

Review

A risk assessment based proactive management strategy for aquatic weeds in New Zealand

Paul D. Champion*, Mary D. de Winton and John S. Clayton

National Institute of Water & Atmospheric Research (NIWA), PO Box 11-115, Hamilton, New Zealand

E-mail: paul.champion@niwa.co.nz (PDC), mary.dewinton@niwa.co.nz (MDV), john.clayton@niwa.co.nz (JSC)

*Corresponding author

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Abstract

Aquatic weeds are notoriously difficult to manage once established. This paper discusses a range of proactive management actions undertaken by regulatory authorities based on the assessment of risk posed by those organisms using the Aquatic Weed Risk Assessment Model (AWRAM). AWRAM scores potential risk characters such as habitat range, ability to displace other species, seed and vegetative propagule output, dispersal mechanisms, potential economic and environmental impacts, potential distribution and ease of control. Species with the largest sum of risk character scores are regarded as the worst potential aquatic weeds and AWRAM provides a decision support tool for management agencies. Management actions include prevention of deliberate introduction into New Zealand and subsequent spread within that country, as well as eradication programs targeting high-impact, low-incidence aquatic weeds species. Progress to date has been the exclusion from sale and distribution of 29 potential aquatic weeds and the ban from importation of a further 10 species. Current regulations have effectively ceased legal importation of aquatic plants into New Zealand, but evidence of illegal importation provides concern. Six freshwater weeds have been eradicated nationally and central and regional government agencies have initiated eradication programs for a further 13 aquatic weeds, with additional species managed in this way at a regional or island level. These proactive management activities are effective methods to achieve elimination or reduction of both propagule and colonization pressure of high-risk aquatic weeds, thereby reducing the likelihood of those species becoming widespread problems in the future.

Key words: invasive alien freshwater plants, aquatic weed risk assessment, management strategies, eradication

Introduction

New Zealand is geographically isolated, with the nearest large land mass (Australia) being approximately 1500 km away. Such isolation means the unaided (non-human mediated) introduction of freshwater plants from other countries is unlikely, requiring the plant to be taken from a freshwater habitat in the donor country, survive a long journey out of water and establish in a new freshwater habitat within New Zealand (Closs et al. 2004). Nevertheless, strong evidence exists for natural introductions over geological timeframes. Migratory waterfowl seem responsible for introducing most of the 61 freshwater taxa (66% of the indigenous freshwater flora) that are native to both New Zealand and

Australia, with some additional wind-dispersed species such as *Typha orientalis* C. Presl. likely to have been introduced via the prevailing westerly winds (Champion and Clayton 2000). In a similar way Chatham Island (800 km east of New Zealand) has a species subset comprising 32% of New Zealand's freshwater flora (Champion and Clayton 2004). Although the rate of natural introduction to New Zealand is slow, with few naturally dispersed aquatic species reported since the botanical characterization of the New Zealand flora began over 200 years ago, there are occasional Australian species that have established within the past few decades e.g. *Gratiola pedunculata* R.Br. and *Utricularia gibba* L. (de Lange 1997; Salmon 2001). In both cases migratory waterfowl are implicated as vectors of seed introduction leading to their colonization of New Zealand.

A further 68 aquatic plant species are considered non-native and naturalized in New Zealand having been introduced by human activity. Many of these species are only represented by a single sex or do not produce seed in New Zealand, whereas others have seed poorly adapted for bird/wind dispersal. They are thus unlikely to have dispersed to New Zealand naturally. The majority of these species have naturalized within the last century, illustrating the acceleration of human mediated species establishment compared with natural introduction rate. Seventy five percent of these species were imported as ornamental pond and aquarium plants (Champion and Clayton 2000), with similar proportions of naturalized aquatic plants originating from pond and aquarium plants reported in other countries (Les and Mehrhoff 1999; Petroschevsky and Champion 2008). Many of the species introduced to New Zealand have become major invaders with 30 of the 68 species being subject to some management activities under New Zealand legislation. Nineteen of these species are currently restricted to less than 10 field sites in New Zealand with most <1 ha in extent (Champion et al. 2013).

This paper discusses the prediction of potential impact resulting from the introduction of aquatic plant species, and various proactive management strategies to prevent the further introduction, spread and establishment of species predicted to become high-impact weeds in New Zealand.

Aquatic weed risk assessment

The Aquatic Weed Risk Assessment Model (AWRAM) (Champion and Clayton 2000; 2001a) was developed because existing, predominantly terrestrial based, models used to assess weed risk (e.g. Pheloung et al. 1999) did not adequately separate the impacts of major aquatic weeds. For example, application of the model of (Pheloung et al. 1999) to aquatic plants in New Zealand resulted in similar levels of assessed risk for the submerged Hydrocharitacean weeds *Elodea canadensis* Michx., *Lagarosiphon major* (Ridley) Moss, *Egeria densa* Planch. and *Hydrilla verticillata* (L.f.) Royle and almost all aquatic plants assessed by that model were likely to be classed as potential weeds. Gordon and Gantz (2011) independently assessed the performance of the Pheloung et al. (1999) model on aquatic plants and confirmed that this model weights all major invasive aquatic plants heavily toward the conclusion of invasiveness, but it also categorized 83% of the non-invaders as would-be invaders.

AWRAM was designed to better reflect differences in the perceived risk and relative management importance of aquatic plant species (Champion and Clayton 2000; 2001a). AWRAM allocates scores to characters such as range of habitat, ability to displace other species, seed and vegetative propagule output, dispersal mechanisms, potential economic and environmental impacts, potential distribution and ease of control. Not all species had sufficient information in the literature to confidently assess their potential risk. Likewise, other species lacked field performance data in New Zealand. For those species only recently reported as naturalized or those that were present in New Zealand but had yet to naturalize, an experimental evaluation of competitive ability was undertaken (Champion et al. 2007; Burnett et al. 2007) to further inform the assessment.

The maximum theoretical AWRAM score would be 100, however the highest ranked New Zealand species was *Phragmites australis* (Cav.) Steud. (75). Figure 1 outlines the assessment system with a worked example for *Alternanthera philoxeroides* (Mart.) Griseb. This species ranks highly for biological success attributes such as wide habitat versatility, competitive and clonal ability and also for weed impact attributes such as obstruction of water uses, effects on natural and productive systems, lack of effective long-term control and recognition of these impacts in other temperate countries. *A. philoxeroides* has a total AWRAM score of 63, the 9th highest ranked species in New Zealand. Rankings for other aquatic plant species of concern to New Zealand are shown in Table 1.

Gordon et al. (2012) tested AWRAM for potential application in the USA using 130 plant species variously assigned as major, minor or non-invaders. Their literature search found sufficient information to apply the model to all but three of those species. They found that major invaders were distinguished from minor and non-invaders with 91% accuracy, while major invaders and non-invaders were correctly predicted as such 85% and 98% of the time respectively. These studies have shown that AWRAM can be used to accurately separate potential aquatic weeds from those species unlikely to cause unwanted impact and this model has been applied to assess aquatic weeds in Australia (Petroschevsky and Champion 2008), Micronesia (Portland State University 2011) and has potential to be applied in Europe (Champion et al. 2010; Hussner 2012).

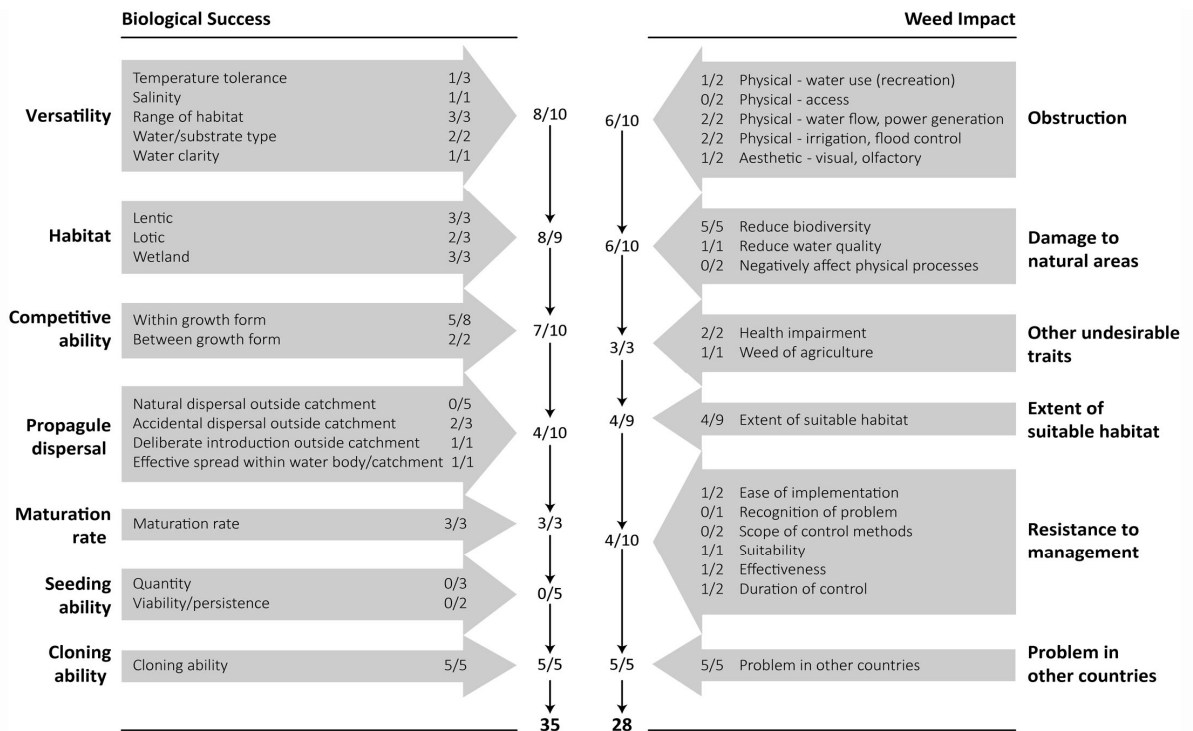


Figure 1. Example using the Aquatic Weed Risk Assessment Model (AWRAM) to evaluate *Alternanthera philoxeroides*, showing derived attribute scores giving an overall AWRAM score of 63.

Management of aquatic weeds in New Zealand

AWRAM has been used to support management agencies and policy development in New Zealand as discussed in the following sections and summarized in Figure 2.

Importation of aquatic plants

Two pieces of legislation are of relevance to the importation of aquatic plants into New Zealand. The Biosecurity Act (1993) provides legislative support for the management of any organism capable of forming a self-sustaining population with the potential to cause adverse effects on environmental, economic or social values. Based on assessments using AWRAM, a number of high-risk aquatic plants not known to be present within New Zealand, or species that were thought to have been eradicated from New Zealand have been declared Notifiable Organisms (Table 1), under the Biosecurity (Notifiable Organisms) Order (2010). The Biosecurity Act requires that any person who believes that a notifiable organism is present must report this to the relevant

authority, the Ministry for Primary Industries (MPI). Failure to do so is an offence under the Act. A black list has been established using AWRAM which identifies those species that may not be imported into New Zealand without permission from MPI (Table 1). The Biosecurity Act also specifies import quarantine regulations (Import Health Standards IHS) to ensure no hitchhiker or disease organisms are imported along with nursery stock or seeds for sowing. Additionally, the Hazardous Substances and New Organisms Act (1996) requires that the potential importer of any organism not known to be present in New Zealand makes an application to the New Zealand Environmental Protection Authority (EPA) outlining the potential effects of the species on the environment, human health, society, Māori culture and traditions, and the market economy. With this information EPA will perform an independent risk assessment. Costs for the provision of information and EPA assessment are borne by the proposed importer. No aquatic plants have been assessed for importation in the past two decades and very few terrestrial plants have been assessed or approved by this process (Williams et

Table 1. Problem aquatic plant species present or managed under the Biosecurity Act (1993) in New Zealand, showing their Weed Risk Assessment Score (AWRAM) and management status (NPPA – National Pest Plant Accord, NIPR – National Interest Pest Response, RPMP – Regional Pest Management Plan).

Species	AWRAM score	Current/ previous status in New Zealand	NPPA	Notifiable (NO) or unwanted organism (UO)	Statutory management in New Zealand
<i>Phragmites australis</i> (Cav.) Steudel	75	naturalized	yes	NO	NIPR, managed for eradication nationally
<i>Hydrilla verticillata</i> L.f.	74	naturalized	yes	NO	NIPR, managed for eradication nationally
<i>Zizania latifolia</i> (Griseb.) Stapf	68	naturalized	yes	NO	NIPR, managed for national (eradication outside of core infestation area)
<i>Myriophyllum spicatum</i> L.	73	not present	no	NO	Entry prohibited
<i>Ceratophyllum demersum</i> L.	67	naturalized	yes	UO	NIPR, South Island only – eradicated there
<i>Eichhornia crassipes</i> (Mart.) Solms-Laub.	67	naturalized	yes	NO	NIPR, managed for eradication nationally
<i>Egeria densa</i> Planch.	64	naturalized	yes	UO	RPMP, managed for eradication in some South Island regions
<i>Ludwigia peruviana</i> (L.) H. Hara	64	not present	no	NO	Entry prohibited
<i>Alternanthera philoxeroides</i> (Mart.) Griseb.	63	naturalized	yes	UO	RPMP, managed for eradication in some regions
<i>Trapa natans</i> L.	63	not present	no	NO	Entry prohibited
<i>Lagarosiphon major</i> (Ridley) Moss ex Wager	60	naturalized	yes	UO	RPMP, managed for eradication in one region
<i>Nymphoides peltata</i> (Gmel.) Kuntze	58	not naturalized	yes	UO	Eradicated
<i>Typha latifolia</i> L.	58	not naturalized	yes	NO	Eradicated
<i>Gymnocoronis spilanthoides</i> (D. Don) DC.	57	naturalized	yes	UO	RPMP, managed for eradication in all regions
<i>Salvinia molesta</i> Mitchell	57	naturalized	yes	NO	NIPR, managed for eradication nationally
<i>Najas marina</i> L.	57	not present	no	NO	Entry prohibited
<i>Myriophyllum aquaticum</i> (Vell. Conc.) Verdc.	56	naturalized	yes	UO	RPMP, managed for eradication in South Island
<i>Typha domingensis</i> Pers.	56	not present	no	NO	Entry prohibited
<i>Potamogeton perfoliatus</i> L.	55	not naturalized	yes	NO	Eradicated
<i>Utricularia gibba</i> Lam.	54	naturalized/indigenous	yes	UO	No management
<i>Lythrum salicaria</i> L.	54	naturalized	yes	UO	RPMP, managed for eradication nationally
<i>Najas guadalupensis</i> (Spreng.) Magnus	54	not present	no	NO	Entry prohibited
<i>Azolla pinnata</i> R.Br.	54	naturalized	no	NO	No management
<i>Sagittaria sagittifolia</i> A. Rich.	53	naturalized	yes	NO	RPMP, managed for eradication nationally
<i>Sagittaria platyphylla</i> (Engelm.) Smith	52	naturalized	yes	UO	RPMP, managed for eradication nationally
<i>Iris pseudacorus</i> L.	52	naturalized	yes	UO	RPMP, managed for eradication in some regions
<i>Vallisneria australis</i> S.W.L.Jacobs & Les	51	naturalized	yes	UO	RPMP, managed for eradication in some regions
<i>Ludwigia peploides</i> (Kunth) Raven	51	naturalized	yes	UO	No management
<i>Glyceria maxima</i> (Hartman) Holmb.	51	naturalized	no	UO	RPMP, managed for eradication in one region
<i>Nymphaea mexicana</i> Zucc.	47	naturalized	yes	UO	No management
<i>Sagittaria montevidensis</i> Cham. & Schlecht	46	naturalized	yes	NO	RPMP, managed for eradication nationally
<i>Schoenoplectus californicus</i> (C.A. May) Palla	46	naturalized	yes	UO	RPMP, managed for eradication in one region
<i>Nymphoides geminata</i> (R. Br.) Kuntze	46	naturalized	yes	UO	RPMP, managed for eradication nationally
<i>Elodea canadensis</i> Michx.	46	naturalized	no	NO	No management
<i>Hydrocleys nymphoides</i> (Humb. et Bonpl.) Buchneau	45	naturalized	yes	UO	RPMP, managed for eradication nationally
<i>Menyanthes trifoliata</i> Tournef.	45	not naturalized	yes	NO	Eradicated
<i>Zizania palustris</i> L.	45	naturalized	no	NO	Eradicated
<i>Nuphar lutea</i> (L.) Sibth. et Sm.	43	naturalized	yes	NO	RPMP, managed for eradication nationally
<i>Pistia stratiotes</i> L.	42	not naturalized	yes	NO	Eradicated
<i>Stratiotes aloides</i> L.	42	not present	no	NO	Entry prohibited
<i>Eleocharis dulcis</i> (Burm.f.) Trin. ex Hensch.	37	not naturalized	no	UO	No management

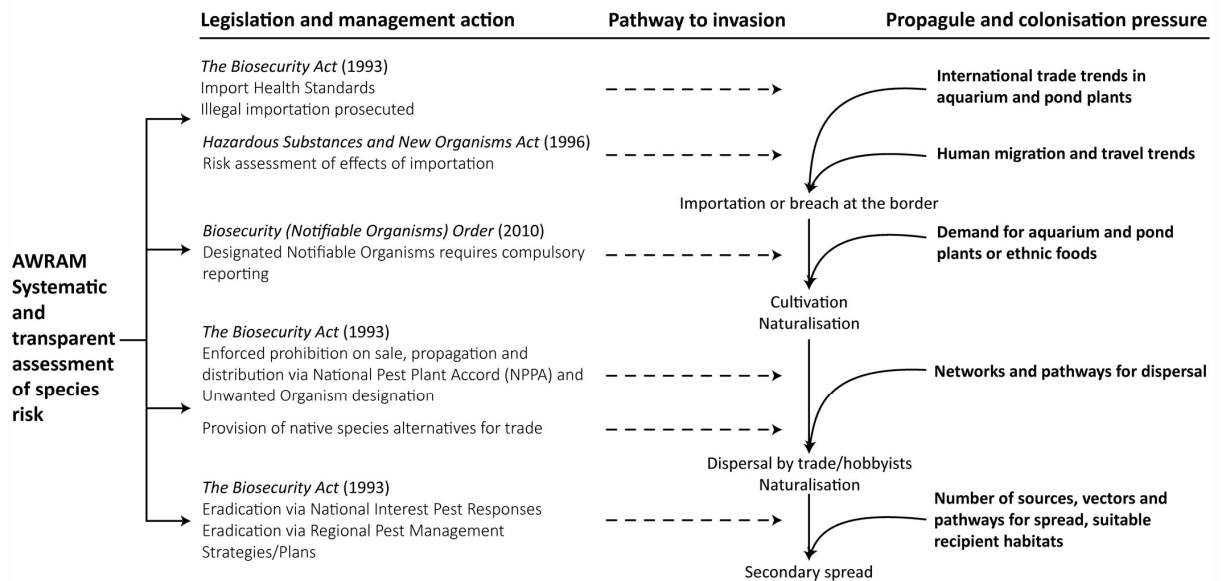


Figure 2. Overview of proactive management actions in New Zealand, identifying input from the Aquatic Weed Risk Assessment Model (AWRAM), the stage of the invasion process targeted and major drivers of the invasion process.

al. 2010; Auld 2012). As a consequence, the legal importation of new aquatic plants has been effectively halted by the financial constraints relating to this legislation.

Unfortunately, illegal importation apparently continues, with imported aquatic plants not being screened via relevant IHS with biosecurity risks posed both by the imported plants and any associated organisms (as documented by Keller and Lodge 2007; Duggan 2010). Champion and Clayton (2001b) found that 27% of aquatic plants available from aquarists and nurseries were unknown at the last census of species in the 1980s and were unlikely to have been legally imported. Since that time, a number of consignments of aquarium plants including species new to New Zealand including *Proserpinaca palustris* L., *Mayaca fluviatilis* Aubl. and *Aegagropila linnaei* Kützing have been intercepted at the International Mail Centre and two successful prosecutions under the Biosecurity Act have resulted. Additionally, a viable shoot of *H. verticillata* (one of the highest ranked species using AWRAM) was intercepted with an illegal shipment of cherry shrimps (*Neocaridina heteropoda* Liang).

The National Plant Pest Accord

The majority of New Zealand’s aquatic weeds were introduced as aquarium or ornamental pond

plants. MPI administer the National Pest Plant Accord (NPPA), a cooperative agreement between central government agencies, local government agencies and the Nursery and Garden Industry Association. This lists 135 species (or genera) legally prohibited from sale, propagation and distribution under provision of the Biosecurity Act including the 29 aquatic species listed in Table 1. All commercial nurseries, pet and aquarium shops are regularly inspected by officers warranted under the Biosecurity Act to ensure compliance.

The rationale for inclusion on the NPPA list is that plants of limited distribution within New Zealand that have major deleterious impacts and are difficult to control once established may be prevented from further distribution, where deliberate distribution by human activities would increase their potential range and level of impact (Champion 2005). NPPA plants are all declared as Unwanted Organisms under the Biosecurity Act making them amenable to statutory management programs by central or regional government agencies. Despite this, not all are necessarily subject to any other statutory control activities (four of the species in Table 1 are not controlled by any other means under the Biosecurity Act). The process used to determine these species is discussed in Newfield and Champion (2010) involving the use of weed risk

assessment models by a panel of experts as part of the evaluation process.

In addition to banning the sale of potential aquatic weeds, the identification of suitable native aquatic plants for tropical and cool temperature aquaria and provision of cultured native plants to aquarium hobbyists has provided alternatives to these problem species in New Zealand. So far, 17 species of native aquatic plants have been successfully cultivated and assessed by hobbyists. Growers found the most popular and desirable species were *Limosella lineata* Glück and *Myriophyllum robustum* Hook. f., the latter species a threatened endemic milfoil. Their suitability for New Zealand aquaria does not necessarily confer low risk in other countries, with two native species *Crassula helmsii* (Kirk) A. Berger and *Glossostigma cleistanthum* W.R. Barker already proving invasive in Europe and North America respectively (Hussner 2012; Les et al. 2006).

Eradication programs

Eradication is often used liberally as a management goal. In its strictest sense eradication of a weed can be defined as the complete extirpation of a population including all propagules, with the aim to carry this out nationally or for a statutorily defined territory e.g. regional council boundary.

Low incidence alien invasive aquatic weeds with high AWRAM scores have been targeted for eradication nationally under the provisions of the Biosecurity Act. Champion and Clayton (2003) reported the successful eradication of five species from all known field sites within New Zealand, with a further species *Typha latifolia* L. eradicated from the one known field site soon after its detection (Champion et al. 2007) (see Table 1). These eradications can be regarded as effective incursion responses, with none of the target species occupying more than three distinct populations with a total area of less than 1 ha.

In 2008 MPI initiated eleven species-led eradication programs termed National Interest Pest Responses (NIPR) for species with high potential impact, but current low incidence. These included the aquatic species *P. australis*, *H. verticillata*, *Zizania latifolia* (Griseb.) Stapf., *Ceratophyllum demersum* L., in addition to *Eichhornia crassipes* (Mart.) Solms and *Salvinia molesta* Mitchell which had been managed for eradication by MPI (previously Ministry of Agriculture and Forestry) for over 20 years (Champion and Clayton 2003). The first five

species are the highest AWRAM ranked species found in New Zealand, with *S. molesta* ranked 12th (Table 1).

These programs are well resourced and based on science-based management plans (e.g. Champion and Hofstra 2006). This ensures appropriate follow-up inspections are undertaken to detect regrowth/germination of plants within each field site and ensure no production of seed/propagules. *P. australis*, *H. verticillata*, *E. crassipes* and *S. molesta* are of limited distribution within New Zealand and are targeted for national eradication, whereas *C. demersum* is well established and widespread in the North Island of New Zealand, but only a few South Island populations have been recorded and *Z. latifolia* is targeted for eradication of all sites outside of a containment zone where it dominates over 50 km of a river in Northland.

In the case of *E. crassipes* and *S. molesta* programs run for a minimum of 20 years and 3 years respectively. *E. crassipes* produces viable seed in New Zealand, with viability of up to 15 years. Of the approximately 100 field populations of this plant 80% are considered eradicated. *S. molesta* is a sterile hybrid so the program is much shorter, but more intensive (Yamoah et al. 2013). In this case more than 170 populations have been eradicated with 51 populations supporting plants within the past two years (Yamoah et al. 2013). Continued discovery of new field populations of *E. crassipes* and *S. molesta* has occurred, presumably originating from plants maintained in cultivation (Champion and Clayton 2003; Yamoah et al. 2013).

Of the more recently initiated eradication programs, the most successful have been with the two submerged species. *C. demersum* eradication efforts are restricted to the South Island, with all sites declared eradicated in 2013. *H. verticillata* has been reduced to less than 1% of its former abundance in all known sites (Hofstra and Clayton 2014). In addition to central government control programs, each territorial authority (mostly known as regional councils) manage a range of pest species across New Zealand under Regional Pest Management Strategies/Plans (RPMP). Eight more aquatic weed species are managed for eradication at all known sites by local government agencies and therefore these are effectively additional national eradication programs.

A further eight species are targeted for eradication in at least one region (Table 1), but as they are well naturalized and widespread in

some areas of New Zealand national eradication of these species is unlikely to be attainable.

Discussion

The main rationale of these management activities is to prevent the introduction of potential weed species and prevent dispersal of the highest ranked weeds already present in New Zealand through prevention of deliberate spread (sale and distribution) and removal of source populations working towards national eradication. Many authors have related the success of invasive species predominantly to their introduction effort, using the term propagule pressure to describe the number and size of propagules of a species being introduced (Williamson 1996; Reaser et al. 2008; Simberloff 2009; Lockwood et al. 2009). Lockwood et al. (2009) also use the term colonization pressure, referring to increased likelihood of successful colonization based on the number of species being introduced via a specific pathway, e.g. contaminated ballast water. The aquatic plant trade distributes a large number of plant species and propagule numbers globally. In the case of aquatic plants and the geographic isolation of New Zealand, this pathway overcomes the transport issues requiring the movement of propagules from a freshwater source in the source country to freshwater habitat in the donor country. Reaser et al. (2008) discuss potential policies that could effectively manage (eliminate or minimize) the propagule pool, with Keller and Lodge (2007) suggesting three policy approaches that could be adopted with regard to the introduction of new invasive species through the trade. These were to allow all new species, ban all new species or evaluate introductions using a risk assessment approach. Currently the importation of new aquatic plants to New Zealand resembles the second situation, but Keller and Lodge (2007) regard this as undesirable because it severely and unnecessarily restricts trade. Additionally, this approach appears to have promoted illegal importation facilitating entry of unscreened species along with associated pathogens and hitchhiker species.

AWRAM has been used as a decision support tool to compile a black-list of aquatic plant species prevented from importation, to prevent the deliberate spread of high risk species through trading bans and also to prioritize eradication efforts. de Winton et al. (2009) documented the impact of removing the prohibited status for sale

and distribution of *Vallisneria spiralis* L. (now determined as *V. australis* S.W.L.Jacobs and Les) in 1993, whereas it was previously banned under older legislation (the Noxious Plants Act - 1978). Subsequently, a considerable number of naturalized sites were detected since 2000 representing deliberate plantings as culture sources for the aquarium and pond plant trade. In response, this species was included on the NPPA list in 2007. Although, illegal cultivation of at least some of these species still occurs (Champion and Clayton 2003; Yamoah et al. 2013), the number of propagules spread by illicit means would be far smaller than if trade were permitted.

The independent validation of AWRAM by Gordon et al. (2012) for use to screen imports of aquatic plants, to distinguish between non-invaders and harmful invaders and prioritize management efforts for established species, demonstrates the applicability of the model for application to the risks posed by potentially invasive aquatic plants in other countries. A modification of AWRAM was used for this purpose in Australia and Micronesia (Petroeschevsky and Champion 2008; Portland State University 2011). The approach used to develop AWRAM may provide a framework for assessment of other biological groups or pest risk to non-aquatic habitat types. Assessment of habitat requirement, competitive ability, reproductive output, dispersal mechanisms, potential economic and environmental impacts, potential distribution and ease of control are generic relevant characters to be considered when determining pest risk.

In conclusion, we consider proactive management measures facilitated by AWRAM have been greatly beneficial in the reduction of propagule pressure for potential aquatic weed species in New Zealand and thus reduces the likelihood of those species becoming widespread problems in the future. We advocate the use of similar risk assessment approaches to enable pro-active aquatic weed management in other countries.

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