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Alien aquatic plant species in European countries

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Summary

Alien aquatic plant species cause serious ecological and economic impacts to European freshwater ecosystems. This study presents a comprehensive overview of all alien aquatic plants in Europe, their places of origin and their distribution within the 46 European countries. In total, 96 aquatic species from 30 families have been reported as aliens from at least one European country. Most alien aquatic plants are native to Northern America, followed by Asia and Southern America. *Elodea canadensis* is the most widespread alien aquatic plant in Europe, reported from 41 European countries. *Azolla filiculoides* ranks second (25), followed by *Vallisneria spiralis* (22) and *Elodea nuttallii* (20). The highest number of alien aquatic plant species has been found in Italy and France (34 species), followed by Germany (27), Belgium and Hungary (both 26) and the Netherlands (24). Even though the number of alien aquatic plants seems relatively small, the European and Mediterranean Plant Protection Organization (EPPO, http://www.eppo.org) has listed 18 of these species as invasive or potentially invasive within the EPPO region. As ornamental trade has been regarded as the major pathway for the introduction of alien aquatic plants, trading bans seem to be the most effective option to reduce the risk of further unintended entry of alien aquatic plants into Europe.

Keywords: aquatic weed, biodiversity, invasive species, alien plant, macrophyte.

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Introduction

Biological invasions are recognised as one of the major causes of losses in biodiversity. Recently, it has been shown that alien aquatic species show a higher proportion of species causing ecological or economic impacts upon their habitats than terrestrial species (Vila *et al.*, 2009).

Freshwater aquatic plant species generally show broad distribution ranges, and limitations in plant dispersal occur almost solely because of geographical barriers or major disjunctions in the different climatic regions (e.g. tropical to temperate regions) (Santamaria, 2002). Natural range extension of aquatic plants occurs (Cook, 1985), but the ornamental trade is considered as the major pathway of aquatic plant introduction within the different continents and climatic regions and thus into Europe (Brunel, 2009). Currently, more than 400 non-native aquatic and semi-aquatic plant species for aquarium or garden pond purposes are traded in Europe (Hussner, 2008) and most of them have to be considered as potential invaders to European freshwater habitats.

During the last decade, problems associated with the spread of certain alien aquatic plant species (e.g. *Elodea* spp., *Eichhornia crassipes* (Mart.) Solms, *Ludwigia* spp., *Hydrocotyle ranunculoides* L.*f*., *Myriophyllum aquaticum* (Vell.) Verdc.) were found to be increasing in Europe (Sheppard *et al.*, 2006; Hussner, 2009). High biomass production by these species can hinder run-off in rivers, restrict recreational use of waters (e.g. boating, swimming, fishing) (Pot, 2003), cut off light penetration in the water column, prevent wind-induced mixing, change hydrochemistry and cause oxygen deficiency (Laranjeira & Nadais, 2008), as well as displace native vegetation and

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alter food web structure (Stiers *et al*., 2011). In Europe, some high-cost intensive control programmes have been conducted to control invasive aquatic plant species (e.g. Pot, 2003; Laranjeira & Nadais, 2008; Hussner *et al*., 2010). Some European countries have prepared national Pest Risk Assessments (PRA) for several alien aquatic plant species to clarify the pest potential of the species and classify these into black, grey and white lists. Species listed on the black list should be generally under management and/or trade control. Unfortunately, the risk classification is mostly dissimilar between the countries (Verbrugge *et al*., 2012), which makes it difficult to act on a European wide scale.

The European and Mediterranean Plant Protection Organization (EPPO) has established the 'EPPO List of Invasive Alien Plants' as a list of priorities (http://www.eppo.org). The listed plant species have been identified as posing an important threat to the environment, biodiversity and plant health. Based on this list, some species have been studied more intensely, and some more general PRA for the species with the highest suggested threat potential within the EPPO region (http://www.eppo.org) have been prepared. The species, which are recommended for regulation as quarantine pests, have been listed as A1 (recently absent from the EPPO region) or A2 species (locally present in the EPPO region) in the 'EPPO A1/A2 Lists'. Furthermore, an additional 'Alert List' has been prepared to categorise species, which may present a risk to the EPPO region. These species are generally absent or only of limited distribution within the EPP region yet (http://www.eppo.org).

However, even though there are a number of publications and ongoing activities concerning the most invasive aquatic plant species in Europe, a comprehensive study of all alien aquatic plant species in Europe is still lacking. This study presents an overview of all alien aquatic plant species within Europe, based on literature and online databases.

Material and methods

Definitions

In this study, all species that grow at least a part of their life history submerged or are closely bound to aquatic habitats have been considered. Plant species that grow in other habitats also, such as fields (e.g. *Paspalum paspalodes* (Michx.) Scribn., Cook, 1985), have been excluded from this study.

Unfortunately, the definition of the term 'alien' differs between the European countries (European Commission, 2011). Furthermore, EPPO regards plants to be alien within the EPPO region, when they either have no or only a small native range within the EPPO region, but are alien in a significant part of the EPPO region (Brunel *et al*., 2010).

In this study, the definitions of Pyšek *et al*. (2004) have been used to distinguish between native and alien plant species on a national basis. Following this, all plant species, whose presence in a country is 'due to intentional or unintentional human involvement, or which have arrived there without the help of people from an area in which they are alien' (Pyšek *et al*., 2004), have been considered as aliens and listed, even if the species have native occurrences within other European countries. Owing to the lack of data on the naturalisation and years of introduction of the non-native aquatic plant species within Europe, no distinction between established and non-established species and between archaeophytes and neophytes could have been made.

The naming of the plants follows The Plant List (http://www.theplantlist.org), a working list of all known plant species, provided by a consortium of the Royal Botanic Garden, Kew Garden and Missouri Botanical Garden. The accepted names of 94 plant species of The Plant List have been listed in this study, and for one additional species (*Rotala macrandra* Koehne), the name is still unresolved. Based on new findings from Pereira *et al*. (2011), *Azolla caroliniana* Willd. has been regarded as an independent and valid taxon and has not been listed as a synonym of *Azolla filiculoides* Lam., as noted in The Plant List.

Literature and internet survey

Presence of alien aquatic plant species in all 46 European countries (Table 1) was determined using both online databases and published literature. The international databases and websites http://www.daisie.org, http://www.eppo.org, http://www.nobanis.org and http://www.issg.org were the main sources. Owing to the lack of data in these international databases, national databases (Belgium: http://ias.biodiversity.be; Germany: http://www.neoflora.de; Ireland: http://invasivespeciesireland.com; Lithuania: http://www.ku.lt/lisd/index.html; the Netherlands: http://www.werkgroepexoten.nl; Poland: http://www.iop.krakow.pl/ias/Baza.aspx), revisions of genera (Cook & Lüönd, 1982) and recently published articles (Essl & Rabitsch, 2002; Chytrý *et al*., 2005; Wittenberg, 2005; Larson & Willen, 2006; Alexandrov *et al*., 2007; Anastasiu *et al*., 2007; Thiebaut, 2007; Borsic *et al*., 2008; Vukov *et al*., 2008; Celesti-Grapow *et al*., 2009; Eliáš *et al*., 2009; Mesterházy *et al*., 2009; Zenetos *et al*., 2009; Arianoutsou *et al*., 2010; Hussner *et al*., 2010; Imeri *et al*., 2010; Talevska, 2010; Tosheva & Traykov, 2010) about invasive species have also been used. However, no data

Table 1 List of all non-indigenous aquatic plants species, which have been reported as introduced from at least one European country

Scientific name	Geographical origin	Known occurrences in Europe
Alternanthera philoxeroides (Mart.) Griseb.	S-America	14, 19, 38
Ammannia senegalensis Lam.	Africa	16
Aponogeton distachyos L.f.	S-Africa	4, 11, 14, 18, 27, 34, 43
Azolla filiculoides Lam.	N-, C-, S-America	2, 4, 6, 7, 9–11, 14–19, 22, 27, 28, 31, 32, 34–36, 38, 39, 42, 43
Azolla caroliniana Willd.	N-, C-, S-America	6, 14–16, 27, 39
Bacopa monnieri (L.) Wettst.	Asia, N-America	31
Baldellia ranunculoides Parl.	Europe, N-Africa	31
Blyxa japonica (Mig.) Maxim. Ex. Asch. & Gürke	Asia	31
Cabomba caroliniana A. Gray	S-America	4, 11, 15, 17, 27, 34, 39
Callitriche brutia Petagna	Europe	31
Callitriche deflexa A. Braun ex. Hegelm.	C-, S-America	31
Crassula helmsii (Kirk) Cockayne	Australia	4, 7, 11, 14, 15, 18, 19, 27, 28, 31, 34, 36, 38, 40, 41, 43
Ceratophyllum demersum L.	Asia, Africa, Europe, N-, C-, S-America	6, 17, 32
Ceratophyllum submersum L.	Europe, Asia	6, 10, 13, 18, 39
Ceratopteris thalictroides (L.) Brongn.	Asia	2, 17, 32
Cryptocoryne crispatula Engl.	Asia	2
Egeria densa Planch.	S-America	2, 4, 11, 14, 15, 17–19, 27, 31, 38, 40
Eichhornia crassipes (Mart.) Solms	S-America	4, 9, 14, 15, 17, 19, 27, 31, 32, 38
Eleocharis parvula (Roem. & Schult) Link ex Bluff, Nees & Schauer	Europe, Asia, N-, C-America	16
Elodea callitrichoides (Rich.) Casp.	S-America	2, 11, 14, 15, 39, 43
Elodea canadensis Michx.	N-America	1–15, 17–25, 27–43
Elodea nuttallii (Planch.) H. St. John	N-America	4, 7, 9–11, 14, 15, 17–19, 23, 27, 28, 32, 34–36, 39, 40
Gymnocoronis spilanthoides (D. Don ex. Hook. & Arn) DC.	S-America	17
Groenlandia densa (L.) Fourr.	Europe	18, 37
Heteranthera limosa (Sw.) Willd.	N-, S-America	14, 16, 19, 24, 38
Heteranthera reniformis Ruiz & Pav.	N-, C-, S-America	14, 16, 19, 31
Heteranthera rotundifolia (Kunth.) Griseb.	N-America	16, 19, 31
Heteranthera zosterifolia Mart.	S-America	2
Hydrilla verticillata (L.f.) Royle	Asia	2, 14, 15, 17, 18, 20. 22, 30, 33
Hydrocharis morsus-ranae L.	Europe, Asia	23
Hydrocotyle bonariensis Lam.	N-, C-, S-America	14, 19, 31, 38
Hydrocotyle moschata G. Forst	New Zealand	11, 18, 34
Hydrocotyle novae-zelandiae D.C.	New Zealand	4, 34
Hydrocotyle ranunculoides L.f.	N-, C-, S-America	4, 11, 14, 15, 17–19, 27, 43
Hydrocotyle sibthorpioides Lam.	Asia	19
Hydrocotyle verticillata Thunb.	N-, C-, S-America	38
Hygrophila polysperma (Roxb.) T. Anderson	Asia	15, 30
Lagarosiphon major (Ridl.) Moss	S-Africa	2, 4, 7, 11, 14, 15, 18, 19, 27, 28, 34, 40, 43
Landoltia punctata (G. Mey) Les & D.J. Crawford	Australia, Asia	14, 19, 27, 31
Lemna aequinoctialis Welw.	S-America	14–16, 19
Lemna gibba L.	Europe, Asia, N-America	33
Lemna minor L.	Africa, Asia, Europe, N-America	31
Lemna minuta Kunth.	N-, C-, S-America	2, 4, 7, 11, 14–19, 27,32, 34, 36, 38, 40, 43
Lemna perpusilla Torr.	Asia, Africa, N-, C-, S-America	14
Lemna turionifera Landolt	Asia, N-America	4, 9, 13, 14, 15, 27, 30, 39
Lilaeopsis carolinensis J.M. Coult & Rose	N-America	31, 38
Ludwigia grandiflora (Michx.) Greuter & Burdet	S-America	4, 11, 14, 15, 18, 19, 27, 38, 40
Ludwigia peploides (Kunth) P.H. Raven	S-America	4, 11, 14, 16, 19, 27
Murdannia keisak (Hassk.) Hand.-Mazz.	Asia	19
Myriophyllum aquaticum (Vell.) Verdc.	S-America	4, 7, 11, 14, 15, 17–19, 27, 28, 31, 32, 34, 38, 43
Myriophyllum heterophyllum Michx.	N-America	2, 4, 14, 15, 27, 38
Myriophyllum verrucosum Lindl.	Australia	11
Najas graminea Delile	Asia, Africa, Australia	14, 19

Table 1 (Continued)

Scientific name	Geographical origin	Known occurrences in Europe
Najas guadalupensis (Spreng.) Magnus	Asia, N-, C-, S-America	17
Najas gracillima (A. Braun ex. Engelmann) Magnus	N-America	14, 16, 19, 38
Najas orientalis L. Triest & Uotila	Asia	16
Nelumbo nucifera Gaertn.	Asia, Africa	14, 17, 19, 32
Nuphar advena (Aiton) W.T, Aiton	N-America	11, 34
Nuphar pumila (Timm.) DC.	Europe, Asia	18
Nuphar japonica DC.	Asia	10
Nymphaea alba L.	Europe, Asia	23, 31
Nymphaea lotus L.	Africa, Asia, S-America	17, 32
Nymphaea mexicana Zucc.	N-, C-America	38
Nymphaea malabarica Poirr.	Unknown	17, 27
Nymphaea rubra Roxb. ex. Andrews	Unknown	17
Nymphoides peltata (S.G. Gmel.) Kuntze	Europe, Asia	39
Orontium aquaticum L.	N-America	10, 13, 29, 39
Ottellia alismoides (L.) Pers.	Asia, Australia	19
Pistia stratiotes L.	S-America	4, 9, 15, 17, 19, 27, 31–33, 37, 38
Pontederia cordata L.	N-, S-America	4, 11, 14, 15, 18, 19, 27, 38, 40
Potamogeton epihydrus Raf.	N-America	11, 34, 43
Potamogeton nodosus Poir.	Europe, Asia. N-America	23
Potamogeton trichoides Cham. & Schltd.	Europe, Asia	6
Rotala indica (Willd.) Koehne	Asia	19, 31, 38
Rotala macrandra Koehne	Asia	17
Rotala ramosior Koehne	N-America	16, 19
Rotala rotundifolia (Buch.- Ham ex. Roxb.) Koehne	Asia	17
Sagittaria graminea Michx.	N-America	14
Sagittaria latifolia Willd.	N-America	2, 4, 6, 7, 9–11, 13, 14, 15, 19, 29, 32, 38, 39, 42
Sagittaria platyphylla (Engelm.) J.G. Sm.	N-America	19, 42
Sagittaria rigida Pursh	N-America	11, 18, 43
Sagittaria subulata (L.) Buchenau	N-, S-America	15, 17
Sagittaria sagittifolia L.	Europe, Asia	14
Salvinia auriculata Aubl.	C-, S-America	4, 15
Salvinia adnata Desv.	S-America	2, 4, 19, 27
Salvinia natans All.	Europe, Asia	2, 4, 27, 38
Saururus cernuus L.	N-America	4, 15, 19
Shinnersia rivularis (A. Gray) R.M. King & Rob.	C-America	15, 17, 36
Spirodela polyrrhiza (L.) Schleid.	Europe, Asia, N-, C-America	18, 21
Stratiotes aloides L.	Europe	14, 18, 40
Trapa natans L.	Europe, Asia	4
Utricularia gibba L.	N-, C-America, Asia	16
Vallisneria nana R. Br.	Australia	17
Vallisneria spiralis L.	N-Africa, Asia, Europe	1, 2, 4, 6, 8–11, 14-17, 23–27, 30, 32, 35, 38, 40
Wolffia arhiza Wimm	Europe, Asia, Africa	3, 17, 19, 32
Zannichellia repens Boenn.	Europe, N-America	33

1 = Albania; 2 = Austria; 3 = Belarus; 4 = Belgium; 5 = Bosnia; 6 = Bulgaria; 7 = Channel Islands; 8 = Croatia; 9 = Czech Republic; 10 = Denmark (incl. Faeroes, Greenland); 11 = England; 12 = Estonia; 13 = Finland; 14 = France (incl. Corsica); 15 = Germany; 16 = Greece; 17 = Hungary; 18 = Ireland; 19 = Italy (incl. Sardinia); 20 = Latvia; 21 = Liechtenstein; 22 = Lithuania; 23 = Luxembourg; 24 = Macedonia; 25 = Moldova; 26 = Montenegro; 27 = the Netherlands; 28 = Northern Ireland; 29 = Norway; 30 = Poland; 31 = Portugal (incl. Azores, Madeira); 32 = Romania; 33 = European part of Russia; 34 = Scotland; 35 = Serbia; 36 = Slovakia; 37 = Slovenia; 38 = Spain (incl. Baleares, Canary Islands); 39 = Sweden; 40 = Switzerland; 41 = European part of Turkey; 42 = Ukraine; 43 = Wales; no data have been found for Cyprus, Iceland and Malta.

about alien aquatic plant species could be found for Cyprus, Iceland and Malta.

The native ranges of all species were determined using revisions of genera (*Ammannia*: Graham, 1985; Graham *et al*., 2011; *Cabomba*: Orgaard, 1991; *Cryptocoryne*: Rataj, 1975; *Hydrocotyle*: Hussner & van de Weyer, 2004; *Lilaeopsis*: Affolter, 1985; *Ludwigia*: Raven, 1963; *Najas*: Rendle, 1899; *Nuphar*: Padgett, 2007; *Vallisneria*: Les *et al*., 2008), European floras (Tutin *et al*., 1964–1980; Casper & Krausch, 1980) and the review by Cook (1985).

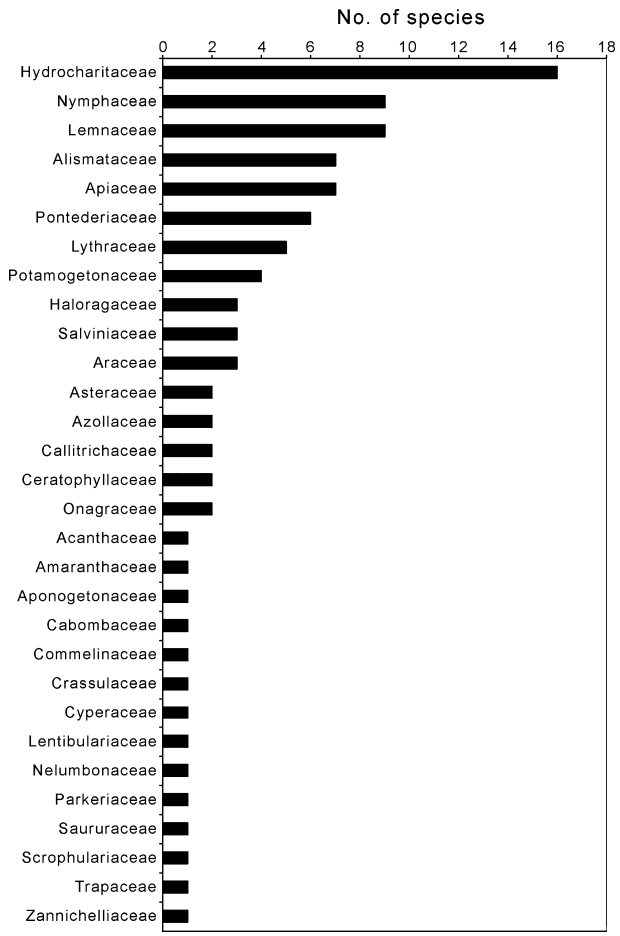

Fig. 1 Number of alien aquatic species in different families.

Results

In total, 96 aquatic species from 30 families have been reported as alien from at least one European country (Table 1, Fig. 1). Sixteen species, including some of the worst, like *Elodea* spp., *Hydrilla verticillata* (L.f.) Royle and *Egeria densa* Planch., belong to the family of Hydrocharitaceae, followed by the Nymphaeaceae and Lemnaceae (both with nine plant species). Fourteen families currently occur in Europe with only a single alien plant species (Fig. 1).

Places of origin of the introduced aquatic plants

An overview of the places of origin of all reported alien aquatic plants in Europe is given in Fig. 2 and Table 1. Three species (3.2%) are native to parts of Europe, but occur in at least one European country as an alien species. Additionally, 19 (19.9%) species are native to Europe, but have multiple origins. Most aquatic plant species introduced into Europe originated from North America (16% or 16.8% species are exclusively native to Northern America and 25% or 26.3% are native to Northern America but with multiple origin), followed by Asia (12; 12.6%/28; 29.4%), Southern America (12; 12.6%/18; 18.9%), Central America (1; 1.1%/18; 18.9%), Africa (3; 3.2%/11; 11.5%) and Australia and New Zealand (5; 5.3%/5; 5.3%) (Fig. 2).

Number of alien aquatic plants species in the European countries

The highest number of alien aquatic plant species was found in Italy (34 species; 34 in mainland of Italy and three in Sardinia) and France (34 species; 32 in mainland of France and six in Corsica), followed by Germany (27), Belgium and Hungary (both 26) and the Netherlands (24) (Table 1, Fig. 3). Lowest numbers of alien aquatic plants have been found in the Balkan region and the northern and eastern parts of Europe (Fig. 3).

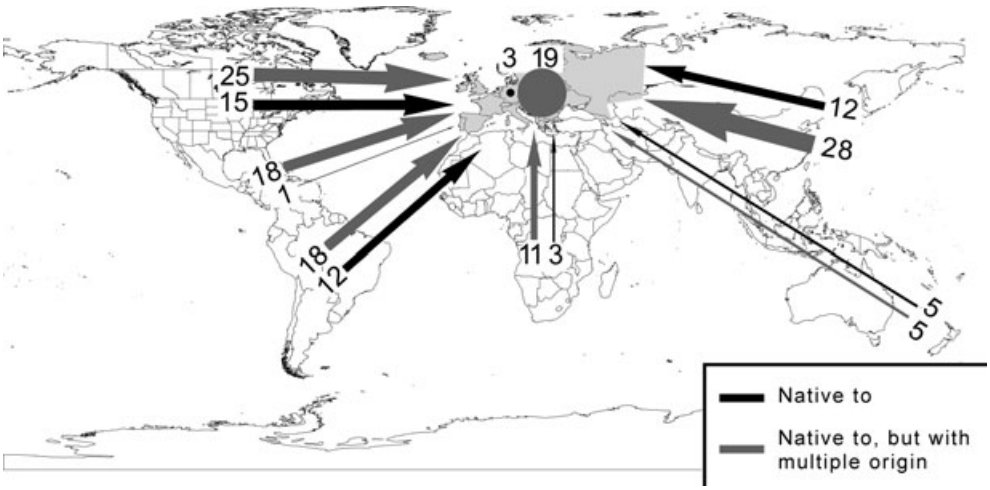

Fig. 2 Places of origin of non-indigenous aquatic plant species in Europe.

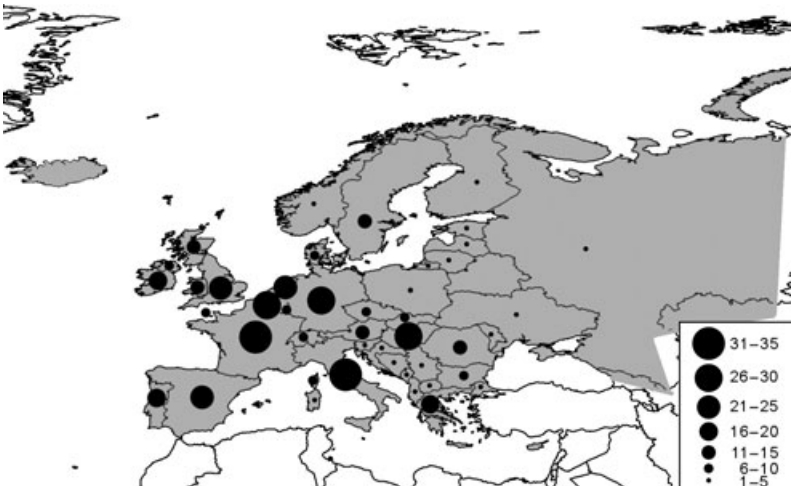

Fig. 3 The number of non-indigenous aquatic plant species in European countries.

Distribution of alien aquatic plants within Europe

Elodea canadensis Michx. is the most widely distributed alien aquatic plant in Europe, occurring in 41 European countries (Table 1, Fig. 4), but no reports of *E. canadensis* have been found from Cyprus, Malta, Iceland, Greece and Montenegro. *Azolla filiculoides* ranks second (25 countries), followed by *Vallisneria spiralis* L. (22) and *Elodea nuttallii* (Planch.) H. St. John (20). *Elodea nuttallii* has caused serious problems in several European countries during the last decades (see, e.g. Podraza *et al*., 2008). Some species recently became invasive, including *H. ranunculoides* (reported from nine countries), *Ludwigia grandiflora* (Michx.) Greuter & Burdet (9), *Cabomba caroliniana* A. Gray (7) and *Ludwigia peploides* (Kunth) P.H. Raven (6). These currently occur only in a few countries and might not have yet finalised their spread within Europe. In contrast to these recently already widespread and currently spreading alien aquatic species, 34 of the listed 96 species have been reported as aliens from only one European country yet (Table 1). These include species that have been recently introduced into Europe (like *Najas guadalupensis* (Spreng.) Magnus) and, for which, the further spread potential seems still unclear. There are also species which are native to parts of Europe, but have been reported as alien from other European countries (e.g. *Lemna minor* L., reported as an alien from the Azores).

Categorisation of alien aquatic plants in Europe in the EPPO listings

Even though the number of alien aquatic plants is relatively small, the EPPO has listed 18 of these species in their listings about invasive plants (http://www.eppo.org; Table 2). Five alien aquatic plant species (50% of all listed aquatic and terrestrial plant species in this list) are listed on the 'EPPO List of pests recommended for regulation as quarantine pests, as A2 species. Additionally, six species (16.7%) are listed on the 'EPPO List of invasive alien plants' (IAP) and seven species (30.4%) on the 'EPPO Alert List' (Table 2).

Discussion

The number of 96 alien aquatic plant species is relatively low, compared with the total number of alien plant species in Europe (5798 species, Lambdon *et al*., 2008). Surprisingly, the number of alien aquatic plant species, which caused serious threats during the past or are suggested to cause economic and/or ecological impacts in the future is really high, as has been indicated by the EPPO listings. In general, 30% of all alien freshwater species (including both flora and fauna) have an ecological impact on the ecosystems, 24% have an economic impact (Vila *et al*., 2009), which is comparable with the percentage of alien aquatic plant species that have been categorised as pest or potentially pest species by EPPO (http://www.eppo.org). However, this is not only caused by the uniformity of most freshwater habitats, which allows aquatic plants to occupy very large ranges (Cook, 1985). In general, aquatic ecosystems represent stressful habitats for plants. There is some evidence that, particularly, the availability of dissolved inorganic carbon might play a major role for the spread of alien plant species in freshwater habitats (Spierenburg *et al*., 2009). Low carbon availability acts as a major limiting factor for aquatic plant growth and photosynthesis (Santamaria, 2002), which results in the selection of stress-tolerant plant species showing broad tolerances (e.g. to low carbon availabilities). Interestingly, almost all invasive submerged aquatic plant

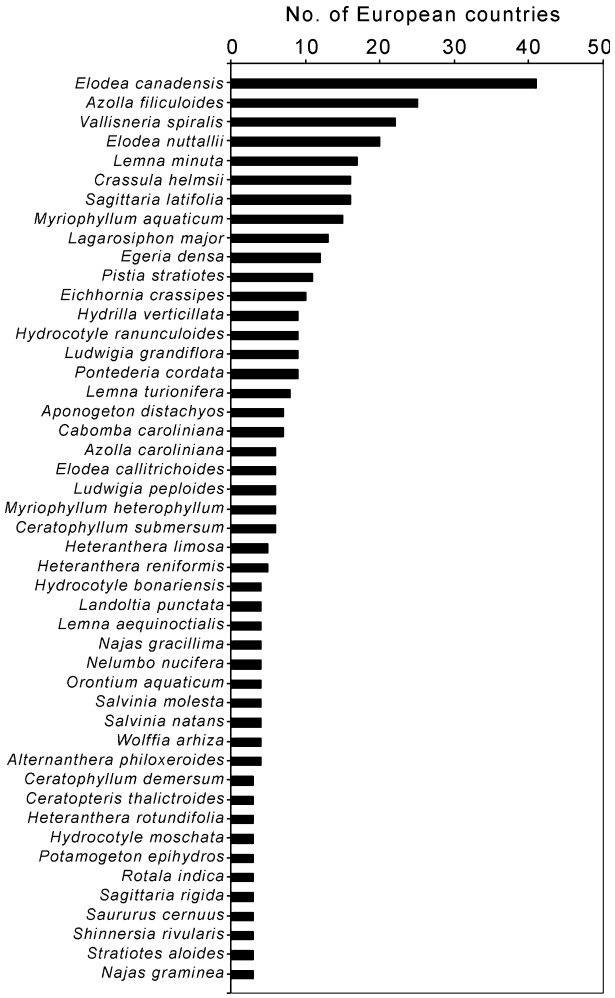

Fig. 4 Non-indigenous aquatic plant species and the number of countries with known occurrences. Only species are shown, which occur in at least three European countries.

species in Europe show different kinds of carbon concentrating mechanisms (CCM), which may increase their weed potential, such as C_3/C_4 switch (*H. verticillata*, *E. densa*), or recently not fully understood CCM, which allow the species (e.g. *E. canadensis*, *E. nuttallii*, *Lagarosiphon major*, *V. spiralis*, *M. aquaticum* and *Myriophyllum heterophyllum*) to use HCO_3^- as an additional carbon source (Spencer & Bowes, 1990; Bowes, 2011). A number of the plant species, which are known to have a kind of CCM, belong to the family of Hydrocharitaceae, which might be a reason for the high number of alien aquatic plant species in Europe that belong to this family. However, there might be other ecological and physiological factors that might have played a role in the history of the spread of alien aquatic plants in Europe, but have not yet been reported.

Most alien aquatic plants in Europe are native to North and South America, followed by Asia, but only 23% of the reported alien aquatic plant species originate from Europe. This is much less than the 53% of all plant species in general, which are alien in Europe but also native in other parts of Europe (Lambdon *et al.*, 2008). The strong imbalance between the native origin of the alien aquatic plants in Europe is probably caused by the fact that Europe is contiguous with Asia and Africa and is thereby not a phytogeographical distinct region (Cook, 1985), which allowed aquatic plants in the past to spread within the European, Asian and African continents. In contrast with terrestrial plants, aquatic plants mostly disperse as plant fragments, rather than by seeds. This will limit their potential for natural long-distance dispersal between America and Europe.

However, the ornamental trade has been considered as the major pathway of introduction of alien aquatic plants throughout the world (Kay & Hoyle, 2001; Brunel, 2009). Hussner *et al.* (2010) reported a significant relationship between the number of reported alien aquatic plants and the number of inhabitants in the German federal states and thus the number of aquarium plant keepers and thus potential vectors for aquatic plant introduction.

The high number of imported aquatic plant species into Europe, mainly originating from Asia, is an ongoing threat for European freshwater ecosystems. For example, Brunel (2009) reported 41 different species from the Araceae family, which have been introduced into Europe for aquarium and outdoor purposes. This high number of introduced plants from Asia is still not included in the number of alien plants from Asia that have been found in European waters. Climatic reasons will play a key role for the establishment and further spread of these potentially alien aquatic plant species in the future, as most imported aquatic plants from Asia are tropical species.

Climatic reasons will also be a major factor that explains the clear differences in the number of alien aquatic plants within the study area. The longer growing season and mild winter temperatures, in particular, may explain the higher number of alien aquatic plants in the southern and western parts of Europe than in northern and eastern parts (Chytrý *et al.*, 2009). However, this may not be the whole story, as some Mediterranean countries, for example, Albania, Bosnia and Montenegro, show low numbers of alien aquatic plants as well. In these cases, a lack of studies and therefore published literature may be an explanation for this (Lambdon *et al.*, 2008). Additionally, most invasions, for example, for *Ludwigia* spp., occur from west to east, thus first being recorded in France or the Benelux countries.

In Germany, more than 60 species from the two popular aquarium genera *Anubias* and *Cryptocoryne* of the family of Araceae, which are mostly tropical species, are found in the aquaculture trade (A Hussner, unpubl.

Table 2 Alien aquatic plants in Europe and their EPPO listing (http://www.eppo.org)

Species name	No. of countries	EPPO-Listing	Growth form
Azolla filiculoides	25	List of IAP	Free floating
Cabomba caroliniana	7	List of IAP	Submerged
Egeria densa	12	List of IAP	Submerged
Elodea nuttallii	20	List of IAP	Submerged
Lagarosiphon major	13	List of IAP	Submerged
Myriophyllum aquaticum	15	List of IAP	(sub)/emerged, floating leaved
Crassula helmsii	16	A 2	Sub/emerged
Eichhornia crassipes	10	A 2	Free floating
Hydrocotyle ranunculoides	9	A 2	Emerged, floating leaved
Ludwigia grandiflora	9	A 2	(sub)/emerged, floating leaved
Ludwigia peploides	6	A 2	(sub)/emerged, floating leaved
Alternanthera philoxeroides	3	Alert List	Sub/emerged
Gymnocoronis spilanthoides	1	Alert List	Sub/emerged
Hydrilla verticillata	6	Alert List	Submerged
Hygrophila polysperma	2	Alert List	Sub/emerged
Myriophyllum heterophyllum	5	Alert List	Submerged
Pistia stratiotes	11	Alert List	Free floating
Salvinia adnata	4	Alert List	Free floating

EPPO, European and Mediterranean Plant Protection Organization.

obs.). Surprisingly, in addition to the two widely known alien aquatic plant species of this family, *Pistia stratiotes* and *Orontium aquaticum*, only one species in the genus *Cryptocoryne*, *C. crispatula*, has been found as an alien in European waters, but which is restricted to the thermal water of the Villach Warmbad in Austria (Essl & Rabitsch, 2002) (Table 1). Similarly, there are no records of other common aquarium plants in the field, like plants from the tropical genus *Echinodorus* (Alismataceae; > 50 species in trade) or *Aponogeton* (Aponogetonaceae; 14 species in trade), except *Aponogeton distachyos*. In general, the establishment of frost-sensitive tropical species seems to be limited to a few European waters that have abnormal temperature regimes. In such warm waters, different alien aquatic plants became established outside of their potential alien range, like *Shinnersia rivularis*, *Hygrophila polysperma* and *P. stratiotes* (Hussner & Lösch, 2005; Sajna *et al*., 2007; Gabka & Owsianny, 2009; Mesterházy *et al*., 2009).

Prohibiting the import and sale of potentially invasive aquatic weed species seems to be the major option to prevent further introduction of invasive aquatic plant species. Such trading bans have to be based on PRA of invasive and potentially invasive aquatic plant species, like the Aquatic Weed Risk Assessment Model (AWRAM), which has been established in New Zealand and Australia to guide the management of aquatic weeds (Champion *et al*., 2010). The establishment of such a model, which scores plant characteristics like habitat versatility, competitive ability, reproductive output, dispersal mechanisms, as well as the range of potential impacts (Champion *et al*., 2010), should be given high priority in the future. To summarise, in general, the prevention of introduction of potentially invasive aquatic plants is easier, and of course cheaper, than control following invasion and establishment.

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