA area – Low
Justification for uncertainty score: The current uncertainty score of low is due to the current distribution of *M. heterophyllum* within the EPPO region. Spread of this species is due to a combination of fragmentation rates and connectivity of suitable habitats.

Impact in the current area of distribution – Low
Justification for uncertainty score: Impacts are severe as *M. heterophyllum* has displaced native vegetation.

Potential impact in the PRA area – Low
Justification for uncertainty score: Impacts are expected to be severe as dense mono-specific growth of any aquatic plant species can incur impacts on native plant communities and other aquatic organisms such as invertebrates and fish. *Myriophyllum heterophyllum* has both environmental and economic impacts in the EPPO region.

19. Remarks
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 DG Environment on the eligibility of the species for inclusion on the list of IAS of EU concern.

Inform industry, other stakeholders
Inform on the need for correct identification and labelling of the species and on the risk the species present

State whether a detailed PRA is needed to reduce level of uncertainty (if so, state which parts of the PRA should be focused on)
No

Specify if surveys are recommended to confirm the pest status
No

State what additional work/research could help making a decision.
N/A

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Appendix 1. Relevant illustrative pictures (for information)

Figure 1. Submerged shoots with submerged and emerged leaf forms. Photographer Andreas Hussner

Figure 2. Terrestrial leaf form of *Myriophyllum heterophyllum*. Photographer Andreas Hussner

Figure 3. Emergent leaf form of a flowering shoots of *Myriophyllum heterophyllum.* Photographer Andreas Hussner

Figure 4. Regenerating fragment of *Myriophyllum heterophyllum.* Photographer Andreas Hussner

Figure 5. Mono-culture of *Myriophyllum heterophyllum* in Germany. Photographer Andreas Hussner

Figure 6. Mono-culture of *Myriophyllum heterophyllum* in Germany. Photographer Andreas Hussner

Appendix 2. Distribution maps of *Myriophyllum heterophyllum*

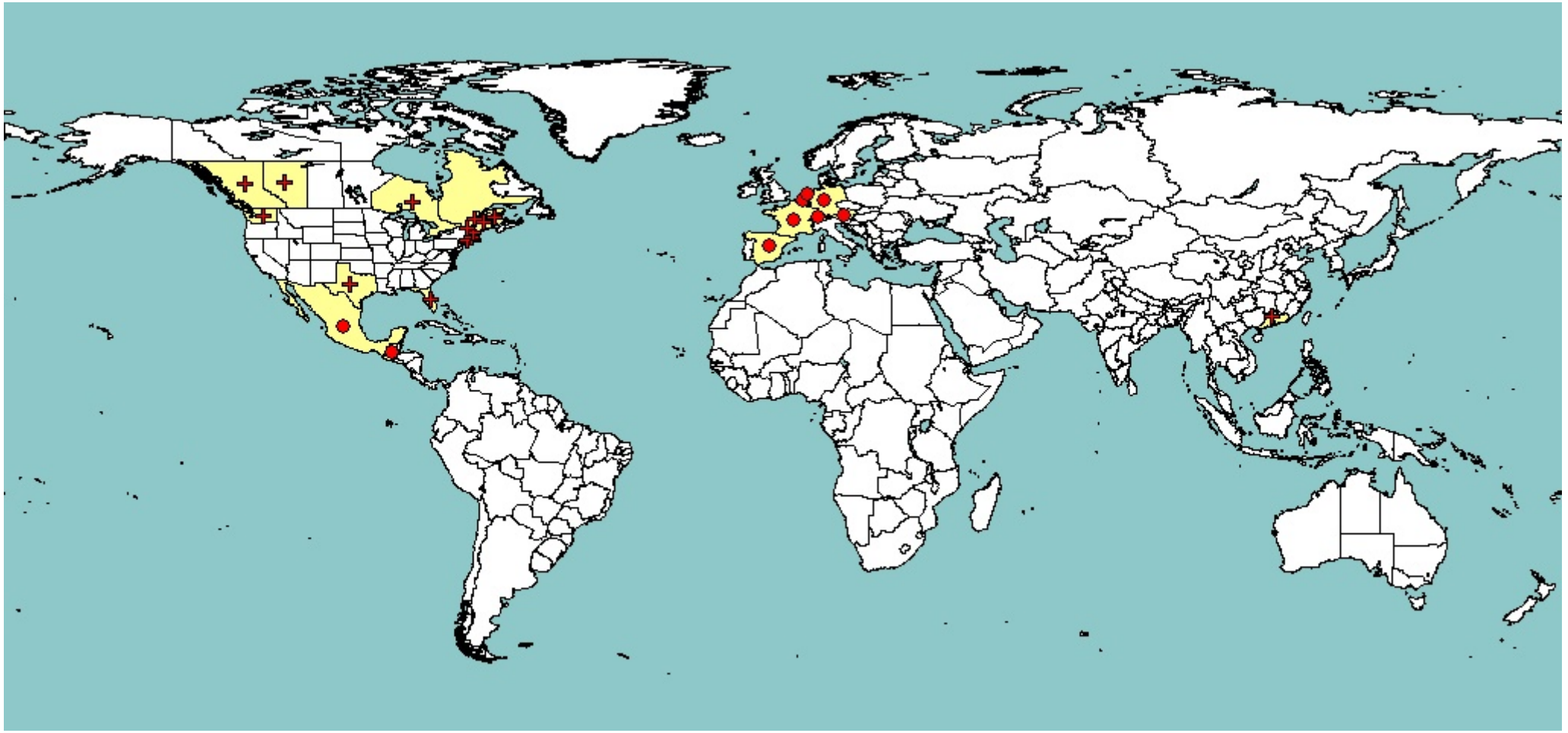

Figure 7: Global occurrence of *Myriophyllum heterophyllum* (EPPO PQR)

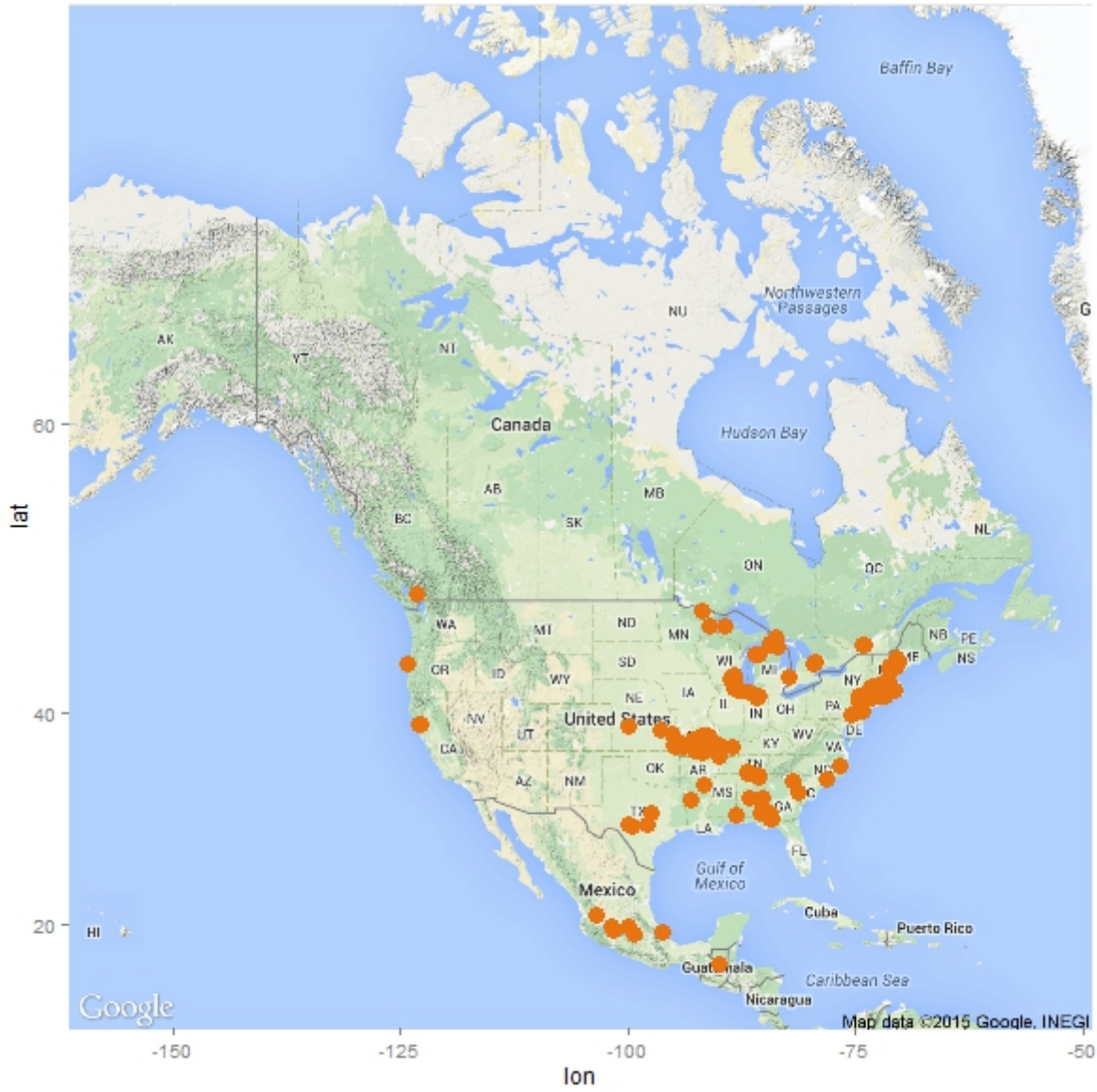

Figure 8. Occurrence of *Myriophyllum heterophyllum* in North America (Data taken from Gbif). Additional points added from scientific sources using Google maps, ggmap Library (R version 3.1.2 (2014-10-31).

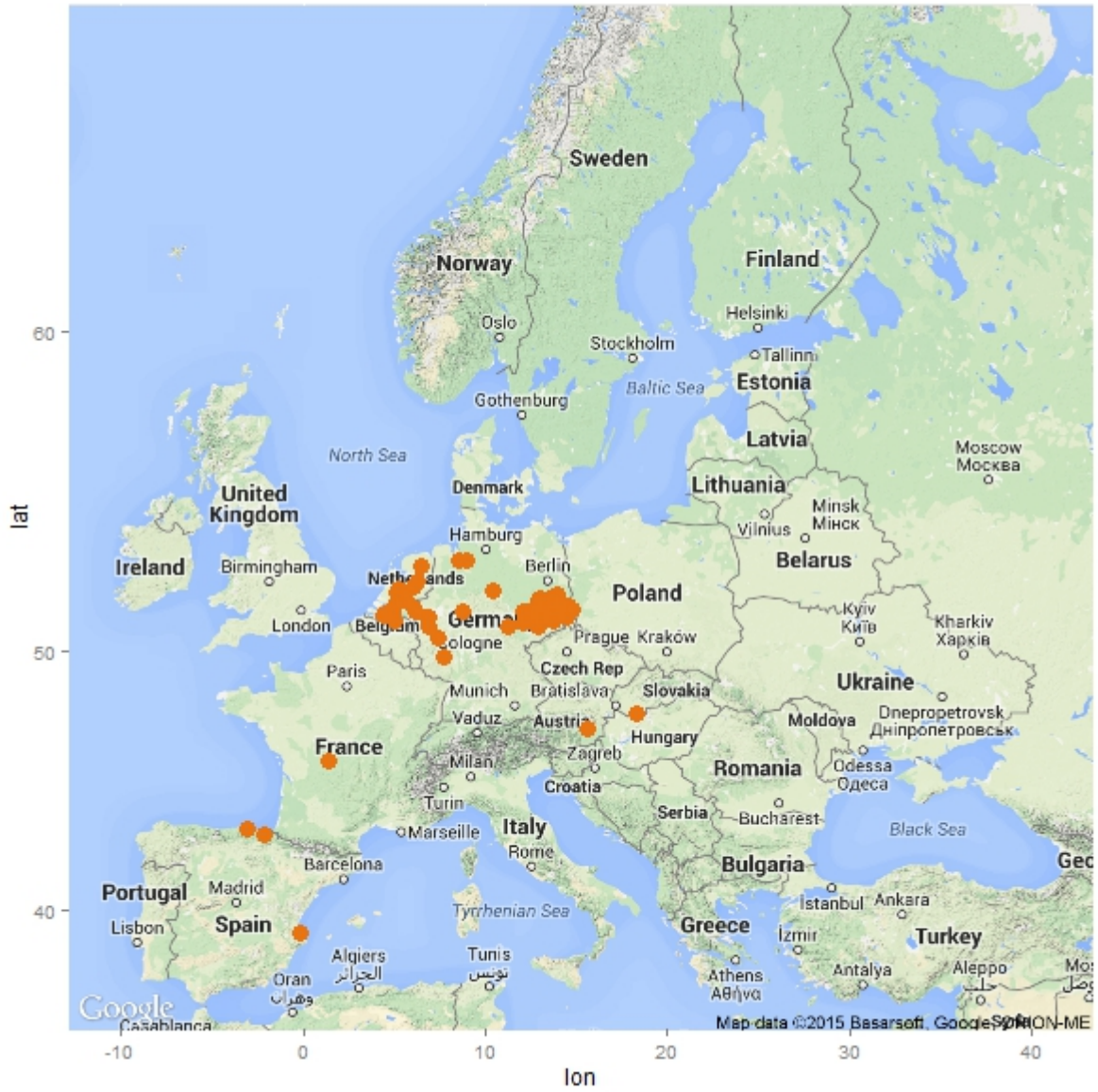

Figure 9. Occurrence of *Myriophyllum heterophyllum* in Europe (Data taken from Gbif). Additional points added from scientific sources using Google maps, ggmap Library (R version 3.1.2 (2014-10-31). Note: there are no specific localities for the presence of *Myriophyllum heterophyllum* in Switzerland.

Appendix 3. Geiger Climatic Zones

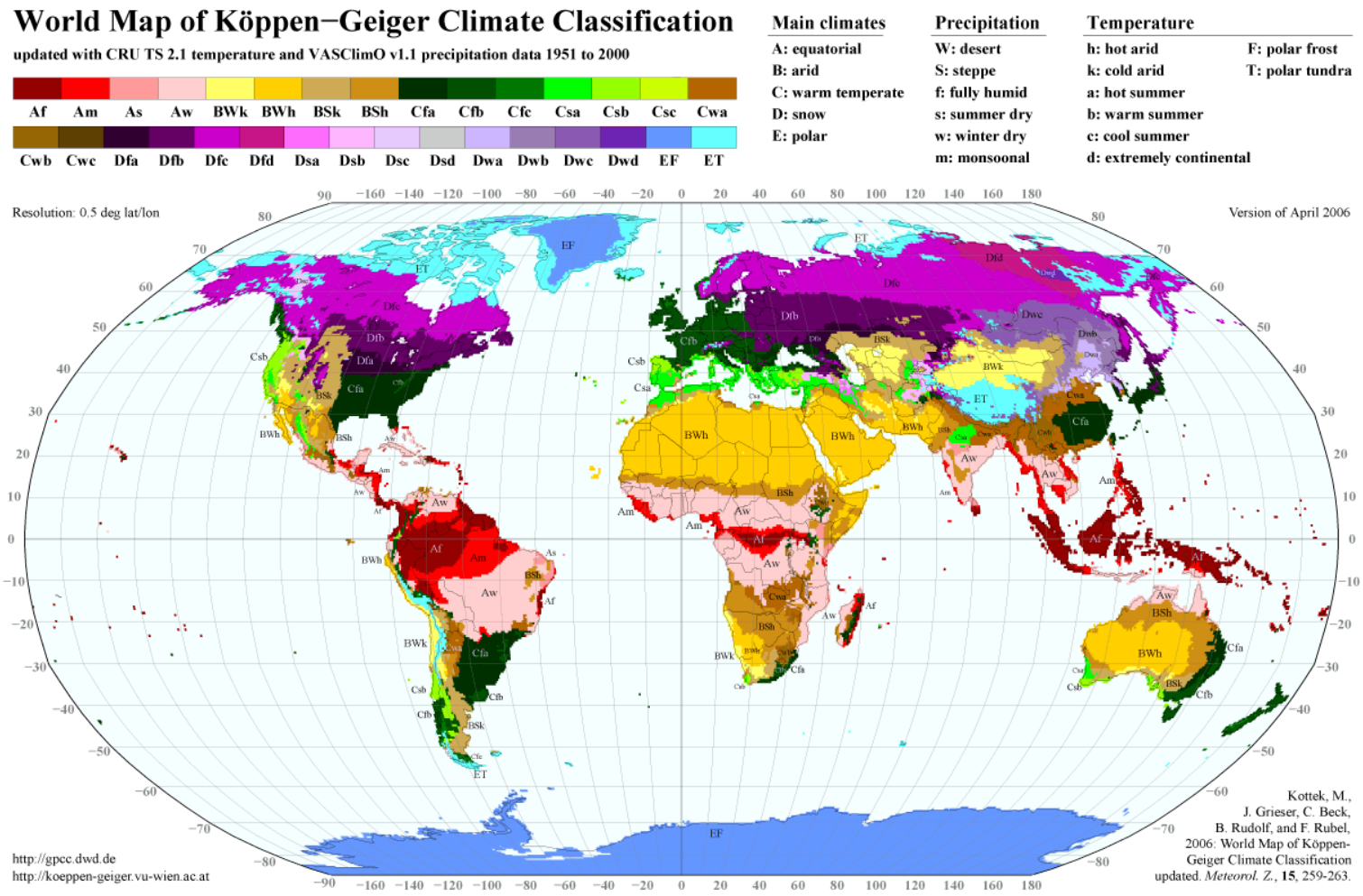

Figure 10. Geiger Climatic Zones