Hydrobiologia (2010) 656:167–172
DOI 10.1007/s10750-010-0446-x

AQUATIC WEEDS

Review Paper

Nipping aquatic plant invasions in the bud: weed risk assessment and the trade

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Published online: 4 September 2010

Abstract The importation and sale of ornamental pond and aquarium plants is the most important pathway for the introduction of potential aquatic weeds into and subsequent spread of these within a country. Most current aquatic weeds were at one time deliberately imported for ornamental use. This article discusses a weed risk assessment approach to evaluating new potential weeds. It assesses the potential invasiveness of an aquatic plant based on its habitat versatility, competitive ability, reproductive output and dispersal mechanisms, range of potential impacts, potential distribution and resistance to management activities. The Aquatic Weed Risk Assessment Model (AWRAM) has been used to evaluate potential aquatic weeds in New Zealand, Australia and the USA. A similar approach could be used to guide the management of aquatic weeds in Europe. Banning the importation of highly ranked species effectively keeps biosecurity risks off-shore. Assessment of aquatic plant trade patterns, especially volumes of high-risk species, along with knowledge of current and potential distribution of those species and ease of management, are all factors to be considered when evaluating candidate plants for prevention of sale and distribution. This is a highly effective way of restricting both long-distance dispersal and density of propagules. A cooperative approach involving researchers, policy and trade representatives has been an effective way to achieve regulation of this risk pathway. European initiatives to prevent the distribution of potential aquatic weeds include the preparation of lists of known invasive aquatic species by the European and Mediterranean Plant Protection Organization (EPPO), with recommendations to member countries to consider measures to prevent their spread (e.g. banning importation of, banning sale and distribution of, and undertaking control programmes against those species). Belgian initiatives include an upcoming Royal Decree concerning the importation, exportation and possession of non-native invasive species, development of codes of conduct with the horticultural sector and prohibiting the sale, purchase and intentional release of these species in the wild. This article reviews these approaches and discusses other species of concern.

Keywords Biosecurity · Ornamental aquarium & pond plant trade · Proactive management · Ban from sale

Guest editors: A. Pieterse, S. Hellsten, J. Newman, J. Caffrey, F. Ecke, T. Ferreira, B. Gopal, J. Haury, G. Janauer, T. Kairesalo, A. Kanninen, K. Karttunen, J. Sarvala, K. Szoszkiewicz, H. Toivonen, L. Triest, P. Uotila, N. Willby / Aquatic Invasions and Relation to Environmental Changes: Proceedings of the 12th International Symposium on Aquatic Weeds, European Weed Research Society

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The ornamental aquatic plant trade

The ornamental pond and aquarium trade of plants is a major pathway for the distribution of aquatic plants globally. For example, over 400 species of freshwater aquatic plants have been legally traded in Australia over the last 30 years (Petroeschevsky & Champion, 2008). In Europe the Danish company Tropica produces over 2,000,000 plants for sale each year. Brunel (2009) obtained data for 10 EPPO countries that import aquatic plants and found the biggest importing countries were the Netherlands, France, the Czech Republic and Germany. Plants were mostly imported from South East Asia, including Singapore, Indonesia, Thailand and Malaysia, with other specific plants imported from their country of origin (e.g. *Aponogeton* spp. from Madagascar). In total 206 species were imported that are not known to be naturalised in Europe, with a further 41 species already established in the wild within Europe. Brunel (2009) estimated an annual importation of over 7,000,000 plants, with nearly 2,000,000 of these being one species, *Egeria densa* Planch. Other imported species >50,000 plants include (in decreasing order of magnitude) *Cabomba caroliniana* A. Gray, *Hygrophila polysperma* (Roxb.) T. Anderson, *Vallisneria spiralis* L., *Echinodorus bleheri* Rataj, *V. americana* Michx., *Najas marina* L. and *H. difformis* (L. f.) Blume. Additionally, a large range of aquatic plants are cultivated in Europe, including *Eichhornia crassipes* (Mart.) Solms, *Myriophyllum aquaticum* (Vell.) Verdc. and *Houttuynia cordata* Thunb. (Moerings, 2009).

Pathways for aquatic weed distribution

Of the species mentioned in the previous section, all except *E. bleheri* and Madagascar *Aponogeton* spp. are regarded as weedy and have naturalised outside of their indigenous range. *V. spiralis* and *N. marina* are indigenous to Europe, although *V. spiralis* is also naturalised in some European countries (Flora Europaea online, 2009). Several of those species are naturalised in Europe, with *E. densa* and *M. aquaticum* being widespread, whereas *C. caroliniana* is restricted to several northern countries and *E. crassipes* to southern Europe. The remaining species are naturalised elsewhere (Champion & Clayton, 2001).

The contribution of the aquatic plants trade to the introduction and spread of aquatic weeds is significant. An estimated 75% of naturalised aquatic species in New Zealand were imported through the trade (Champion & Clayton, 2000), with similar figures for New England (Les & Mehrhoff, 1999) and Australia (Petroeschevsky & Champion, 2008). Only 3 of the 30 aquatic species managed under legislation in New Zealand were not imported through the trade (Champion & Clayton, 2000). Other pathways of entry include deliberate introduction for medicinal or culinary purposes (e.g. *Acorus calamus* L. and *Ipomoea aquatica* Forsk., respectively) and contamination of other ornamental plants (e.g. *Nymphoides peltata* (S. Gmel.) Kuntze introduced into New Zealand as a contaminant of water lily (*Nymphaea* cultivars) rhizomes) (Champion & Clayton, 2000).

Additional risks arise from the aquatic plants trade because, unlike other ornamental plant industries, a significant amount of aquatic plant material is collected from the wild (Petroeschevsky & Champion, 2008). Maki & Galatowitsch (2004) ordered plants from around the USA and found 93% of 40 orders contained contaminant additional plants, animals, fungi, or algae. Ten percent of the orders included other plants classified as alien invasive species. Similarly Brunel (2009) found illegitimate names, spelling mistakes and mislabelling of imported plants in her study.

The aquatic weed risk assessment model (AWRAM)

Champion & Clayton (2000) developed a weed risk assessment model specifically for aquatic plants (AWRAM). This model scores characters such as habitat versatility, competitive ability, reproductive output, dispersal mechanisms, range of potential impacts, potential distribution and resistance to management activities. The resulting score can be used to allow comparison of the weed potential of that plant with others and, from this comparison, determine if the species requires management action. The theoretical maximum score is 100, although the highest scoring species to date is *Phragmites australis* (Cav.) Trin. ex Steud. This is an alien invasive species in New Zealand that scored 75 on the AWRAM scale. This model has been used in New

Zealand, Australia and Indiana (USA) as part of a decision support system for managing the importation and/or sale of aquatic plants (Champion et al., 2007; Petroeschevsky & Champion, 2008). Species scoring >50 are managed either by banning sale or by statutory control, with the top ranked 5 species targeted for eradication in central government funded programmes. A total of 36 species are either banned from entry or sale in New Zealand (Ministry of Agriculture and Forestry Biosecurity New Zealand, 2009). Petroeschevsky & Champion (2008) recommended that 25 aquatic plants be banned from the aquarium/pond plant trade in Australia, with a further 21 species requiring further evaluation. In both New Zealand and Australia, representatives from the ornamental nursery trade have been involved in the decision-making process for banning those species.

Preventing sale and distribution of high-risk aquatic plants

AWRAM can be used to predict the weed potential of an aquatic plant species, but management by stopping the legal distribution of the highly ranked potential weed species is not always appropriate. If a plant was already abundant and widely distributed in cultivation (or widely naturalised) throughout a country, then prevention of further spread by banning sale and distribution would achieve little in the management of the species. Likewise, if a plant has little or no appeal as an ornamental plant and is not widely grown as such, then its inclusion on any banned list would provide little management value. The volume of trade (or importation) of a species is a good indicator of the propagule pressure and introduction effort likely to result (Reaser et al., 2008; Simberloff, 2009).

The lower the incidence of a potential weed species within a country, the greater the potential gain from prevention of further spread (stopping sale, distribution and propagation) and active control. Perhaps the greatest effectiveness would be preventing the distribution of species that had yet to naturalise or were only known from a few naturalised sites. Distribution of plants through deliberate spread increases the potential for long-distance dispersal of founding populations. Thus, there are still benefits in preventing sale, distribution and propagation provided that that taxon is not fully dispersed within its potential naturalised range.

Control or eradication of alien invasive aquatic plants is dependent on several factors including ease of detection, ease of access to the plant, available control/eradication techniques and acceptability of control methods to the general public. The more difficult control of established populations of a plant is, the higher the priority to stop a species establishing and, therefore, inclusion on a banned list would be beneficial. However, once widely established, this benefit would significantly decrease.

What species to manage in Europe?

EPPO list the following aquatic plants for member countries to consider measures to prevent their spread (Table 1).

Based on the AWRAM scores, all but *P. stratiotes* score >50. The latter species is more tropical in distribution than other free-floating species such as *E. crassipes* and *S. molesta*, with an invasive range throughout the tropics and including the Canary Islands in Europe. It is unlikely to be weedy in mainland Europe under current climatic conditions.

To date, only Belgium appears to be progressing with management initiatives from EPPO recommendations. These include an upcoming Royal Decree concerning the importation, exportation and possession of non-native invasive species, development of codes of conduct with the horticultural sector and prohibiting the sale, purchase and intentional release of these species in the wild. Aquatic weed species included on the Belgian black, watch and alert lists are *C. helmsii*, *E. densa*, *Elodea* spp., *H. ranunculoides*, *L. major*, *L. grandiflora*, *L. peploides*, *M. aquaticum*, *M. heterophyllum*, *A. filiculoides*, *Lemna minuta* Kunth., *C. caroliniana* and *H. verticillata* (E. Branquart, Belgian Biodiversity Platform/Centre de Recherche de la Nature, des Forêts et du Bois (CRNFB), unpublished data). The list will be used to derive legislation tools and codes of conduct with the horticultural sector. The preparation of codes of conduct will start in early 2010 with sector representatives but preliminary contacts have already been made with some plant producers.

Table 1 Aquatic alien invasive plants listed by the European and Mediterranean Plant Protection Organization (EPPO, 2009)

Species/EPPO Classification	Naturalised distribution in Europe	AWRAM score
Quarantine pest A2		
Crassula helmsii (Kirk) Cockayne	Belgium, Denmark, France, Germany, Netherlands, United Kingdom	51
Eichhornia crassipes (Mart.) Solms	Portugal and Spain, transient in United Kingdom, Belgium, the Netherlands, probably in France	67
Hydrocotyle ranunculoides L.f.	Belgium, France, Italy, the Netherlands, Portugal, Spain, United Kingdom	63
Alert pest		
Alternanthera philoxeroides (Mart.) Griseb.	France, Italy	63
Hydrilla verticillata (L.f.) Royle	Ireland, Latvia, Lithuania, Poland, Russia	74
Myriophyllum heterophyllum Michx.	Austria, Germany, Spain	68
Pistia stratiotes L.	Canary Islands	42
Salvinia molesta D. S. Mitchell	Italy, Portugal	57
Other priority species		
Azolla filiculoides Lam.	Widespread	54
Cabomba caroliniana A. Gray	Belgium, Hungary, the Netherlands, United Kingdom	51
Egeria densa Planch.	Widespread	64
Elodea nuttallii (Planch.) H. St. John	Widespread	50
Lagarosiphon major (Ridley) Moss	Austria, France, Germany, Italy, Portugal, Spain, Switzerland, Ireland, United Kingdom	60
Ludwigia peploides (Kunth) P.H. Raven & *L. grandiflora* (Michx.) Greuter & Burdet	Belgium, Italy, France, the Netherlands, Spain, Switzerland, United Kingdom, Ireland	52
Myriophyllum aquaticum (Vell.) Verdc.	Widespread	56

EPPO list these as quarantine A2, alert list or other priority species. Their naturalised distribution in European countries and aquatic weed risk assessment (AWRAM) score, based on New Zealand criteria, are also presented

Other aquatic plant species of concern that are commonly traded internationally, based on New Zealand and Australian weed risk assessment exercises, include *Gymnocoronis spilanthoides* (D. Don ex Hook. & Arn.) DC., *Limnobium* spp., *Heteranthera reniformis* Ruiz & Pav., *Sagittaria platyphylla* (Engelm.) J.G. Sm., *S. latifolia* Willd., *S. montevidensis* Cham. & Schltdl., *V. americana, Nymphaea mexicana* Zucc., *Nymphoides geminata* (R. Br.) Kuntze and *Hydrocleys nymphoides* (Humb. & Bonpl. ex Willd.) Buchenau (Champion & Clayton, 2000; Petroeschevsky & Champion, 2008).

The current focus of aquatic weed management in Europe is on species that are already naturalised there. A more proactive approach would be:

- To identify species that have a weed history in other countries with similar climates (e.g. Randall, 2002).
- Survey aquatic plants traded in Europe, identifying those with a weed history elsewhere and, if possible, ascertain the volumes of each species distributed.
- Undertake a weed risk assessment of the potential invasive species.

This approach would potentially allow management of aquatic weeds before they have naturalised.

Acknowledgments We would like to thank New Zealand Foundation for Research, Science and Technology, Department of Conservation and MAF Biosecurity New Zealand, and the Australian 'Defeating the Weed Menace' programme for

providing funding for this research. We also thank Sarah Brunel (EPPO) and Etienne Branquart (CRNFB) for providing unpublished information to assist with this article.

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Author Biographies

Paul Champion is a Principal Scientist at the National Institute of Water and Atmospheric Research (NIWA) in Hamilton, New Zealand, where he has been a part of the aquatic plant management research team since 1988, with over 25 years' experience in the field of plant ecology. His current research mostly concerns proactive management strategies for aquatic weeds including evaluating and managing introduction pathways both internationally and internally, working in conjunction with government policy and management agencies. Other research includes optimising surveillance programmes and incursion response to new invasions. He is a graduate of the University of Leicester, UK (B.Sc. Hons.) and University of Waikato, New Zealand (M.Sc.).

John Clayton is a Principal Scientist and group leader of the aquatic plant management research team at NIWA. He has nearly 40 years' experience researching lake ecology and has been instrumental in raising the awareness of the threats posed by aquatic weeds in New Zealand, and also the development of tools and strategies for their management, especially the use of aquatic herbicides. He has also developed a tool utilising submerged plants as ecological indicators of lake condition. He is an internationally recognised expert in the field of aquatic weed ecology and management, working collaboratively with researchers in the USA and Europe and has served on the Editorial Board of *Aquatic Botany* for 28 years. He is a graduate of Auckland University, New Zealand with a Ph.D. in Botany.

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