Best Management Practice for Aquatic Weed Control

Part One: The Framework

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Executive summary

The Aquatic Weed Management Best Practice Guide was funded by an Envirolink Tools Grant (R12-1) with NIWA Strategic Science Investment Funding from the Freshwater Biosecurity Programme.

This report is Part One of this project, comprised of three tools: (1) Strategic analysis; (2) Incursion detection and (3) Aquatic weed control toolbox. A second report will provide details of 74 species including: distribution, current and potential distribution in New Zealand (maps), potential impacts, legal status and control options.

The Strategic analysis tool provides the context to decide which aquatic weed management option is appropriate. Despite the difficulties presented by the aquatic environment, there are opportunities to proactively manage aquatic weeds due to the reliance of humans as pathways of dispersal between catchments. Critical information needed to evaluate potential species-led or site-led aquatic weed management programmes involve an assessment of the characters of weed species (weed risk assessment), the current and potential distribution of that species (both within the region and neighbouring regions) and dispersal mechanisms (pathway assessment). Based on this evaluation a response can be proposed, incorporating prioritisation of the threats posed and the management goals. The management goals are informed by the National Policy Direction for Pest Management 2015, under the legal framework provided by the Biosecurity Act (1993). Each of the management goals is discussed with examples along with the decision not to manage a species. Currently, a total of 51 aquatic and wetland weeds are managed by at least one region, comprised of 12 species managed for exclusion, 32 for eradication, 13 for progressive containment, 10 for sustained control and 24 managed at a site-specific level. Generally, the prioritisation of resources should be made for proactive management, with exclusion and early detection, rapid response the most cost-effective management actions. A decision-support framework is provided to outline all the information required to design a Regional Pest Management Plan for aquatic and wetland weeds.

The Incursion detection tool details the management interventions that can be taken to prevent incursion of new aquatic weeds to a region, or specific sites (water bodies) within the region. This encompasses advocacy to prevent new species introduction, assessment of freshwater resource values for site-led management, surveillance strategies and management responses to newly detected weeds. Assessment of high-risk species yet to become naturalised within a region, likelihood of their introduction and potential introduction pathways, can be used for the preparation of an exclusion list and an active surveillance programme. The first step to protecting regional freshwater resources from the impact of invasive aquatic weeds is to identify aquatic systems and their relative value and status. Surveillance methods need to be tailored to the water body to maximise the chances of early detection in relation to effort spent. If an aquatic weed incursion is detected, a five-stage programme should be implemented comprising; delimitation, assessment of management options, containment, control and follow-up monitoring.

The Aquatic weed control toolbox focusses on operational tools, methods and approaches currently used in New Zealand. Control methods can be grouped into physical, chemical and biological categories or their combination in integrated control. Choice of appropriate control requires consideration of key factors such as the amount and extent of the weed and the utility of the control tool. Monitoring the effectiveness of weed control operations is used to inform progress towards goals and to adapt the approach or control methods being used to optimise the outcome and gauge how selective the control has been regarding damage to non-target organisms for compliance monitoring.

1 Introduction

Of the more than 70 aquatic plant species naturalised in New Zealand, more than 75% have become problem weeds or have been assessed as having the potential to become future problem weeds. Most of our lakes, rivers and streams are affected by at least one of these species (Champion et al. 2013). A conservative estimate of the current nationwide cost of their management was $27 M per annum in 2010. The threats and impacts of invasive aquatic weeds require management within a complex range of environments with utilisation of a variety of control methods. Management of aquatic pest plants is a core biosecurity function for regional councils and their key biosecurity partners. Additionally, these pests require management by other regional council groups to ensure efficient land drainage to protect agricultural and urban areas, and to protect and enhance aquatic biodiversity.

The need for a Best Management Practice for aquatic weeds fits strategically within both biosecurity and freshwater priority areas of the Regional Council RS&D strategy. Aquatic weeds are stressors to water resources, additional to water quality and quantity issues. Weeds severely impact water uses such as drainage, irrigation and power generation, and are likely to proliferate into the future, unless management interventions are taken.

Implementation of this project will accrue benefits from the co-ordinated adoption of best practice for aquatic weed management, also fulfilling the purpose of the National Policy Direction for Pest Management 2015 (NPDPM) (New Zealand Government 2015). In addition to better informed decision-making, including preventative and reactive management of aquatic weeds, these guidelines will ensure legal compliance. Failure to meet these requirements could prejudice future aquatic weed management, with loss of some tools within an already limited control toolbox. Financial benefits will accrue from increased efficiency and effectiveness of control (both in direct control costs and reduced costs resulting from poor control outcomes (e.g., increased flood damage, ineffective management of weed spread). A key component of the development of this Best Management Practice is the provision of feedback from regional council practitioners and managers as well as researchers into the framework. This feedback will ensure currency and allow ongoing maintenance of the framework after completion of this project, to enable continued improvement and effectiveness of aquatic weed management.

This project was funded by an Envirolink Tools Grant (R12-1) with additional NIWA Strategic Science Investment Funding (SSIF) as part of the Freshwater Biosecurity Programme.

1.1 National best practice guidance for aquatic weed management

The project provides a framework of best practice to support decision-making and management of aquatic weeds by regional councils in New Zealand. This report documents the framework which has three main components:

Tool 1: Strategic analysis.
Tool 2: Incursion detection.
Tool 3: Aquatic weed control toolbox.

A second report will provide the information that is specific to each target aquatic weed, including: distribution, potential impacts and methods of control.

This BMP tool provides an interpretation of the NPDPM (NZ Government 2015) to ensure that activities under Part 5 of the Biosecurity Act provide the best use of available resources for New Zealand's best interests and alignment of regional pest management plans. This will contribute to prevention, reduction, or elimination of the adverse effects of harmful organisms on economic wellbeing, the environment, human health, enjoyment of the natural environment, and the relationship between Māori, their culture, and their traditions and their ancestral lands, waters, sites, wāhi tapu, and taonga.

The Strategic analysis tool informs the rationale for aquatic weed control by providing an evaluation of desired outcomes from management. This tool explores why aquatic weeds differ from their terrestrial counterparts, the legislation facilitating their management. The rationale includes weed species risk assessment, distribution of that species both within a region and in neighbouring regions, and dispersal mechanisms. Based on this information a framework outlining the rationale for management options based on the NPDPM (also considering where no management is an appropriate choice) is presented and discussed.

The Incursion detection tool includes prioritisation of target species based on their proximity to the region and dispersal pathways, regional prioritisation of sites for surveillance based on assessment of high value sites and the use of modelling to characterise anthropogenic drivers of aquatic weed spread (e.g., proximity of population centres, nearest weed source, road networks, and hydrological connections). Additionally, this toolbox will include surveillance techniques and their strategic application, prioritisation of sites for surveillance within a water body or catchment and delimitation of weed incursions and strategies to improve their containment.

The Control toolbox will include details of methods for aquatic weed control (physical, mechanical, habitat manipulation, chemical and biological), recommended approaches for use (e.g., for herbicides: rate, additives, application technique) and identifying management goals (e.g., eradication, on-going maintenance control and spread prevention). Legislation affecting the use of control methods and legal constraints on their use (e.g., controls or conditions set under HSNO or RMA consents) are included in this component, along with environmental monitoring (effectiveness of control and off-target impacts).

2 Tool 1: Strategic analysis

2.1 Introduction

The Strategic analysis tool provides the context to decide which aquatic weed management option is appropriate. This tool explores why aquatic weeds differ from their terrestrial counterparts, the legislation facilitating their management and a framework outlining the rationale for management. The rationale includes weed species risk assessment, distribution of that species both within the region and neighbouring regions and dispersal mechanisms. Based on this information the setting of management goals are based on the National Policy Direction for Pest Management 2015.

2.2 Why aquatic weeds are different

The freshwater environment presents many challenges to aquatic plants. Living under water provides a range of stresses for aquatic plants as water contains low concentrations of both oxygen and especially carbon dioxide, essential for photosynthesis. Light availability is also a limiting factor, with suspended sediments and planktonic algae often intercepting light before it reaches submerged plants. As few plants are able to pollinate underwater, reproductive strategies include either getting their flowers to the water surface, such as having long filamentous stalks, waiting for drought conditions that expose plants that then trigger flowering or essentially remaining asexual. Dispersal to new freshwater islands across a sea of dry land is also problematic unless plants have adaptations to facilitate dispersal by water fowl or wind. However, such natural transfer of introduced aquatic weed species is uncommon, with dispersal of most problem weeds being reliant on human transfer between catchments (Champion et al. 2002).

Conversely, beneficial characters of freshwater include buffering temperature extremes, providing buoyancy reducing the need for structural tissue and of course being surrounded by unlimited supplies of water (Champion 2017).

Aquatic weeds are plants that are highly specialised to thrive in their environment and have managed to overcome the stresses and benefit from the factors that constrain the growth of terrestrial weeds; lack of extreme temperatures, limited need for structural tissues and effective asexual dispersal within their environment by fragmentation. Essentially, they are pre-selected for aquatic invasion. The best adapted aquatic weeds have the fastest growth rates of any plant species and rapidly colonise available habitats, being well renowned weeds globally (Holm et al. 2014).

The majority of aquatic weeds in New Zealand are also weedy elsewhere outside of their native range, with many commonly cultivated and traded as aquarium and ornamental pond plants internationally (Champion and Clayton 2000). However, some species are solely known to have naturalised and become weedy here in New Zealand e.g., marshwort (*Nymphoides montana*) (Clayton and Tanner 1985) and bogbean (*Menyanthes trifoliata*) (Webb et al. 1988).

Compared with terrestrial weeds, aquatic weeds are disproportionally represented on lists of species to be managed by regulations. For example, van Valkenberg (2018) reports that 40% of the species evaluated for pest potential in the European Union are aquatic plants. Five of the nine National Interest Pest Response species managed for eradication by the Ministry for Primary Industries (MPI) are also aquatic weeds.

The freshwater environment presents many challenges to the management of new weeds.

New Zealand's freshwaters are recognised as our national treasures, with the degradation of our freshwaters identified as the number one issue facing this country in a Colmar-Brunton poll commissioned by Fish and Game New Zealand (New Zealand Herald January 2, 2019). The range of freshwater stakeholders is unique. In addition to obstruction of water flow relating to primary production (water supply and drainage), freshwater weeds impact electricity generation, with many groups of recreational users also affected.

Freshwaters are integral to Māori culture and well-being and the impact of freshwater pests on cultural activities is ever increasing.

Detection and recognition of new weed incursions at an early stage of invasion (see Section 3, Tool 2) is problematic, especially in the case of submerged species. Additionally, there are constraints on the tools available for aquatic weed management relating to targeting submerged weeds within the connected aquatic medium, the acceptability of control methods to water body users and legislative constraints (Section 4, Tool 3).

Despite these challenges, there are opportunities to proactively manage aquatic weeds due to the reliance of humans as vectors for dispersal between catchments.

2.3 Legislation

The Biosecurity Act (1993) provides the legal framework for New Zealand management agencies to help keep harmful (invasive non-native) organisms out of New Zealand, respond to new incursions across the national border and manage established invasive species. The New Zealand government assigned accountability to the Ministry for Primary Industries (MPI) for the end-to-end management of the biosecurity system. MPI interact with other natural resource management agencies (e.g., Department of Conservation, Land Information New Zealand) to ensure nationally consistent biosecurity management. While MPI are charged with the responsibility for management of harmful organisms by preventing their entry into New Zealand, intercepting their importation and responding to newly established invasive species populations, much of the management of established invasive species is undertaken by 16 territorial authorities (mostly termed regional councils) managed under regional pest management plans.

Additional to the Biosecurity Act, the evaluation of invasive risk and permitting for importation of organisms not known to be present in New Zealand is the responsibility of the New Zealand Environmental Protection Authority (EPA), under the Hazardous Substances and New Organisms (HSNO) Act 1996.

2.3.1 The Biosecurity Act

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. There two designations of risk organisms relevant to their statutory management; notifiable and unwanted organisms.

Notifiable Organisms

The Biosecurity (Notifiable Organisms) Order 2016 (New Zealand Government 2016) was made under section 45(2) of the Biosecurity Act 1993. It lists a number of organisms that must be reported by anyone either finding them or suspecting their presence in risk goods. The list included five aquatic weeds, four of which are managed under the MPI NIPR programme (phragmites (*Phragmites* *australis*), Manchurian wild rice (*Zizania latifolia*), Salvinia (*Salvinia molesta*) and water hyacinth (*Eichhornia crassipes*)), the fifth species, water lettuce (*Pistia stratiotes*), is considered to be eradicated from New Zealand, previously included as a Class A Noxious Plant under the Noxious Plants Act 1978.

Unwanted Organisms

A number of aquatic plants are declared unwanted organisms by the Chief Technical Officers (CTO) of MPI, DOC and EPA and listed on the Unwanted Organisms Register (MPI 2019a). The CTO may declare any species as an Unwanted Organism under the Biosecurity Act (1993), Section 2 (1), which defines these as:

- Any organism that a CTO believes is capable or potentially capable of causing unwanted harm to any natural and physical resources or human health, and:
    - includes any new organism, if the Environmental Protection Authority (EPA) has declined to import that organism; and any organism specified in the Second Schedule of the HSNO Act 1996 (see Section 2.2.2 of this report)
    - but does not include any organism approved for importation under the HSNO Act 1996 unless the organism is an organism which has escaped from a containment facility and the CTO believes that the organism is capable or potentially capable of causing unwanted harm to any natural and physical resources or human health.

A total of 54 aquatic and wetland plants are listed on the Unwanted Organisms Register, with the apparent omission of the cord grasses (*Spartina alterniflora, S. anglica* and *S.* x*townsendii*), which are listed as unwanted organisms under several Regional Pest Management Plans (Section 2.2.3). The CTO of MPI has declared 16 aquatic or wetland species, including the most recent, fanwort (*Cabomba caroliniana*) in 2016. The CTO of DOC declared 37 species, with the CTO of EPA (then known as the Environmental Risk Management Authority) declaring Chinese water chestnut (*Eleocharis dulcis*) as an unwanted organism in 1996. This species is grown in New Zealand for its edible tubers but has never naturalised and is not considered further in this BMP.

Eleven of the unwanted organisms have never been confirmed as present in New Zealand. These species are marestail (*Hippuris vulgaris*), Peruvian water primrose (*Ludwigia peruviana*), Eurasian water milfoil (*Myriophyllum spicatum*), southern water nymph (*Najas guadalupensis*), spiny naiad (*Najas marina*), grass-leaved arrowhead (*Sagittaria graminea*), water spangles (*Salvinia minima*), branched bur-reed (*Sparganium erectum*), water soldier (*Stratiotes aloides*), water chestnut (*Trapa natans*) and narrow-leaved cat-tail (*Typha domingensis*). As these species are unknown from New Zealand, their management is not considered in this report. Formerly these species were declared as Notifiable Organisms (Champion et al. 2014) prior to the 2016 Biosecurity (Notifiable Organisms) Order.

The remaining 42 aquatic and wetland plants that are unwanted organisms are listed on the National Pest Plant Accord (MPI 2019b). The NPPA is a cooperative agreement between MPI, New Zealand Plant Producers Incorporated (NZPPI), unitary and regional councils and DOC. Species cannot be distributed or sold in New Zealand and all plant nursery and aquarium plant outlets are regularly inspected by unitary and regional council staff to ensure compliance. This prevention of sale has been a very effective tool to prevent the deliberate spread of these potential weeds to parts of New Zealand where they have yet to naturalise or become problematic, especially where dispersal is primarily human mediated (Champion et al. 2010). Champion and Clayton (2000) reported that 75 percent of current aquatic weeds declared as unwanted organisms were introduced through the aquatic plant trade.

Appendix A presents the legal status of aquatic weeds under the Biosecurity Act 1993, NPPA and inclusion in Department of Conservation consolidated list of environmental weeds (Howell 2008).

The designation of Unwanted Organism provides legislative support for the management of aquatic weeds under the Biosecurity Act. Most species managed under Regional Pest Management Plans and also MPI run NIPR and incursion response programmes have this status. In the case of some smaller scale incursion responses or site-led control, some species are not Unwanted Organism.

National Policy Direction for Pest Management

The National Policy Direction for Pest Management 2015 (NPDPM) (New Zealand Government 2015) outlines requirements for pest management plans (including aquatic weed management) run by central or regional government to ensure they meet the purpose of Part 5 of the Biosecurity Act 1993 (New Zealand Government 1993), which is to provide for the eradication or effective management of harmful organisms that are present in New Zealand.

The NPDPM states for each subject in a pest management plan or pathway management plan, the plan must contain one or more of the following programmes, and may not contain any other types of programmes:

- "Exclusion Programme" in which the intermediate outcome for the programme is to prevent the establishment of the subject, or an organism being spread by the subject, that is present in New Zealand but not yet established in an area.
- "Eradication Programme" (if applicable) in which the intermediate outcome for the programme is to reduce the infestation level of the subject, or an organism being spread by the subject, to zero levels in an area in the short to medium term.
- "Progressive Containment Programme" (if applicable) in which the intermediate outcome for the programme is to contain or reduce the geographic distribution of the subject, or an organism being spread by the subject, to an area over time.
- "Sustained Control Programme" (if applicable) in which the intermediate outcome for the programme is to provide for ongoing control of the subject, or an organism being spread by the subject, to reduce its impacts on values and spread to other properties.
- "Site-led Pest Programme" (if applicable) in which the intermediate outcome for the programme is that the subject, or an organism being spread by the subject, that is capable of causing damage to a place is excluded or eradicated from that place, or is contained, reduced, or controlled within the place to an extent that protects the values of that place.
- "Pathway Programme" in which the intermediate outcome for the programme is to reduce the spread of harmful organisms.

The NPDPM underpins this strategic toolbox and outlines the management options available to regional councils under their Regional Pest Management Plans.

Regional Pest Management Plans

A total of 51 aquatic and wetland weeds are managed by at least one region (see table in Appendix B). This is comprised of 12 species managed for regional exclusion, 32 for eradication, 13 for progressive containment, 10 for sustained control and 24 managed at specific sites within a region.

2.3.2 The Hazardous Substances and New Organisms Act

The Hazardous Substances and New Organisms Act (1996) (HSNO) (New Zealand Government 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. Once evaluated, a species is either permitted entry into New Zealand or it becomes an Unwanted Organism (Champion et al. 2007).

Since the inception of HSNO, no new to New Zealand freshwater or wetland plant has been assessed for importation. Consequently, the legal importation of new aquatic plants has been effectively halted. Unfortunately, illegal importation apparently continues, with imported aquatic plants not being screened via relevant Import Health Standards with biosecurity risks posed both by the imported plants and any associated organisms (Duggan 2010). A total of fifteen species of naturalised invertebrates are likely to have been imported through the aquarium trade in New Zealand (Champion 2018a). Champion and Clayton (2001) 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 such as *Proserpinaca palustris*, *Mayaca fluviatilis* and marimo balls (*Aegagropila linnaei*) have been intercepted at the International Mail Centre and two successful prosecutions under the Biosecurity Act have resulted. Additionally, a viable shoot of hydrilla (*Hydrilla verticillata*) (one of the highest ranked aquatic weeds, subject to a national eradication programme) was intercepted with an illegal aquarium shipment of cherry shrimps (*Neocaridina heteropoda*) (Champion et al. 2014).

Thus, the illegal importation of aquatic weeds currently not known to be present in New Zealand, poses an additional threat to that posed by the current suite of species that are present here. A horizon-scan (sensu Roy et al. 2016) approach is recommended. This involved the systematic examination of future potential threats and opportunities, leading to prioritization of overseas threats that were likely to impact on native biodiversity but were not yet established in the wild in Great Britain. This was achieved by preliminary consultation with experts to derive ranked lists of potential pests. In this case experts covering five groups (plants, terrestrial invertebrates, freshwater invertebrates, vertebrates and marine species) were used to rank each group and then consensus was reached covering all groups. A similar approach is used in New Zealand and MPI has 13 targeted programmes that focus on specific biosecurity risks. None of these surveillance programmes focus on pest plants or freshwater habitats.

NIWA was engaged by MPI to prepare a stocktake of freshwater surveillance and monitoring activities (Clayton et al. 2011) detailing over 40 potential activities that aligned with the requirements for a freshwater surveillance programme. Most of these activities were led by DOC and Fish & Game with a wide geographic representation. It was considered that, with some modification, a number of these activities could contribute towards a national freshwater biosecurity surveillance programme. Existing capacity within current surveillance and monitoring activities could be harnessed but would require resourcing and the support of ongoing capability in freshwater biosecurity knowledge and expertise. They also identified that the opportunity to harness less structured capacity, provided by a variety of Māori and community-based sources, should also be considered.

The MPI led Freshwater Biosecurity Partnership Programme works to understand and manage regional and national pathways through which significant freshwater pests are spread. This is a partnership programme (with partners also including Department of Conservation (DOC), Land Information New Zealand (LINZ), regional councils, Fish and Game New Zealand, iwi representatives, Genesis and Meridian Energy) focused on increasing knowledge about the issues and best practice for management, sharing expertise and leading a public behaviour change programme (Check, Clean, Dry). However, active surveillance programmes are currently excluded from the scope of this group (MPI 2017).

In the absence of nationally run freshwater weed (and other pest) surveillance programmes, a coordinated regional surveillance programme would be beneficial in the detection of new naturalisations nationally, as well as new regional incursions (see Section 3.4).

2.4 Rationale for aquatic weed management programmes

Critical information needed to evaluate potential species or site-led aquatic weed management programmes involve an assessment of the characters of weed species (weed risk assessment), the current distribution of that species (both within the region and neighbouring regions) and dispersal mechanisms (pathway assessment).

Based on this evaluation, a response can be proposed incorporating prioritisation of the threats posed and the management goals. The management goals are informed by the NPDPM (NZ Government 2015) but should also include the 'no management' option. Where a site-led approach is considered, an asset evaluation ranking is also advocated (see Section 3.3).

2.4.1 Weed risk assessment

The weed potential of aquatic plant species is well recognised in generic weed risk assessment models, e.g., Pheloung et al. (1999), a model used in many countries for pre-border evaluation. Most of the weed characters scored by this model are assigned a score of one, however the model recognises the predominance of introduced aquatic species becoming weedy by giving those plants a score of five. As a score of six or greater would result in a recommendation not to permit importation, almost all aquatic plants are recognised as potential weeds, and many aquatic weeds have similar scores under this model, despite obvious differences in their weed impacts and competitive ability (Champion and Clayton 2000). 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 categorised 83% of the non-invaders as would-be invaders.

The Aquatic Weed Risk Assessment Model (AWRAM) (Champion and Clayton 2000) was developed to better reflect differences in the perceived risk and relative management importance of aquatic plant species and has been used to support national management decisions (Figure 1).

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.

The maximum theoretical AWRAM score would be 100, however the highest ranked New Zealand species was phragmites (75). Appendix C presents the ranked AWRAM scores and Appendix D shows comparable risk assessments of wetland species that are not commonly aquatic. Species with the highest score or ranking provide the greatest weed risk, should they establish. Assessments of the potential impacts caused by each species are outlined in the Part Two report.

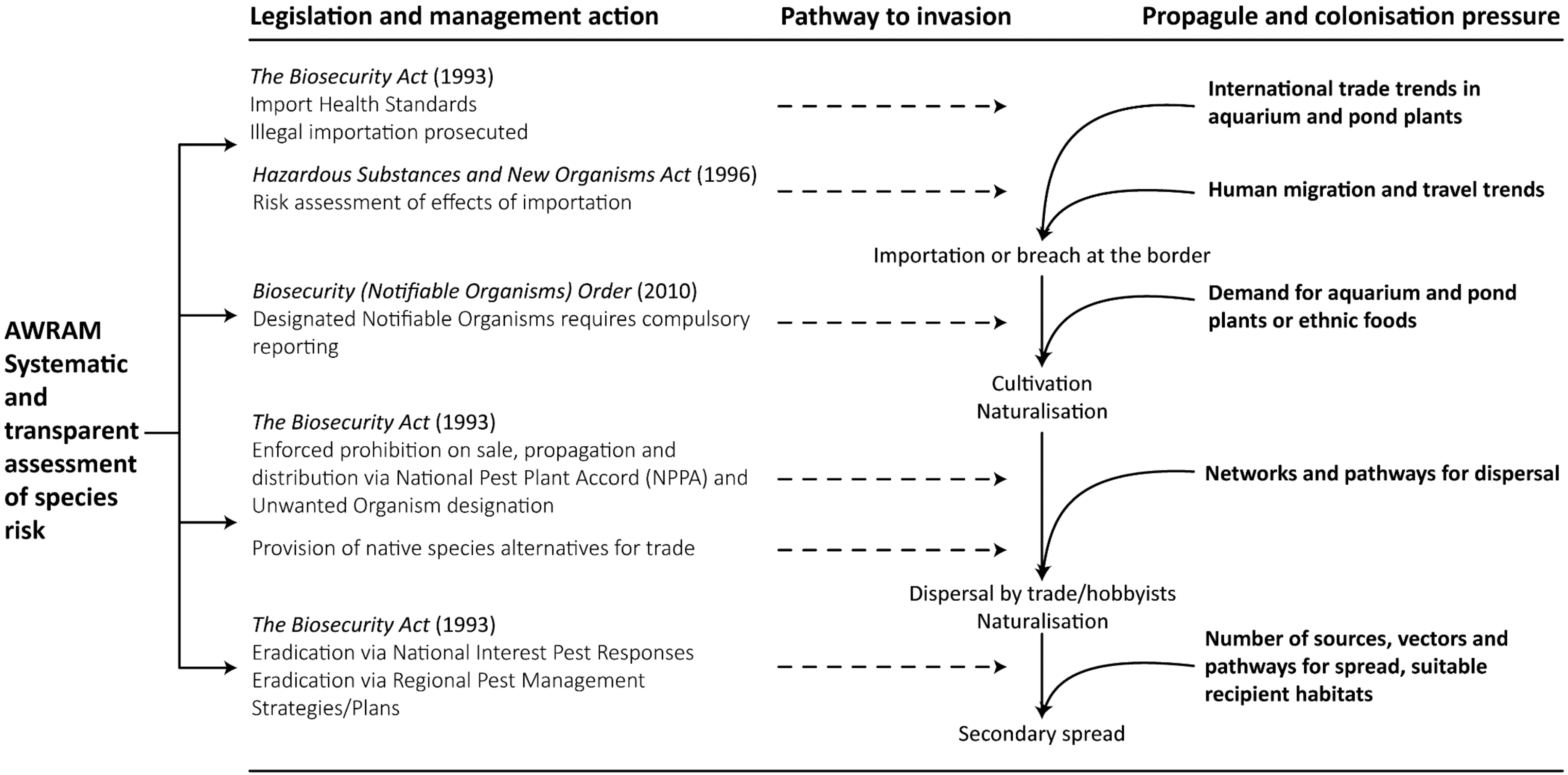

Figure 1: Overview of proactive management actions in New Zealand. Identifying input from the Aquatic Weed Risk Assessment Model (AWRAM), the stage of the invasion process (from Champion et al. 2014).

2.4.2 Species distribution

The Part Two report provides distribution data on over 70 species, based on information provided by each region, records from NIWA databases, the Virtual Herbarium of Australasia and the New Zealand Plant Conservation Network.

The potential distribution maps for each species (Part Two report) use information on the overseas native and naturalised range of each species (from the Global Biodiversity Information Facility - GBIF), to identify likely regions that have habitats where that weed species could establish. Interestingly, some aquatic species of tropical or sub-tropical origin (e.g., alligator weed (*Alternanthera philoxeroides*), parrot's feather (*Myriophyllum aquaticum*) and egeria (*Egeria densa*) have all naturalised in temperate countries and could grow throughout lowland habitats in New Zealand.

2.4.3 Pathway analysis

Aquatic weeds may be dispersed to new sites by a range of natural and human means. Pathways and likelihood of spread of the highest-ranking weeds are discussed in this section.

Natural dispersal includes the movement of propagules by:

- water (e.g., flood waters spreading contents of ornamental ponds)
- waterfowl (e.g., seed palatable to ducks or attached to their legs etc.)
- wind (e.g., spores of royal fern (*Osmunda regalis*) and seed of grey willow (*Salix cinerea*)).

Weed dispersal by humans can be divided into deliberate and accidental means as follows:

- Deliberate dispersal:
    - liberation of aquarium contents and dumping of garden waste
    - plantings in natural water bodies (ornamental or misguided 'enhancement' e.g., duck shooters planting willow (*Salix* spp.), salvinia, alligator weed and egeria
    - introduction of aquatic plants with coarse fish.
- Accidental dispersal:
    - contaminated watercraft or vehicles
    - contaminated fishing nets
    - contaminated drain clearing or weed cutting machinery.

The risk of transfer of these propagules to unimpacted water bodies is essentially the probability that one or more of the pathways noted above will move plant material (seeds or vegetative fragments) from a weed source to an unimpacted area.

These distribution pathways and their relevance to the spread of aquatic weeds are discussed in the following sections.

Natural dispersal

Most of the submerged aquatic weeds discussed in Section 3 do not set seed in New Zealand, either because only one sex is present or, in the case of hornwort (*Ceratophyllum demersum*), due to unfavourable environmental conditions and/or self-incompatibility. Therefore, natural dispersal is not going to move these species to a new catchment. Flood events could feasibly transfer those species to downstream sites should an outdoor pond containing one of those species be inundated by floodwaters.

Those species that do produce seed like curled pondweed (*Potamogeton crispus*) and water buttercup (*Ranunculus trichophyllus*) can be spread by waterfowl and are widespread throughout much of New Zealand. Humped bladderwort (*Utricularia gibba*) was first recorded in New Zealand in 1978, but a more recent seed producing form was first found near Kaitaia in 1999 (Champion 2015). By 2018,it had rapidly spread from Northland to coastal Taranaki and Bay of Plenty. Species with seed dispersed by wind include grey willow, royal fern and the most recently described invasive wetland weed, giant willow herb (*Epilobium hirsutum*). Grey willow is common throughout much of New Zealand, apart from Northland and Stewart Island, but the other species are absent from large areas of the country.

Thus, aquatic weeds adapted for spread by birds or wind have the potential to be effectively dispersed between catchments and their spread is impossible to contain if they are widely naturalised.

However, most species are dispersed between catchments by human activities, knowingly or unknowingly, as discussed in the following sections.

Deliberate dispersal

The majority of alien submerged aquatic weeds present in New Zealand were intentionally introduced for ornamental ponds or aquaria.

As the majority of these weeds do not reproduce sexually, deliberate or unintentional transfer by human activities provides the main means of dispersal. A number of species with high weed potential have been declared as Unwanted Organisms and included on the National Pest Plant Accord (MPI 2019b), under legislation to prevent sale, distribution and propagation (Sections 52 and 53 of the Biosecurity Act 1993) to strongly discourage their dispersal around New Zealand.

Despite their ban from sale and distribution (some from as early as 1983), some of these plants are still being illegally distributed around New Zealand as pond and aquarium plants. Private residences adjacent to natural water bodies may provide a potential reservoir for invasive aquatic weeds.

The deliberate transfer of coarse fish is often accompanied by release of aquatic plants that may have been used to transport fish or eggs from site to site, as evidenced in the South Island hornwort incursions where this species was found in water bodies also containing the pest fish rudd (*Scardinius erythrophthalmus*).

Accidental dispersal

Most problem submerged weeds are dispersed via stem fragmentation and their main mode of spread to new water bodies is via contaminated watercraft, drainage machinery and weed harvesters and fishing nets. Scuba equipment is also a potential mechanism, with some recreational diving and scuba dive training classes taking place in lakes.

Assessing risk of introduction

The risk of accidental spread of these weeds is dependent on a number of factors:

- adaptations of weed species enabling dispersal to new sites (such as tolerance to desiccation, ease of attachment to a vector, regenerative capacity)
- proximity of weed source to an unimpacted site. Generally, the closer the distance the greater the risk (Johnstone et al. 1987)
- abundance of weed sources. The greater the number and extent of sources, the greater the risk of spread
- type of dispersal vector (boats, nets or diggers)
- accessibility of the weed site(s) and unimpacted sites to the potential vector (such as well-formed boat ramps)
- frequency of vector movements between sites.

Compton et al. (2012) used Boosted Regression Tree (BRT) modelling to predict the likelihood of invasive weed spread between lakes via boat transfer as an important tool for focusing proactive management efforts to lakes deemed susceptible to invasion. This approach used variables that indirectly described weed spread and found that weed occurrence was more likely when there was good road connection to the lake, adjacent human population density was high and if the lake was large (ca. 55 km^2) comparing modelling results to records of weed species establishment. Prediction of new incursions was improved by upweighting observations close to the edge of the current invasion fronts of those species. The probabilistic estimates of risk, as derived from the models, together with other information for prioritising lakes, could be used to focus surveillance and protection efforts.

2.4.4 Management goals

Once a ranked list of high-risk aquatic weeds is identified (Section 2.4.1), the distribution or potential distribution is known (Section 2.4.2) and the dispersal pathways are understood (Section 2.4.3) for each species, this information should be critically examined to assign the following management responses:

- no management response
- nearest source of the weed should it not be present (pathway analysis and exclusion goal)
- presence and abundance within the region (control goals), or
- identification of priority sites within the region that are currently free of the weed or where management could protect high value assets (site-led).

No management response

A common perception held by water body managers and the general public is that any aquatic weed growth is undesirable. However, aquatic plants provide many advantages to an aquatic ecosystem and their control and removal may be unnecessary (Champion et al. 2002). Situations where no management may be a suitable option include where:

- The weed species is not regarded as a major threat to the system/region/country compared with other species.
- The weed's distribution is too widespread for management within the available budget.
- The weed is dispersed by pathways (e.g., wind or bird dispersed) that make containment unachievable.
- There is no effective control method(s).
- Use of effective control method(s) is not permitted by legislative, social or cultural constraints.
- The system is of low value.

Weed threat posed by each species can be informed by AWRAM. Champion et al. (2007) regard species scoring greater than 50 as having a high weed potential, those scoring 40–50 have a moderate weed potential, and those scoring < 40 have a low potential. Most species with a score greater than 50 are currently subject to management under national or regional plans, while species scoring between 40 and 50 may be managed if they are of limited distribution. In the majority of occasions, these species are managed under Regional Pest Management Plans. Occasionally, species with scores lower than 40 are managed, but these are normally community- and site-led projects. If a system is heavily impacted by a highly ranked species, there is little benefit managing a lesser weed within the same life-form. For a submerged weed example, a water body dominated by hydrilla, hornwort or egeria is unlikely to be impacted by lagarosiphon (*Lagarosiphon major*) or elodea (*Elodea canadensis*), so their management is unwarranted. However, both species should be managed for Exclusion should they threaten a water body where neither species is present (e.g., lagarosiphon on the West Coat of the South Island).

Some species are unlikely to be problematic in more southern parts of New Zealand including ferny azolla (*Azolla pinnata*), arrowhead (*Sagittaria montevidensis*), Christmas berry (*Schinus terebinthifolia*) and humped bladderwort. All but ferny azolla are banned from sale and distribution under the NPPA. However, if they were to be introduced to southern South Island regions, they are unlikely to naturalise and be problematic under current climates.

Several aquatic and wetland weeds are widely distributed through much of New Zealand (e.g., elodea (*Elodea canadensis*), curled pondweed, reed sweet grass (*Glyceria maxima*) and water cress (*Nasturtium* spp.) and are not classified unwanted organisms under the Biosecurity Act. Some of the highest ranked weed species are well established in some regions e.g., alligator weed in Northland and Auckland regions, and hornwort, egeria and lagarosiphon throughout much of the North Island. These are unwanted organisms, listed on the NPPA and actively managed outside of the core area of their distribution.

The absence of management in one region may have a major impact on the success of management responses from other regions.

Conversely, in the case of alligator weed in the Waikato and Bay of Plenty Regional Council areas, Progressive Containment/Eradication are their management goals, whereas the regions to the south are afforded a degree of protection from this weed but are not contributing to its management (apart from an incursion response by Horizons Regional Council). Although there is a degree of coordination of pest management between regions, it would be beneficial to align regional species management at least on a North or South Island basis.

Naturally dispersed weeds pose a problem with containment and exclusion as their continued invasion would be difficult to manage. Highly ranked weeds like ferny azolla and humped bladderwort are effectively spread by waterfowl and have continued to spread southwards by this means, with ferny azolla recently collected in the Wellington Region and humped bladderwort in coastal Taranaki and Bay of Plenty. Both of these species also lack effective control methods. Similarly, wind dispersed species such as grey willow, royal fern and giant willow herb are likely to colonise new catchments. Grey willow is common throughout much of New Zealand, apart from Northland and Stewart Island, but the other species are absent from large areas of the country. Although effective control methods are available for such species, they should be targeted for Exclusion in regions distant from current infestations, as they would be very difficult to contain once a naturalised population establishes.

The lack of effective control options is dependent on the stage of invasion of an aquatic weed. Early incursions can be managed mechanically or by habitat manipulation, including bottom lining (Section 4.2.1). However, these methods are only effective when there are low numbers of easily detected plants. A number of species have long-lived seed banks, so even if there are effective control methods for above-ground parts, continued recolonisation from germination needs to be factored into a response programme. Again, such species should be targeted for Exclusion via Incursion Response (Section 0). The provision of new selective management tools has been a long-term focus of NIWA's research programme (Champion 2018a), with seven new herbicides and biodegradable bottom-lining methods evaluated and, in many cases, adopted for species management programmes where the previous lack of methods prevented effective control (e.g., phragmites, hydrilla, Manchurian wild rice, cord grasses and lagarosiphon). However, a limited toolbox of control methods remains an issue that could be resolved by future research projects.

There is often resistance to the use of some control options, especially herbicides and grass carp, by the general public and Māori. In cases where consent is not gained, and management is not undertaken, the consequences of 'doing nothing' may include degradation of the freshwater system and increased likelihood of spread of the uncontrolled aquatic weed species to new water bodies.

Section 4.2 of Tool Three (Control) outlines the legislative constraints imposed on the use of control tools by HSNO, the Conservation Act 1987, Freshwater Fisheries Regulations 1988 and the Resource Management Act 1991. If the requisite controls, conditions or permissions required to undertake aquatic/wetland weed control cannot be met then those control tools must not be used in those situations.

Systems that are already heavily impacted by invasive weed species are likely to be degraded by the presence of those plants and consequently may be of little perceived value, with little incentive for management. Submerged weed beds can often be left alone, even when there is a perceived threat to power generation or to recreational users. For example, control of large weed beds immediately upstream of a dam can result in greater weed fragment generation and blockage of nearby screen intakes. Disturbance of such weed beds is often unnecessary if for example, the risk of their dislodgement is low and water flows are not significantly impeded (Champion et al. 2002).

Another reason for adopting a leave-alone strategy is that regular control of weed beds has been shown to encourage regrowth and extend the duration and commitment required for satisfactory control (Barko et al. 1994). On the other hand, no control can lead to reduced plant biomass after a number of years, which may not happen if regular control were practised. The leave-alone strategy has the added benefit of minimising ongoing costs – and possibly long-term costs as well – with control restricted to intermittent but essential removal costs, if and when detachment leads to health and safety threats, or stranding occurs in an unacceptable location for example.

However, if the uses and values of a water body are being or are likely to be adversely impacted by alien aquatic weeds, then there are a range of control options available as outlined in the following sections.

Exclusion

Section 2.4 provides the steps required to identify priority aquatic weed species for regional exclusion, based on the risks they pose, potential sources outside of the region and their pathways of introduction. A combination of weed risk and the likelihood of introduction can be used to create a regional 'black list'.

It is noted that only 12 species are currently designated for Exclusion on RPMPs, with four species nominated in Northland, two in Waikato, Horizons and Canterbury and individual species in Auckland, Hawkes Bay and Tasman (Appendix B). Most of those species have been eradicated from the region by a previous regional pest management strategy. Only one species, heath rush (*Juncus squarrosus*), an Exclusion pest in Horizons Region, is not an unwanted organism.

As Exclusion (prevention) is the most cost-effective point of intervention, greater emphasis on identification of future pests is warranted. Tool 2 (Section 3) details the management interventions that can be taken to prevent the incursions of new aquatic weeds to a region.

Eradication

Tool 3 (Section 4) details the limited number of control tools that can be utilised in Eradication programmes. Control of above-ground parts (or plants in the water column) is usually a relatively straight forward process, but Eradication requires the management of all individuals including propagules, both vegetative such as rhizomes, corms, bulbs and tubers and in addition potentially long-lived seed banks. Eliminating the last few individuals of a target population will often cost much more than getting rid of all the others (Simberloff 2014).

Management of submerged weeds is much more problematic than for terrestrial plants. Simberloff (2014) noted that eradication of aquatic organisms has proven particularly difficult. Factors listed included their early detection and delimitation being more difficult in the aquatic environment, than for a terrestrial site, and the restrictions around the use of eradication tools and effective deployment of those tools in the aquatic environment.

Essential components in planning a successful Eradication programme were identified by Simberloff (2014). These included ensuring there were sufficient resources to undertake a programme, that actions were backed by efficient legislation, that tools targeting vulnerable life stages of the weed were available and that the likelihood of reinvasion from outside of the Eradication zone had been evaluated.

Section 3 of this report outlines a five-stage incursion response programme that should be implemented on the discovery of a new weed infestation. The response programme is comprised of delimitation, assessment of management options, containment, control and follow-up monitoring.

The majority of pest management activities undertaken under RPMPs are for regional eradication, with 32 species, including MPI managed species. Excluding NIPR and national incursion-led responses, the northern four North Island councils are managing for Eradication between six and nine species, with four species in Horizons, Canterbury and Southland, three in Tasman and one species in Hawkes Bay, Greater Wellington, West Coast and Otago (spartina is regarded as one species here). Spartina is targeted for Eradication in seven regions, Senegal tea (*Gymnocoronis spilanthoides*) and purple loosestrife (*Lythrum salicaria*) in five and arrowhead (*Sagittaria montevidensis*) in four regions. Twelve species are only targeted for Eradication in one region (Appendix B). Only four Eradication species (monkey musk (*Erythranthe guttata*) from Northland, reed sweet grass in Tasman District and tall reed (*Phragmites karka*) and mud sagittaria (*Sagittaria subulata*) from Auckland) are not unwanted organisms.

Successful eradications undertaken by regional responses to date include:

Nationally eradicated:

- Bogbean, fringed water lily (*Nymphoides peltata*), clasped pondweed (*Potamogeton perfoliatus*) and greater reedmace (*Typha latifolia*).

Regionally eradicated:

- Alligator weed, Senegal tea, purple loosestrife, yellow water lily (*Nuphar lutea*) and marshwort.

However, in many cases the intermediate outcome of the Eradication programme (reduce the infestation level of the aquatic weed to zero levels in an area) has not been achieved within the short to medium timeframe identified in the RPMP or previous regionally run programmes.

Often, individual sites may be eradicated, but achievement of the regional Eradication goal is hindered by:

- subsequent and often ongoing discovery of new incursions (including spread by weed fragmentation and water dispersal to new sites)
- failure to detect regrowth in difficult to access sites
- underestimation of the time required to eradicate seed or underground vegetative parts
- unsuitable environmental conditions (water levels, weather) preventing the requisite annual control effort
- inadequate access to eradication tools (limited importation and manufacture)
- inadequate level of experience and effort of individuals charged with implementing eradication programmes (Howell 2012), and/or
- insufficient access to the required resourcing to achieve that goal.

In such cases, those aquatic weeds are probably more appropriately included in a Progressive Containment programme (New Zealand Government 2015) in which the intermediate outcome for the programme is to contain or reduce the geographic distribution of the subject over time. Should progress be made where Eradication is assessed as attainable, within the short- to medium-term following this programme, then a review of the RPMP could change the species-led goal back to Eradication.

Progressive containment

The Progressive Containment goal encompasses both long-term programmes, where ultimately eradication is sought, but also management steps to ensure the likelihood of further spread, from known sites to unimpacted sites, are undertaken.

Essentially the goals of long-term eradication are identical to those discussed in the previous section. Tool 3 (Section 4) details the control tools that can be utilised in Progressive Containment programmes. Resourcing of such Progressive Containment programmes would have to be longer term than for eradication programmes, and implicitly require commitment from the regional authority to provide resources over the life of the programme.

There are currently RPMP Progressive Containment programmes undertaken on nine species (all *Spartina* spp. regarded as one entity here). Canterbury run five Progressive Containment programmes, there are four on the West Coast, two in the Waikato Region and one in Auckland and Hawkes Bay regions (Appendix B). Only Canterbury and West Coast Regions target submerged weeds with Progressive Containment programmes on egeria and lagarosiphon. Only reed sweet grass, a Progressive Containment weed in Hawkes Bay, is not an unwanted organism.

Sustained control

The Sustained Control goal seeks to provide for ongoing control of aquatic weeds to reduce their impact on values and prevent further spread. Tool 3 (Section 4) details the control tools that can be utilised in Sustained Control programmes.

As many of New Zealand's worst aquatic weeds predominantly rely on human activities for their dispersal to new water bodies, Sustained Control involves pathway management where management of a water body occurs at points of entry for users (e.g., boat ramps). Sections 3 and 3.4.1 discuss advocacy strategies and the identification and containment of high-risk sites.

Additionally, targeted weed control at access points will reduce the likelihood of accidental weed transfer to new water bodies. For example, the Bay of Plenty Regional Council have instigated a Sustained Control programme that is also resourced by LINZ to manage submerged weeds in the Rotorua lakes district using the herbicide diquat applied by boat (Champion 2009). Bay of Plenty Regional Council recommend areas for treatment. The main emphasis of control is to prevent the contamination of boats and trailers leaving lakes containing the worst weeds and 16 boat exit points are targeted for control. Bay of Plenty Regional Council devised a ranking system to prioritise treatment sites in 2008 based on the following five parameters:

- Reduced risk of pest exit:
    - Number and ease of use of exit points, proximity to unimpacted lakes, proximity to human habitation.
- Improved surveillance activity:

    - Increase visibility of target species by controlling other vegetation.
- Improved recreational amenities.
- Improved biodiversity values:
    - Protect indigenous vegetation from weed impacts.
- Reduced weed biomass.

There are currently RPMP Sustained Control programmes undertaken on ten species. Bay of Plenty Region and Marlborough District Council each run four Sustained Control programmes, with three in Northland Region (Appendix B). Each of these authorities target at least one submerged aquatic weed with Sustained Control programmes on hornwort, egeria, lagarosiphon and eelgrass (*Vallisneria australis*). Only reed sweet grass, a Sustained Control weed in Marlborough District, is not an unwanted organism.

Site-led management

Essentially, Site-led management can encompass all of the four management goals; exclusion, eradication, progressive containment and sustained control, with the focus on an individual site within a region. The rationale is to protect the values at that sites, whether values be environmental, cultural, economic or recreational.

Site-led resource evaluation and prioritisation is discussed in Section 3.3 and identification of risk weeds, their distribution and pathways of spread are outlined in Sections 2.4.1, 2.4.2 and 2.4.3. Once sites have been selected for protection and target species identified, then appropriate management goals for that site can be determined based on the Rationale for aquatic weed management (Section 2.4). Many of these programmes are run outside of the Biosecurity Sections of the regional and unitary authorities, in some cases being community led. Where management is undertaken by the community, they may have an input into species selection (e.g., Cape pondweed (*Aponogeton distachyos*) in the Waiwhetu Stream, Greater Wellington) but such activities need to be evaluated by the regional council to ensure any unintended biosecurity-related consequences do not occur as a result of such projects. An example is the unintended introduction of egeria to the Avon River in Canterbury, when the weed harvester, used to manage that and other weeds in the Opawa River in Marlborough, was used to manage other weeds there.

There are currently Site-led management programmes undertaken on 22 species (including all *Spartina* spp. regarded as one entity here). These include seven programmes in Waikato, six in Horizons and Greater Wellington, five in Northland, four in Hawkes Bay, and one in Auckland, West Coast, Canterbury and Otago. Of the 22 Site-led management species, eight species (Japanese rush (*Acorus gramineus*), Cape pondweed, beggar's ticks (*Bidens frondosa*), reed sweet grass, gypsywort (*Lycopus europaeus*), Mercer grass (*Paspalum disticum*) and saltwater paspalum (*Paspalum vaginatum*) are not unwanted organisms (Appendix B).

Monitoring

An essential component of any management intervention is Monitoring. Monitoring is required to:

- identify the extent of the pest and its susceptibility to the selected control method, to ensure accurate targeted control of the aquatic weed, with consequent better targeting of control and less off-target impact (pre-treatment monitoring), and

- ensure the intermediate outcomes of the aquatic weed control programme are being achieved (post-treatment monitoring).

In the case of submerged aquatic weeds, this requires evaluation using scuba divers (e.g., Champion 2009).

Pre and post treatment monitoring is important for reporting to regional authorities to secure resources for ongoing programmes and also for compliance monitoring (also see Section 4.4.3) to ensure the programme is compliant with controls, permissions and consent conditions under which that management is permitted.

2.5 Synthesis

This strategic analysis tool outlines all the information required to design a Regional Pest Management Plan for aquatic and wetland weeds. The strategy is informed by Sections 3 and 4 of this report and the Species information in the Part Two Report.

The overarching guidance principle used in this Tool is the prioritisation of resources for proactive management, with exclusion and early detection, rapid response the most cost-effective management action. However, all of the management programmes identified by the NPDPM are relevant to various stages of aquatic and wetland weed invasions within each region. The schematic decision-support diagram for aquatic and wetland weed management () provides all of the requisite components required to design an RPMP (or national led response) for the management of aquatic and wetland weeds.

2.6 Future proofing

The National best practice guidance for aquatic weed management provides a framework of best practice to support decision-making and management of aquatic weeds by regional councils in New Zealand.

This guidance is based on the species currently or potentially impacting aquatic and wetland habitats (and also some species that have been previously in New Zealand but thought to have been eradicated). However, it is likely that new species will be detected in the future, either originating from species currently kept undetected in cultivation, or by new illegal importations.

In a similar way, it is likely that new species detection and surveillance techniques will become available within the near future, including remote sensing and genetic detection techniques. Additional new control tools continue to be developed and are likely to be registered for use in New Zealand, offering more efficacious and selective tools, with a reduced environmental foot print.

It is recommended that the addition of new information to the respective species, detection and control tools should be undertaken on a regular (one to three-yearly) basis, with the consequences of new species or new technologies captured in the Strategic Tool.

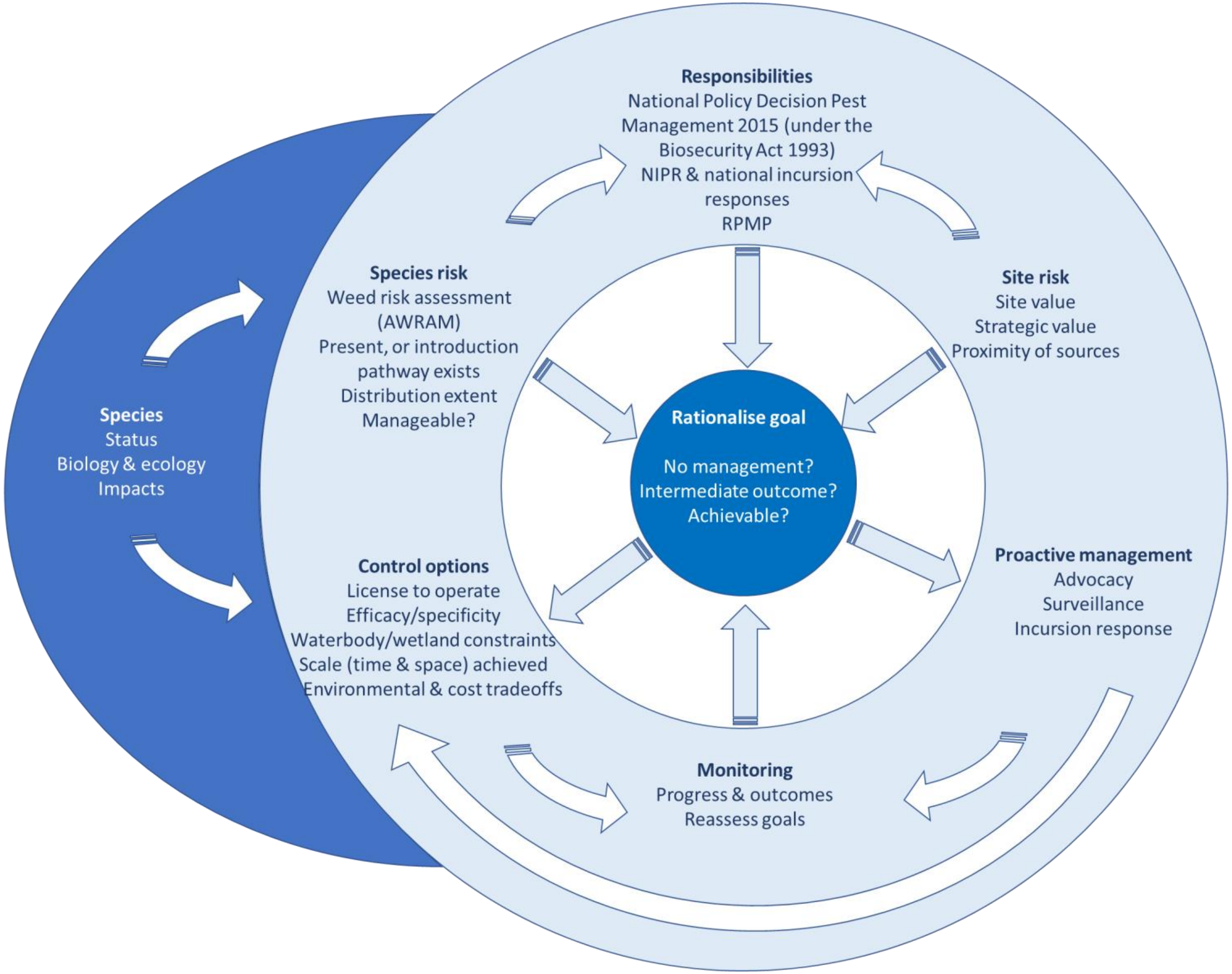

Figure 2: Schematic decision-support diagram for aquatic and wetland weed management.

3 Tool 2: Incursion detection

3.1 Introduction

The Incursion Detection Tool details the management interventions that can be taken to prevent the incursions of new aquatic weeds to a region, or specific sites (water bodies) within the region. The Strategic Analysis Tool (Tool 1) outlines how species weed risk assessment, information on the current and potential distribution of high-risk species and analysis of spread pathways can be used to prioritise weed species for exclusion from a region (see Sections 2.4.1, 2.4.2 and 2.4.3), along with the rationale for investing in targeted early detection rapid response and also the relevant management steps as identified in the NPDPM that include Exclusion and Eradication (new to region incursion response), Site-led (protection of high value sites) and Pathway Programmes.

Tool 2 encompasses advocacy to prevent new species introduction, assessment of freshwater resource values for site-led management, surveillance strategies and management responses to newly detected weeds, and has the following components (Figure 3).

Assess risk: identify weed risk & pathways for entry (Exclusion) →	Use the Aquatic Weed Risk Assessment Model to rank potential aquatic weeds for threat to identified values. Determine likely means of transfer for each weed to the water body and assess likelihood of transfer.
Resource evaluation/ priorisation (Site- →	Water ways are valued for their recreational, aesthetic, utility, and ecological values. Identify which waterways have the greatest risk of invasion and be most impacted.
Surveillance: identify areas of introduction/ establishment →	Determine areas where a weed is likely to be introduced and its likely depth range. For submerged species, access points (e.g. boat ramps, marinas) and anchorages need to be included.
Surveillance: methods and frequency →	Target areas with high chance of early detection. For submerged species, shoreline search, snorkel and SCUBA are suitable methods for searching. Extend coverage with boat assisted tows guided by a GPS depth sounder if required. Annual surveillance is the usual frequency; best in late summer.
Incursion response preparation →	Pre-plan for an incursion: delimitation, containment, and likely treatment options (hand weeding, herbicides, bottom lining and / or suction dredging) need consideration. Pre-plan consents and approvals and maintain a budget available to cover the response.

Figure 3: **Generic surveillance and response guidelines overview.**

3.2 Advocacy to prevent new species introduction to regions

Assessment of high-risk Exclusion species yet to become naturalised within a region; likelihood of their introduction (identify nearest sources) and potential introduction pathways, can be used for the preparation of an Exclusion list.

Many of the species are likely to be managed by exclusion from sale, propagation and distribution through the NPPA, and regional council staff routinely inspect plant nursery and aquarium outlets for compliance. However, as discussed in the previous section, deliberate and accidental spread is likely to continue, requiring intervention to minimise impacts on economic, social and environmental values.

Passive surveillance and reporting of these species by the general public could be achieved through awareness campaigns.

Several regions undertake surveys of private properties containing ornamental ponds to ensure no Exclusion weeds are present (e.g., Champion and de Winton 2005).

Additionally, targeting of high-risk activities such as advocacy for recreational boating, drainage machinery hygiene can be used to raise awareness of these species and mechanisms for the spread of aquatic weeds and other freshwater pests. MPI Biosecurity New Zealand, currently lead the Freshwater Biosecurity Partnership Programme, with two Regional Coordinators that organize education campaigns focused on boat users, in high use sites throughout New Zealand.

Decontamination methods have been trialed using salt for fishing nets (Matheson et al. 2007) and an evaluation of the effectiveness of *Clean* and *Dry* protocols (introduced by MPI in 2005, to slow the spread of the invasive freshwater diatom didymo (*Didymosphenia geminata*) in the South Island) for a wider a range of New Zealand freshwater pests (Burton 2017). This trial found the most effective and practical decontamination protocol tested for freshwater pests was hot water (55°C for 20 minutes or 60°C for 1 minute). Purpose built high temperature wash down facilities (as used in the USA) could be used to safely provide effective decontamination of boating and fishing equipment.

3.3 Resource evaluation and prioritisation (site-led management)

The first step to protecting regional freshwater resources from the impact of invasive aquatic weeds is to identify aquatic systems and their relative value and status. Most regional management authorities will have databases of water bodies within their boundaries and there are also national databases such as the GIS based Freshwater Environments New Zealand (FENZ) (DOC 2019), which consists of a large set of spatial data layers and supporting information on New Zealand's rivers, lakes and wetlands.

Once identified, water bodies can be categorised, for example by size, flow or whether they are natural or artificial. Estimation of value is subjective and can include commercial (e.g., hydro-electric power generation capacity or irrigation supply), recreational (e.g., fishing, swimming or watercraft such as rowing), environmental (e.g., biodiversity) and / or cultural.

Hydroelectric generation produces 54.5% of New Zealand's electricity needs (MBIE 2014) and submerged weeds can have a huge financial impact on power generation (Clayton and Champion 2006). Therefore, there are major economic benefits to protect hydro-lakes which currently do not have the main nuisance weeds (e.g., the lower Waitaki Reservoirs (Clayton et al. 2007)). Water bodies utilised for hydro are often flooded channelised valleys with few inherent biodiversity values.

However, the same principles of risk assessment can be applied to power generation by using characteristics of the water body, such as water level fluctuation, water clarity, shoreline gradient, lake size and exposure to wave action (Clayton and Champion 2006). Water bodies that do not provide large areas suitable for submerged plant establishment and growth may not develop weed problems regardless of the weed species or likelihood of introduction.

To assess native freshwater biodiversity values, data on the current state of the waterbody must first be obtained. Many baseline lake vegetation surveys already exist in the NIWA Aquatic Plant Database (NIWA 2016). Submerged plants have also been used as indicators of water clarity to assess lake condition (Clayton and Edwards 2006), using LakeSPI methodology. The maximum depth of native and invasive species with cover >10%, and the maximum depth of charophyte meadows with >75% cover (together with other parameters) are recorded. These data are then used to calculate indices measuring the intactness, diversity and depth of indigenous submerged vegetation and the impact of invasive alien plant species on submerged vegetation. This methodology is becoming widely adopted (Hamill 2006), being currently used by several regions including Northland, Auckland, Waikato, Environment Bay of Plenty, Hawke’s Bay, Manawatu-Wanganui, Canterbury and several Department of Conservation (DOC) areas (e.g., the Ashburton Lakes).

An assessment of the ecological value of water bodies can be made based on representativeness of biota, intactness of indigenous vegetation, including the surrounding catchment, presence of significant (e.g., nationally threatened) species (e.g., de Lange et al. 2018; Dunn et al. 2018; Grainger et al. 2018; Robertson et al. 2017), absence of pest species impacts, and absence of detrimental catchment impacts such as nutrient enrichment. For example, Northland Regional Council has quantified the ecological value of nearly 100 of their most prominent lakes (Champion and de Winton 2012). These were prioritised based on field assessment of biota, water quality and surrounding catchment with additional information obtained from FBIS, Ornithological Society of New Zealand and DOC Sites of Special Biological Interest records. Lakes were ranked (from best to worst) as: outstanding; high; moderate-high; moderate; low-moderate; and low. Outstanding lakes are nationally important, containing a diverse indigenous biota, with sustainable populations of endangered species. Where a critically endangered species, likely to be heavily impacted by weed invasion, is restricted to one or a few water bodies, then surveillance of that water body would also be a priority, even though it may be lowly rated with respect to other characters.

3.4 Surveillance

Surveillance methods need to be tailored to the water body to maximise the chances of early detection in relation to effort spent. Factors that require consideration include:

- Where to look, especially entry points and areas that fragments are likely to accumulate based on prevailing wind and current patterns.
- Detection methods including passive and active surveillance methods including:
    - On-ground methods.
    - Remote sensing.
    - Environmental samples (eDNA).
- Timing and frequency, with at least annual inspection late in summer (when invasive plants are more easily detected / visible) at high risk sites.

- Site specific variables which are likely to affect the probability of weed detection, such as existing vegetation density and height, water clarity and area of water body requiring inspection.

3.4.1 Site selection

Before undertaking a surveillance programme, selection of sites based on the analysis of introduction pathways and suitable habitat for weed species, allows for a targeted search of high-risk areas within each water body. Likely sites of introduction in the case of watercraft would be boat entry points (e.g., boat ramps and commonly used beach accesses or camp sites) and anchorage areas (such as common fishing areas and sheltered bays) where plant fragments, in the anchor well could be unwittingly liberated.

Submerged weed species are much more difficult to detect than other plant life-forms. To increase the likelihood of detecting a new submerged weed incursion, Bay of Plenty Regional Council have constructed weed cordons at boat access points, in several of their high-value water bodies. These are buoyed cordon panels supporting purse seine net ‘curtains’ that create a physical barrier to reduce the likelihood of the movement of invasive plant fragments out of the cordon and into the main body of the lake (Lass 2012). They create a much smaller search area for surveillance. Recent detections include viable fragments of hornwort (*Ceratophyllum demersum*) and egeria (*Egeria densa*) from Lake Rotoma. Neither species have established in that lake (H. Lass, Bay of Plenty Regional Council, pers. comm.).

3.4.2 Detection methods

On-ground surveillance methods

Passive detection by the public or field staff working in freshwater environments, is dependent on those individual’s ability to detect and document infestations. Aquatic plant identification resources are available as books (e.g., Johnson and Brooke 1998) and on-line resources (e.g., NZPCN 2019, Champion and Reeves 2004, Champion et al. 2014) including fora where plant images may be submitted for expert identification (e.g., iNaturalist NZ 2019). Identification services are provided by herbaria (e.g., the Allan Herbarium, Lincoln and Auckland Museum Herbarium) or agencies such as NIWA that additionally offer identification courses. NZPCN, iNaturalist NZ, herbaria and NIWA all database species distributions, with many databases available through international sites such as GBIF (2019) or the Australasian Virtual Herbarium (2019).

Targeted detection techniques for invasive aquatic plants are related to their life-form or the vegetation community of interest. At a site scale, surveys for plants that can be observed visually from the water’s edge, including shoreline searches, can be undertaken for established floating or emergent weeds or for submerged plant fragments. Desiccated fragments of weed species have been detected at boat access points at Lakes Ohau, Okataina and Taharoa (Northland), triggering intensive surveillance of submerged vegetation in those areas.

Surveillance methods for submerged weeds can include viewing from above water or using drop cams, which have provided limited detection effectiveness to date. Glass bottomed boat or snorkelling can be effective in shallow (<5 m deep) water with good clarity.

However, Scuba is currently the most effective and versatile surveillance method.

For example, three methods were used to carry out submerged weed surveillance in the Bay of Plenty Region (Champion 2009):

- Scuba searches of large areas were carried out using manta board tows (two divers per boat), with the search pattern controlled by the boat operator, also recording location and area travelled by on-board GPS. A series of overlapping traverses ensure the search area was thoroughly covered.
- Near-shore intensive Scuba searches of areas not accessible by boat tow and at the highest risk sites (e.g., boat access structures, weed cordons).
- Shoreline search for submerged weed fragments.

Surveillance was carried out twice a year, with an early summer search in October/November and autumn search in April/May. These activities were timed to coincide with normally high water clarity.

Scuba searches are dependent on good underwater visibility (> 3 m), with shoreline searches more important where visibility is limited. Divers cover the bathymetry of the lake supporting submerged vegetation between depths of 1 and up to 10 m depth.

These surveillance techniques are also used by Northland, Canterbury and Otago/Southland Regional Councils and MPI instigated a species-specific programme for the early detection of hydrilla in Hawke's Bay in at-risk water bodies (Hofstra 2008). Within-lake surveillance is undertaken in some lakes, such as Lakes Wanaka where containment of a weed species (lagarosiphon) is achieved by eradicating outlier populations as they are detected outside of a defined containment zone (de Winton and Clayton 2015).

Remote sensing

Remote sensing has the potential to add to our ability to detect invasive aquatic plant species and provide natural resource managers with accurate and timely information to inform eradication programs (Clements 2017). Different types of remotely sensed data are currently being utilised for a range of surveillance operations including; aerial photographs, multispectral images, hyperspectral images, synthetic-aperture radar (SAR) and LiDAR (high resolution maps). A range of platforms are available to collect remotely sensed data including: low altitude aircraft (unmanned aerial vehicles, UAVs); high altitude aircraft (fixed wing aircraft or helicopters); and spacecraft (satellites). Each of these datasets and data capture techniques have advantages and disadvantages and selecting an appropriate remote sensing method is determined by scale (being the resolution required to detect the target organism or environment of interest) and the resources available to collect the desired dataset. Scale is an issue with any mapping project as it determines the targeted map unit (Lang et al. 2015). Generally, there is a trade-off between scale and resolution when utilising remote sensing for detection of invasive plant species. Usually, large scale techniques have low resolution and therefore are only effective at detecting larger infestations, whereas smaller scale techniques provide greater resolution to detect small infestations but are only effective for monitoring small areas.

The use of remote sensing has been employed on both floating and submersed aquatic weed species. Aerial detection technology has shown promise for invasive floating species (e.g., alligator weed (*Alternanthera philoxeroides*), water hyacinth (*Eichhornia crassipes*), and salvinia (*Salvinia molesta*) (Clements 2017).

Aerial detection of submersed aquatic weeds has proved difficult, with limited success as plants are obscured by the water's surface or high water turbidity. Water absorbs or reflects most wavelengths of electromagnetic energy. Underwater surveillance using submersible cameras (including submarine devices) and side-scan hydroacoustic (echosounder) technology has some promise for future surveillance of submerged weed, especially in low visibility waters.

GPS referenced side scan sonar images of submerged vegetation can be processed by cloud-based providers such as BioBase to create submerged aquatic vegetation maps for entire water bodies. However, with this latter approach, discriminating between species is currently not feasible (Madsen and Wersal 2012). This technique can be used in combination with diver or field support. Detection of taller or otherwise anomalous beds of vegetation can be ground-truthed by divers (or possibly grab samples) to ascertain identity of the plant.

eDNA

A recent study has demonstrated the concept for the early detection of Eurasian watermilfoil (*Myriophyllum spicatum*) (Newton et al. 2016). However, research in this field is in an early stage of development (Clements 2017) and to date there have been no attempts to remotely detect submerged aquatic weed incursions in New Zealand using this method.

3.4.3 Incursion response

If an aquatic weed incursion is detected, a five-stage programme should be implemented comprising:

- delimitation
- assessment of management options
- containment
- control
- follow-up monitoring.

Delimitation requires an intensive initial survey covering the immediate area surrounding the new incursion and other likely sites to ensure all known populations of the weed are delimited. With this knowledge, the feasibility of eradication and suitable control methods can be evaluated.

Should eradication be considered practicable, the known weed populations need to be immediately contained to prevent further dispersal (e.g., using mesh barriers), until the necessary consents to undertake control are obtained. Containment of hornwort in the northern arm of Lake Rototoa (Auckland Region) was sought by installing two net barriers between the detected incursion and the main lake basin in 2007. This containment operation was due to be followed up with an eradication attempt using the herbicide endothall, but subsequent incursions were later detected in the main body of the lake and herbicide treatment did not proceed.

Management agencies can proactively seek consents and permissions required to manage a new incursion prior to this eventuating (e.g., Permissions from the Environmental Protection Authority and regional Resource Consents permitting the use of herbicides in the event of a new aquatic weed incursion).

Eradication techniques (See Control Toolbox – Section 4) include physical removal by hand weeding or suction dredging, covering the plants with lining materials (e.g., hessian matting or weed mat) and use of herbicides or grass carp (Champion and Clayton 2003). However, such techniques require meticulous and competent operators for successful eradication. Regular follow-up surveys are required to ensure no re-growth from buried fragments, or re-introduction of weed material has occurred. As an example, the invasive freshwater plant lagarosiphon (*Lagarosiphon major*) was detected in a Northland dune lake (Lake Ngakapua) in October 2014 as part of the Northland Regional Council annual surveys. Delimitation was undertaken, and established fragments were found in approximately 10% of the southern lake basin, adjacent to emergent macrophyte beds. As the lake was essentially contained, with no inflow or outflow, containment was not attempted. The best eradication option was considered to be the herbicide endothall, which had been used to eradicate this species from other water bodies in New Zealand (Wells et al. 2014). Permissions to use this product were granted and herbicide was applied in April 2015 to areas where lagarosiphon was found in a second delimitation survey. Subsequent monitoring every six months has not detected any living plants of lagarosiphon, with no impact on indigenous biota, and eradication was declared in 2018 (Champion 2018b).

There are similar programmes underway for eradication of the same species in Lake Wakatipu (Otago Region). The discovery of hornwort incursions in Lake Ōkataina in 2010 and in Lake Ōkāreka in 2012 led to the development of incursion response plans (Lass 2017, Bathgate 2015) that have included delimitation surveys, containment nets within contaminated bays in Lake Ōkataina, control works at infested sites and ongoing surveillance. To date the amount of hornwort discovered in both lakes has been reducing and eradication remains possible. Detection of hornwort populations in the vicinity of Motueka and Timaru in the South Island have resulted from DOC pest fish surveillance. All South Island populations of hornwort are now considered eradicated (MPI 2013).

4 Tool 3: Aquatic weed control toolbox

4.1 Introduction

The term 'aquatic plant control' has a variety of definitions, for the purpose of this BMP the definition of the Aquatic Plant Management Society (USA) will be used.

> "*Techniques used alone or in combination that result in a timely, consistent, and substantial reduction of a target plant population to levels that alleviate an existing or potential impairment to the uses or functions of the water body*". (Excerpt from Netherland and Schardt, Undated (https://www.apms.org/resources/control/))

There are a number of control tools or techniques that can be used alone or in combination to control aquatic plants. The choice or selection of the most appropriate control tool(s) in the first instance is determined by relationship between four key components (1) the weed management goal or desired outcomes, and (2) the target weed species (see report - Part Two), (3) the type of waterbody and scale of infestation, and (4) available tools or methods (4.2 Methods).

The control of invasive aquatic plants is likely to result in trade-offs between the ability to control the weed species, the timeframes, costs and limitations of what can be achieved for the waterbody or lake in question with the method or tools used. The decision process requires an overview, with goals for managing the weed, the site and/or the region (Section 2). From the perspective of Strategic Analysis, weed management goals have already been described in that section.

Here, in this section, weed management goals that relate directly to the occurrence and abundance of existing weed problems are broadly categorised as Eradication (as outlined in the NPDWM), or Maintenance Control (covering Progressive Containment, Sustained Control and Site-led Control in the NPDPM). It is recognised that within a weed management programme there may be multiple goals or outcomes that are sought, and that these may change over different spatial or time and examples are given throughout. The utility of the weed control methods described in this section, to support eradication or maintenance control of weeds, is outlined.

This section focusses on operational methods and approaches; i.e., tools, methods or approaches that are available, and in use, in New Zealand, as opposed to those being researched, or herbicides that are not available in NZ. Control methods in general terms can be grouped into three categories (physical, chemical and biological).

- Physical control is a broad category involving removing vegetation or biomass (e.g., mechanical or manual harvesting), or habitat manipulation (e.g., barriers to plant growth).
- Chemical control refers to the use of registered herbicides (e.g., diquat, glyphosate).
- Biological control includes the use of organisms to graze on and control, or suppress the growth of target weeds.

Selecting an appropriate control tool or tools requires consideration of key factors such as the amount of weed biomass, both in terms of the density and area, and the utility of the control tool Figure 4). For example, hand weeding and bottom lining are feasible tools for low density and early weed incursions. Herbicides, harvesting and grass carp (biocontrol) are suitable tools for reducing large weed volumes. Species factors, such as the propensity of the plant to fragment and form new plants, or the presence of seed may mean that harvesting (where plant fragments are created) is only suitable in waterbodies that are already habitat saturated by that species, and where downstream spread is not an issue or can be mitigated. Site factors such as water depth, prevailing winds, wave fetch or substrate type in the littoral zone influence the suitability of mechanical methods or the placement of bottom lining fabrics. Whereas the use of grass carp is subject to statutory approvals and is site dependent. For example, site base factors that limit the use of grass carp include sites with connected watersheds in which grass carp cannot be contained, or with poor water quality or that are very shallow (Hofstra et al. 2014). These use considerations are dealt with in more detail under each method (Section 4.2).

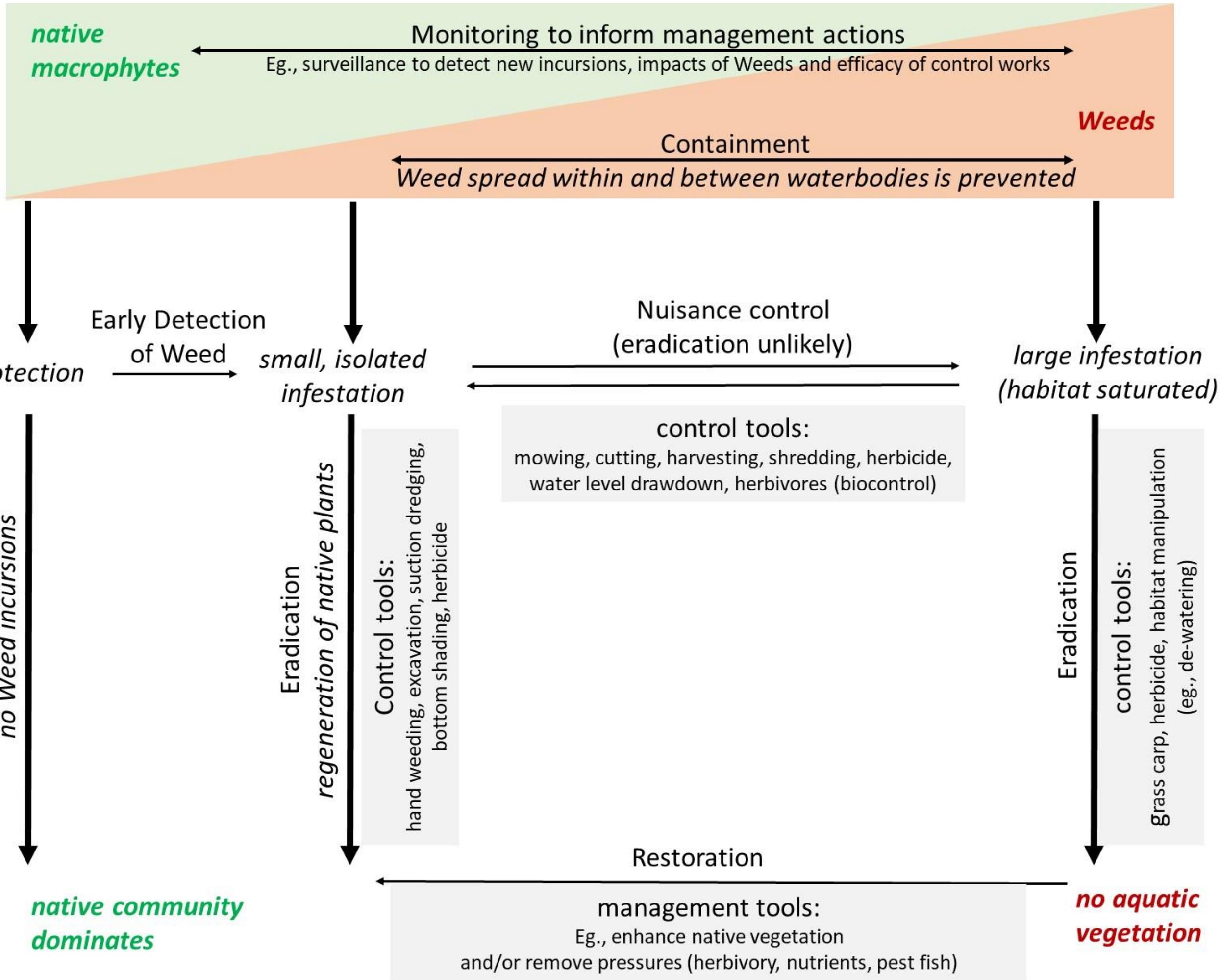

Figure 4: Weed management diagram illustrating the key factors for consideration when selecting appropriate weed control tool(s). The coloured banner represents the state of the ecosystem, with the balance of native (green) and invasive weed (orange) components informing the management goals or actions (black) and examples (grey boxes) of the available control tools to achieve the outcomes. (Adapted from Hussner et al. 2017).

Other weed management considerations include a legislative requirement to control some pest plants in regional pest management plans (see report - Part Two) and the need for monitoring to inform future decision making and progress towards goals (see section 4.4 Environmental monitoring). It is also noteworthy that doing nothing (no action) to control some aquatic weeds (transformer species), is likely to lead to increased environmental challenges in the future. As transformer species continue to persist and dominate the vegetation at a site, local impacts may compound, resulting in legacy issues that make future restoration more difficult (Hofstra et al. 2018). For example, the deterioration of native seedbanks under dense weed beds of submerged aquatic plants has been well established (de Winton and Clayton 1996; de Winton et al. 2000). In the absence of control, downstream impacts and the probability of expansion to new adjacent sites increases over time (Lockwood et al. 2009, Simberloff 2009), as unmanaged infested sites provide a pool of propagules from where dispersal to new sites can occur.

4.2 Methods

4.2.1 Physical – manual, mechanical, habitat manipulation

Amongst all control methods, but particularly physical methods, there are many potential options. The focus below is on those methods that are used operationally and able to deliver weed control as per the definition (*"timely, consistent, and substantial reduction",* (www.apms.org)).

Manual

Manual weed removal such as hand weeding, raking or netting is suitable for low levels of weed biomass.

(i) Hand-weeding
Hand-weeding is effective for removal of an early weed incursion, or the final stages of a containment or eradication programme. Hand-weeding enables the very selective removal of individual plants (including their roots and other sub-surface organs (e.g., rhizomes, tubers)) from small areas, and is suitable for removing target weeds from amongst desirable plants.

Hand-removal is relatively straight-forward for emergent and free-floating weeds, with many examples of eradication of early detected incursions by this method (Champion 2018a). Hand-weeding of submerged weeds may be possible by wading in shallow systems, but scuba or snorkel diving would be required in water depths of 1.2 m or more (Bellaud 2009). For submerged weeds, good visibility (water clarity) is very important, and demarcation of an underwater search grid (i.e., lines and marker buoys) make detection of submerged species more effective (de Winton et al. 2013).Only scuba divers certified by the Department of Labour (Certificate of Proficiency) should be used. Care in completely removing plants (e.g., avoiding shoot breakage, incorporating root crown) is very important (de Winton et al. 2013).

Hand weeding may appear to be an unlikely control tool, but for submerged weed species it often represents a key component of a broader-integrated weed management programme (Clayton 1996), such as for lagarosiphon in Lake Wanaka where suction dredging and herbicide have also been used (de Winton and Clayton 2016).

(ii) Raking and netting
As with hand-weeding, raking and netting can reduce the biomass of submerged weeds within limited areas. Raking and netting may result in plant fragmentation as the biomass is collected for removal. Depending on the target plant and the degree of plant fragmentation that is likely, these methods may not be suitable in eradication programmes, apart from netting of the larger free-floating weeds (e.g., water hyacinth (Tanner 1981). In addition, these methods may need to be repeated within a growing season, depending on weed re-growth from remaining plant material (e.g., basal stems or root crowns) (de Winton et al. 2013).

Summary – Manual control

Availability: Manual weed removal such as hand weeding, raking or netting is suitable for low levels of weed biomass.

Legislation: Weed disposal needs consideration.

Effectiveness: Effective for a range of species where there are low levels of weed biomass, in specific or targeted patches.

Constraints: Time consuming. For submerged plants water clarity is important. The potential for fragmentation and weed spread requires consideration.

Outcomes: Manual weed control is effective for removal of an early weed incursion, or the final stages of an eradication programme.

Mechanical

Mechanical control of invasive aquatic plants involves a diverse array of tools from weed cutters, harvesters and pulverisers to suction dredges. These tools are suitable for use at different sites and scales of weed infestation.

(i) Suction dredge and excavators

Diver operated suction-dredging (venturi suction pump) is useful for removal of targeted submerged infestations from areas at an early stage of establishment, or as part of on-going management where weed biomass is progressively controlled (leading to eradication) (e.g., Lakes Waikaremoana and Wanaka). It is suitable for small aquatic systems (<0.1 ha) or partial areas of larger systems, such as public amenity areas like boat ramps, to minimize the risk of weed transfer within a lake and between waterbodies (de Winton et al. 2013). Using a diver-operated suction-dredge, there is the potential to remove whole plants, including roots, and the dredged plants can be collected onto a floating barge, fine mesh bags and removed from the lake (Hofstra et al. 2018, Chapter 8). A clearance rate of up to 20 days per ha is likely in dense weed beds. Operations are likely to be one-off, particularly if the goal is weed eradication (with follow-up by hand weeding) or sediment removal. Shore-based suction dredging may be possible in small waterbodies (<0.1 ha), but larger systems are likely to require access for a barge. Water clarity, diver visibility, is also important. Although there may be temporary impacts on water clarity due to sediment disturbance, this technique is less suitable for hard-bottomed or rocky substrates (de Winton et al. 2013). Suction dredging, combined with follow-up hand weeding, has eradicated weeds from some sites in lakes (de Winton et al. 2013).

Similarly, excavators (drainage diggers, draglines etc.,) can be used for the eradication of localised populations of marginal aquatic weeds (in conjunction with follow-up monitoring), or for the control of weeds in drainage ditches and small waterbodies (Hussner et al. 2017).

(ii) Mowing, cutting and harvesting

Mowing and cutting, as the names suggest, refer to methods of controlling nuisance weeds that are akin to lawn mowing, and are best suited for maintenance control, or for the relatively instant removal of weed biomass for amenity or utility values. Mowing usually refers to the cutting of marginal aquatic plants, for example on ditch banks, whereas cutting is the term used for submerged weed beds, and often in conjunction with harvesting where the cut material is removed from the water body, rather than being left to drift downstream.

In effect, mowers, saw blades or 'weed eaters', may be used to reduce plant biomass and height to a near ground level. Suppression of tall-growing bank-side weeds such as yellow flag iris, reed sweet grass, Californian bulrush (*Schoenoplectus californicus*) or spartina may be provided by on-going mowing, although extra effort may be required to cut these back initially (de Winton et al. 2013). Repeated or maintenance mowing over time may also deplete the reserves in underground rhizomes of some of these weeds and result in a lower stature weeds (de Winton et al. 2013). Maintenance mowing of drainage systems in NZ is usually undertaken 2-4 times per year (Hudson and Harding 2004).

For cutting and harvesting, a boat-mounted sickle bar cuts the weed below the water surface and the weed is entrained onto a conveyor belt as the harvester moves forward. The collected lake weed may then be transported to shore directly for "out-of-lake" disposal. Consideration should be given to the risk of fragmentation and weed spread, and the potential of contaminated sites from harvested (dumped) weeds where species are known to accumulate heavy metals (e.g., arsenic).

Alternatively, the harvested weed may be shredded using a boat-mounted unit to reduce the bulk of harvested material thereby increasing the amount of weed that can be harvested prior to off-load at the shore. A further option is for the shredded material to be discharged back into the water, eliminating the need for shore disposal and increasing the efficiency of operations (Sabol 1987, Madsen 2000, Hofstra et al. 2015). Sabol (1987) reported that in-lake disposal of hydrilla reduced harvester down time by 50%. Most harvesting machines extract weed from water depths down to ca. 2 m below the water surface. In contrast to mechanical harvester units, boat-mounted shredders are not as readily available on the commercial market (the units currently in operation were constructed in-house (e.g., "Lois" by Mighty River Power)) (Hofstra et al. 2015).

Mechanical harvesting will not remove all weed biomass and weed beds can re-establish relatively quickly from remnant stems that are not removed. To manage the regrowth, harvesting may need to be repeated within a growing season (Howard-Williams et al. 1996) to prevent weed beds from occupying the entire water column and developing a canopy at the water surface (Wells et al. 2000). Harvesters are suitable in larger systems with extensive submerged weed beds, and require access for machinery as well as a suitable weed off-loading site (Haller 2014). Harvesters are able to operate in relatively shallow water (as little as 0.3 to 0.45 m water depth) (Haller 2014). However, the timeframes for weed removal (ca 3 days/ha cut time) and weed re-growth (species dependent) do need to be considered when assessing the feasibility of using harvesters for maintenance control (Hofstra et al. 2015).

Summary – Mechanical control

Availability: Commercial and bespoke mowers, cutters, harvesters and dredgers are available.

Legislation: Resource consent may be required, in particular for weed disposal.

Effectiveness: Harvesting is effective at reducing small to large volumes of weed (depending on the site and harvester). Individual weedbeds can be controlled for amenity or utility values.

Constraints: Generally not selective - except diver operated suction. The size and shape of waterbody determines which areas of weed are accessible for control. Consideration should be given to the risk of fragmentation, weed spread, and suitable disposal sites for harvested weed. For submerged plants, cutters are restricted to shallow cut depths, so recovery may be rapid.

Outcomes: Cutters and harvesters are suitable for localised control of nuisance weeds. Suction dredging can be utilised for small scale weed eradication or as a component of a larger programme.

Habitat manipulation

Habitat manipulation may be defined as altering the aquatic environment to favour desirable vegetation at the detriment of the target aquatic weeds. This includes techniques such as installing benthic barriers or bottom lining to shade out target plants, or controlling the water level (e.g., water level manipulation or drawdown).

(i) Benthic barriers

Benthic barriers, also known as bottom lining, can be used to smother submerged aquatic plants initially, and impede access to the substrate for rooting by plant fragments or propagules (Hofstra et al. 2015). The use of benthic barriers for localised control of aquatic weeds is well documented (Peterson et al. 1974, Perkins et al. 1980, Engel 1983, Nichols and Shaw 1983, Jones and Cooke 1984, Killgore 1987, Gunnison and Barko 1992, Newroth 1993, Payne et al. 1993, Carter et al. 1994, Eakin and Barko 1995, Eichler et al. 1995, Helsel et al. 1996, Madsen 2000), and many products are readily available for small-scale use. Considerations for successful weed control with a benthic barrier include choice of product, permeability of the product, ease of placement and retrieval (if necessary), the nature of the site (gradient, underlying substrate, wave fetch) and duration of barrier placement required. For example, wind or wave exposed sites with steep shores are not suitable for benthic barriers. The ability to secure the benthic barrier at a potential site, in a way that supports the uses of the area, must also be considered.

Non-permeable products, such as plastic sheeting, inhibit exchange of water and gases between the benthos and the water column. These products may be difficult to install and secure to the bottom of the lake and may billow-up in places due to trapped gas from decomposing plants. Non-permeable benthic barriers are generally nonselective, in that all plants are smothered and controlled over time, with some variation between species in their ability to withstand shading. Plants may also grow through slits in barriers made for gas release, and with permeable barriers some species may persist and grow through the apertures as well as on top of the barriers from newly arrived plant fragments, particularly once suspended sediments have accumulated.

Jute or hessian matting has also been used to smother invasive weeds with the added benefit that desirable native plants are able to regenerate from the seed bank below and grow through the small apertures in the barrier fibre (Caffrey et al. 2011). This type of benthic barrier provides for native plant re-establishment as the barrier degrades (Caffrey et al. 2011, Hofstra and Clayton 2012), and in recent years has been used to control lagarosiphon beds in Lake Wanaka (de Winton et al. 2018). Another advantage is the natural decomposition of the barrier, with breakdown evident ca. 7-10 months before disintegration (Caffrey et al. 2010).

Benthic barriers are appropriate for control of submerged weed species in small areas (such as boat ramps) or systems, with the upper suggested feasible size for installation being 0.4 ha (USACE 2012). Approximately 1 ha was covered with hessian matting in 2017/18 in Lake Wanaka (de Winton et al. 2018). Weed control can be provided for a number of years, with little on-going costs, depending on the site, and the choice of barrier product used (de Winton et al. 2013). For example, most effort is involved at the installation phase, although regular (annual) checks should be undertaken to ensure the barrier has not shifted or if any repairs are required (this again depends on the product choice and the site). Temporary dropping of water levels may be advantageous for the installation of benthic linings. Likewise, the removal of weed biomass by harvester or herbicide might be required prior to laying benthic barriers (de Winton et al. 2013).

Summary – Benthic barrier

Availability: A range of potential barrier products are available.

Legislation: Consent may be required for installation in public lakes.

Effectiveness: Effectiveness has been demonstrated for a range of submerged weeds and products, with selective control of weed species in some cases.

Constraints: Effectiveness is dependent on target weed species, type of benthic barrier and the site suitability. Not all sites are suitable (e.g., exposed and/or rocky sites).

Outcomes: Can support localised nuisance weed control and/or integrated eradication programmes.

(ii) Drawdown

Water level manipulation can be used to control nuisance weed growth. The aim is to expose submerged weeds to drying or freezing conditions, with sufficient desiccation or cell rupture to result in plant mortality. The exposure must be of sufficient duration under suitable conditions to achieve a significant impact on weed survival. Water level drawdown has been trialled in hydro-electric lakes. However, while this technique went some way toward controlling nuisance weed growth, it was discontinued due to cost (lost ability for power generation), adverse environmental impacts (erosion, slumping), and the weed re-growth was often rapid (Clayton et al. 1986). The technique has the potential for lake-wide weed control if dewatering can be achieved, but outcomes are dependent on the plant biomass, with high biomass leading to greater protection of plant material in the bottom layers from desiccation or freezing. A practical difficulty is the accurate forecasting of suitable conditions to time drawdown with conditions for maximal drying or freezing effect.

The complete drawdown or drying out of small waterbodies is a potential control or eradication method for submerged, floating-leaved and free floating macrophytes, where the complete loss of water from a small pond is feasible (Bellaud 2014). Where artificial water bodies (e.g., farm dams and ornamental ponds) are infested with species that produce a long-lived seed bank, draining and filling of the water body and creation of a new dam has been effectively used (e.g., water hyacinth).

Summary – Drawdown

Availability: The method is dependent on the nature of the waterbody and the ability to drawdown sufficient water over an appropriate time period.

Legislation: Consent may be required.

Effectiveness: Can be effective on a range of weeds if the required exposure period is achieved.

Constraints: Weather or operational windows in larger waterbodies may constrain the use of this method. Better suited for smaller, private waterbodies. Exposed, decaying weed beds may be odorous.

Outcomes: Could support weed maintenance or small scale weed eradication programmes (e.g., whole of pond desiccation).

4.2.2 Chemical – available herbicides

The use of herbicides is subject to control set by EPA, on the herbicide active ingredients and permissions to management agencies stating which species may be managed using those herbicides (under Hazardous Substances and New Organisms Act). Regional authorities issue resource consents that must comply with EPA controls (under Resource Management Act). However, not all aquatic herbicides have EPA controls and some may be permitted activities under regional councils and therefore not require a resource consent.

Herbicides can provide selective and targeted biomass reduction, and/or eradication of aquatic weeds. Herbicides are generally recommended for controlling small, new weed incursions, as well as at larger scale infestations where the habitat is saturated (Figure 4).

There are two herbicides, diquat (dibromide salt) and endothall (dipotassium salt), registered for use on submerged aquatic plants in New Zealand. While glyphosate (isopropylamine) may be used to control emergent plants around waterways, and the use of additional 'restricted' herbicides (metsulfuron methyl, haloxyfop methyl, imazapyr isopropylamine and triclopyr triethylamine) is possible under regulated conditions, to enable the eradication and control of priority national and regional pest plants (de Winton et al. 2013).

Products can be applied via hand held sprayers, submerged trailing hoses (e.g., by boat) or from the air (e.g., by helicopter). Product placement can be improved by using dye tracers (e.g., rhodamine dye) to predict water movement, by the addition of gelling agents in the product to alter viscosity in the water, and with GPS tracking to improve accuracy and cover of large weed beds (Hofstra et al. 2018).

Diquat

Diquat (diquat dibromide) is the active ingredient (20% a.i.) in Reglone®. This herbicide is used in New Zealand for agricultural operations (root crop desiccation pre-harvest) and has been the primary method of large scale control of aquatic weed beds in New Zealand lakes and reservoirs since 1960.

Diquat is a selective herbicide that controls most unwanted target weed species in freshwaters (e.g., hornwort, egeria, lagarosiphon and elodea). When diquat is in contact with the green parts of nuisance aquatic weeds (leaves and stems) it is rapidly absorbed producing peroxide that acts like a bleach, desiccating plant tissue and disrupting cell membranes. Diquat is rapidly removed from the water and is deactivated by adsorption onto negatively charged inorganic and organic compounds in the water and sediments (Clayton and Severne 2005). Adsorbed diquat or diquat bound to sediment has no known residual toxicity, and over time this inactive bound form of diquat is degraded by microbial organisms. There is no evidence of food chain accumulation from repeated use of diquat (Clayton and Severne 2005). Traces of adsorbed diquat can be detected in benthic sediments as a chemically bound, biologically inert compound for extended periods of time. This can result in negative public perception, however data collected from sites with long term diquat use do not show any adverse impacts on aquatic biota (Clayton and Severne 2005).

Weed beds can be controlled with diquat at any time of the year, although efficacy is better in the warmer months (Netherland et al. 2000) and plant decay rates are slower in winter. Effective control is best when plants are clean (i.e., little or no epiphytes, detritus or aufwuchs) and water movement is minimal. Water clarity is also an important consideration, since turbid water can significantly reduce diquat efficacy. Important native plant species, such as the charopytes (*Chara* and *Nitella* species), are not affected by diquat (Clayton 2004, Clayton and Severne 2005, Netherland 2014).

Diquat is applied to the water around the target weed bed by spraying on the water surface, via trailing hoses, submerged boom or diver injection. Herbicide effect is possible after a very short contact time (minutes to a few hours), given sufficient concentration (1 ppm) on target species such as hornwort (e.g., Hofstra et al. 2015). Large areas of weed (50 – 100 ha) can be effectively treated within relatively short timeframes of ca. 2 days using aerial spraying, given sufficient concentration and exposure time (ca. hours), collapse of target weed beds usually occurs within 1-2 weeks.

Diquat use is not subject to EPA controls. Its use as an aquatic herbicide is a permitted activity in some regions. Use in other regions requires a resource consent under the Resource Management Act.

Label requirement specify a swimming restriction of 24 hrs to treated waters, including restrictions on water intakes for drinking and irrigation (swimming restrictions are no longer considered necessary in the USA). Weather conditions (particularly wind speed, and occasionally thermal inversion) must be optimal to minimise risk of aerial drift of herbicide. Water intakes for overhead irrigation have a 10 day withholding period following diquat treatment. There is a risk of unsatisfactory control outcomes that may require further treatments.

Summary – Diquat

Availability: Diquat (diquat dibromide) is the active ingredient (20% a.i.) in Reglone® and has been used for aquatic weed control since the 1960s.

Legislation: Diquat has no EPA controls and is a permitted activity by some regional councils. Resource consent may be required.

Effectiveness: Demonstrated efficacy on a range of target aquatic weeds (e.g., hornwort, egeria, lagarosiphon).

Constraints: There are water use restrictions, and weather conditions should be optimal for application. Diquat is deactivated by turbid waters and is less effective when plants are 'dirty'.

Outcomes: Suitable for targeted weed control (e.g., public lake access points), in larger maintenance control programmes, and in integrated programmes for weed eradication.

Endothall

Endothall (dipotassium salt) is the active ingredient in Aquathol K®. Endothall is described as a contact-type herbicide (Sprecher et al. 2002), with a recent study indicating that it has some systemic activity (Ortiz and Nissen 2017). Endothall is a membrane-active herbicide that rapidly produces symptoms of defoliation and desiccation in terrestrial plant parts with which it comes in contact by disrupting solute transport processes in plant cells. Similar symptoms occur in aquatic plants, with defoliation and necrotic tissue followed by death or peak injury within 4 to 6 weeks of initial treatment (Sprecher et al. 2002).

The ability of endothall to affect aquatic plants was discovered in 1953, and it was registered as an aquatic herbicide in the USA in 1960 (Keckemet 1969). Endothall was approved for use as an aquatic herbicide in New Zealand by NZ ERMA (now EPA) in 2004. The aqueous formulation, Aquathol K, is applied in the same way as diquat, by either spraying onto the water surface or pumping it through hoses from a boat. Unlike diquat, endothall is not affected by water turbidity (Hofstra et al. 2001). The pellets, Aquathol Super K, may be scattered over the target area, where they sink to the bottom. Endothall requires a longer contact time than diquat and efficacy is dependent on the concentrations and contact times achieved. The maximum permitted label concentration in water is 5 ppm, but target species are susceptible at lower concentrations provided a longer contact time can be achieved. Susceptible pest plants include hornwort and lagarosiphon but the nuisance weed egeria is not affected (Hofstra et al. 2015). Endothall has been used to eradicate pest plants (hornwort and lagarosiphon) in seven small water bodies to date where 'whole of water body' treatment was feasible (Wells and Sutherland 2013, Wells et al. 2014).

Environmental studies have shown that desirable key native plants (*Chara* and *Nitella* species) are not affected (Hofstra and Clayton 2001), there are virtually no negative impacts on fish and other aquatic life (Hofstra and Clayton 2001), and that endothall is broken down by microbes to simple compounds and is not bio-accumulated (USEPA 2005).

The use of endothall in New Zealand is subject to a number of controls set by ERMA (now EPA). Any use of endothall requires a permission from EPA under HSNO. Restrictions on use include:

- Withholding periods for the use of treated water for drinking, watering livestock, irrigation or preparing agrichemical sprays. Withholding periods are concentration dependent, being:
  - 7 days at concentrations ≤ 0.50 mg/L
  - 14 days at concentrations ≤ 4.25 mg/L
  - 28 days at concentrations ≤ 5.00 mg/L

  unless concentrations do not exceed the TEL (tolerable exposure limit) of 0.28 ppm and the EEL (environmental exposure limit) water 0.086 ppm.
- No taking of fish for consumption within 3 days of application.
- No swimming within 24 hours of application.
- Spray must not be applied to > 25% of the water body area.
- Spray must not be applied into estuaries or water bodies within 1 km of the coast during May 1st to August 31st.
- Monitoring of spray operations include measurements of pH, dissolved oxygen, % plant cover and presence of native plants in the spray area, at least 5 days prior to spray and 15-20 days after herbicide application.

Additionally, a resource consent granted under the Resource Management Act is required for all regions, that must not contravene EPA controls or permissions.

Summary – Endothall

Availability: Endothall (dipotassium salt) is the active ingredient in Aquathol K®, it is described as a contact-type herbicide with some systemic activity and was registered for aquatic use in 2004.

Legislation: Requires compliance with the EPA permit and an RMA consent for all regions.

Effectiveness: Demonstrated efficacy on a range of target aquatic weeds (e.g., lagarosiphon and hornwort).

Constraints: There are water use restrictions, and weather conditions should be optimal for application. Requires a longer contact time than diquat.

Outcomes: Suitable for targeted weed control in maintenance control programmes, and for weed eradication.

Glyphosate

Glyphosate (isopropylamine), is a broad-spectrum, systemic herbicide that may be used to control plants around waterways (de Winton et al. 2013). Glyphosate works by inhibiting protein synthesis in plants, and when applied to green tissue, it is translocated to growing points, including below ground organs (de Winton et al. 2013). Glyphosate should be applied to actively growing target plants and it is effective against emergent and marginal plants and trees such as willows. Both crack willow (*Salix xfragilis*) and grey willow (*Salix cinerea*) have been managed with glyphosate using aerial application and via drill and inject. Glyphosate also effectively controls grasses (e.g., Mercer grass, kikuyu, pampas, tall fescue, reed sweet grass, reed canary grass, creeping bent), sedges (e.g., rautahi), some rushes, and floating ((salvinia (*Salvinia molesta*), water hyacinth (*Eichhornia crassipes*) (Lopez 1993, Martins et al. 2002)), floating leaved ((water poppy, water lilies including *Nymphaea mexicana* (Champion 1999, Hofstra et al. 2013)) and marginal species (e.g., raupo, willow weeds, water cress) (de Winton et al. 2013). Glyphosate does not affect submerged aquatic plants, while variable results have been reported for a number of marginal aquatic weeds ((e.g., alligator weed, Manchurian wild rice, phragmites, purple loosestrife (*Lythrum salicaria*) (Gardner and Grue 1996), sagittaria, Senegal tea or spartina)). In general, glyphosate is less effective against rhizomatous species (de Winton et al. 2013).

There are several products available that have glyphosate as the active ingredient (a.i.) and these may be augmented with surfactants and adjuvants. Only products labelled for use around waterways should be used where contamination of water may occur, due to the toxicity of some types of surfactants for aquatic life. Formulations generally have 360 g per L glyphosate isopropylamine as a soluble concentrate.

Glyphosate may be sprayed or wiped onto green plant surfaces, and for woody species, herbicide may be drilled and injected, or cut stumps applied. At higher rates a spray mix of 8.1 g per L (or mg per kg) should be applied at the rate of 9 L of the 360 g per L a.i. applied per hectare. Application should seek to reduce environmental loads by treating before weed seed-set and spraying banks when water levels are low. It takes several weeks for susceptible plants to die off and may need follow-up where germination of plants occurs throughout the growing season e.g., willow weeds (de Winton et al. 2013).

Glyphosate does not bioaccumulate or persist in a biologically available form in the environment and, as the mechanism of action is specific to plants, it is relatively nontoxic to animals (Solomon and Thompson 2003). In most situations glyphosate is inactivated on contact with soil and has no residual activity.

Glyphosate use where contamination of water may occur is not subject to EPA controls. Its use as an aquatic herbicide is a permitted activity in most regions and is not subject to resource consent requirements (de Winton et al. 2013). However, some regions e.g., Auckland require a resource consent under the Resource Management Act for use in aquatic areas.

Summary – Glyphosate
Availability: Glyphosate (isopropylamine), is a broad-spectrum, systemic herbicide that may be used to control plants around waterways.
Legislation: Only products labelled for use around waterways should be used where contamination of water may occur. In most instances, the use of glyphosate in these environments is not subject to resource consent.
Effectiveness: Controls a wide range of marginal and floating leaved aquatic plants.
Constraints: Glyphosate is not specific, so non-target plants may be affected. Glyphosate is less effective against rhizomatous species.
Outcomes: Suitable for targeted control of nuisance marginal weeds, and for weed eradication in an integrated management plan.

Restricted herbicides

Use of the herbicides (metsulfuron-methyl, haloxyfop-R-methyl, imazapyr isopropylamine and triclopyr triethylamine salt) is possible under regulated conditions (NZ EPA 2012), to enable the eradication and control of priority national and regional pest plants. These products are only for use by organisations with biosecurity responsibilities (e.g., MPI, DOC, Regional Councils) and are not permitted for use for other purposes.

The target aquatic weeds include, but are not limited to: alligator weed (*Alternanthera philoxeroides*), Californian bulrush (*Schoenoplectus californicus*), fringed water lily (*Nymphoides peltata*), Manchurian wild rice (*Zizania latifolia*), marshwort (*Nymphoides montana*), phragmites (*Phragmites australis*), purple loosestrife (*Lythrum salicaria*), arrowhead/sagittaria (*Sagittaria* species), salvinia (*Salvinia molesta*), water hyacinth (*Eichhornia crassipes*), water poppy (*Hydrocleys nymphoides*), Senegal tea (*Gymnocoronis spilanthoides*), *Spartina* species and yellow flag iris (*Iris pseudacorus*).

The EPA set a number of controls around the use of these herbicides including the determination of environmental exposure limits (EEL) that must not be exceeded to protect aquatic organisms and tolerable exposure limits (TEL) for maximum concentrations in drinking water. EPA also set maximum application rates and intervals (Table 1) and conditions or controls on the use of the herbicides (EPA 2013).

The EPA decision should be consulted for the detailed conditions (EPA 2012), although some key points are outlined below:

- A permission must first be obtained from the Authority under section 95A of the Hazardous Substances and New Organisms Act 1996.
- The herbicides can only be applied by an approved handler.
- For substances containing Haloxyfop-R-methyl or triclopyr triethylamine: signage should include restrictions on swimming, food gathering and the taking of water for consumption for 21 days in static water.
- For substances containing metsulfuron-methyl or imazapyr isopropylamine: signage should include restrictions on swimming, food gathering and the taking of water for consumption. For static waterbodies, no more than 33% of the water body can be treated at any one time. Further the herbicide must not be applied to any additional sections of the water body for at least seven days after the last application of the substance to that water body. These controls do not apply if the average dissolved oxygen level for the static water body is less than 4 mg/L at the time of application.

Table 1: Maximum application rates for restricted herbicides. (Source: NZ EPA 2012, Decision APP201365).

	Metsulfuron-methyl	Haloxyfop-R-Methyl	Imazapyr isopropylamine	Triclopyr triethylamine
Maximum application rate	0.084 kg ai/ha	0.75 kg ai/ha	2 kg ai/ha	7.92 kg ai/ha
Maximum application frequency	3 times per year	3 times per year	3 times per year	3 times per year
Minimum application interval	30 days	30 days	30 days	30 days
$\textbf{EEL}_{\text{water}}$	0.0084 µg/L	0.884 µg/L	0.18 µg/L	59 µg/L
$\textbf{TEL}_{\text{drinking water}}$	0.04 mg/L	0.0021 mg/L	9 mg/L	0.1 mg/L

All applications of these herbicides require a resource consent under the Resource Management Act, that must not contravene EPA controls or permissions.

(i) Metsulfuron-methyl

Metsulfuron-methyl was first available in NZ in the 1980s. It is a residual sulfonylurea compound, that is used as a selective pre- and post-emergence herbicide generally for broadleaf and woody weed control. Metsulfuron is rapidly taken up by plant roots and foliage, is translocated throughout the plant, but is not persistent. Amongst aquatic weeds, it provides control of alligator weed, yellow flag and arrowhead. In tolerant plants (e.g., grasses and sedges), this herbicide is broken down to non-herbicidal products (Champion 2012a, b, c).

In experimental studies with alligator weed, metsulfuron at 36 g ai/ha provided the best control of well-established plants (Hofstra and Champion 2010). Root biomass and especially shoot biomass were significantly reduced when plants were retreated compared to single applications (Hofstra and Champion 2010). However, studies have shown when treating alligator weed growing overwater, utilising glyphosate (isopropylamine salt) reduced the number of viable fragments produced by 72-90% compared to metsulfuron and imazapyr. Therefore, reducing the potential for dispersal throughout catchments and waterways (Clements et al. 2017). In urban areas, injection of metsulfuron into alligator weed stems has been a highly effective and selective control method (Champion 2016).

Similarly, metsulfuron (0.3 g ai/L plus 0.1% surfactant) provided excellent control (100% where good coverage was achieved) of yellow flag iris (Hofstra et al. 2018). Important points in this example are an autumn application, and that metsulfuron had the advantage compared with glyphosate, of causing little off target damage to native sedges and raupo (Hofstra et al. 2018).

(ii) Haloxyfop
Haloxyfop-R-methyl was first used in the early 1990s. It is a systemic herbicide, that is readily absorbed through plant leaves, disrupting growth (inhibiting acetyl CoA carboxylase) and resulting in death in two to three weeks after treatment. Haloxyfop is a highly selective graminicide that does not affect broadleaf plants. It selectively controls invasive grasses including spartina, Manchurian wild rice and saltwater paspalum (*Paspalum vaginatum*), with no impact on non-target plants including sedges, rushes and other monocotyledons and dicotyledons at rates effective on target grasses (Champion (2012a).

(iii) Imazapyr
Imazapyr (isopropylamine) is a systemic herbicide that is absorbed by the foliage, and rapidly translocated through the plant, where it inhibits production of the plant enzyme acetolactate synthase ALS. Susceptible plants stop growing, with plant death and decomposition occurring over the subsequent weeks to months (Carey et al. 2005, MacBean et al. 2010, Champion 2012a). Imazapyr is also active in the soil (Netherland 2014).

Imazapyr is a broad-spectrum herbicide that is effectively used on aquatic plants with emergent growth (Netherland 2014). It is reported to control marshwort, fringed waterlily, yellow waterlily, water hyacinth, alligator weed, arrowhead, sagittaria, spartina, giant reed, phragmites, purple loosestrife and willows (Champion 2012a). For example, Imazapyr (at 0.16 to 0.64 kg ai/ha with respray) results provided significant reduction in alligator weed biomass with repeated application on mature plants (Hofstra and Champion 2010).

(iv) Triclopyr
The triethylamine salt formulation of the herbicide triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) is a systemic herbicide that has traditionally been used for the control of woody and broadleaf plants. More recently it has been used for the control of submerged and marginal aquatic plant species such as *Myriophyllum spicatum* in the USA (Getsinger et al. 1997), alligator weed and parrot's feather (Anderson 1999), producing a characteristic auxin-like response in growing plants (Sprecher and Stewart 1995, Hofstra and Clayton 2001, Netherland 2014).

Triclopyr is selective with grasses, sedges, rushes and aquatic species such as the pondweeds (*Potamogeton* species), *Typha*, *Elodea canadensis* and *Vallisneria spiralis* reported as being undamaged in areas where triclopyr was used to control susceptible species (Sprecher and Stewart 1995, Hofstra et al. 2006).

The label for this herbicide recommends its use as a foliar spray against alligator weed and parrot's feather and as a basal stem treatment on willows (Champion et al. 2008).

Based on a greenhouse study, Champion et al. (2008) report that triclopyr at rates between 0.25% and 5% v/v (applied to run-off) resulted in excellent control of grey willow (*Salix cinerea*), crack willow (*Salix* x*fragilis*) alder (*Alnus glutinosa*) primrose willow (*Ludwigia peploides*), water celery (*Apium nodiflorum*), water cress (*Nasturtium officinale*) and *Erythranthe guttata* (monkey musk) at all rates. However, purple loosestrife was not controlled well at the lowest rate. Subsequent field trials found triclopyr gave good control of grey willow, alder, water celery and purple loosestrife

(Champion et al. 2011). Native monocotyledonous species (especially grasses, rushes and most sedges) mostly survived herbicide application, indicating that triclopyr was more selective for these species than glyphosate (Champion et al. 2011).

In mesocosm and field trials triclopyr was effective at controlling parrot's feather, reducing biomass to zero (or near), with little or no plant recovery. Parrot's feather treated with rates of 0.5 and 1 kg ai/ha differed from the plants treated with 2 kg ai/ha, only in the speed of onset of symptoms, and from 6 weeks after treatment (WAT) these plants were all dead. Rates as low as 0.025 kg ai/ha triclopyr significantly reduced the biomass of parrot's feather by 18 WAT. Under field conditions triclopyr has successfully reduced the cover and presence of parrot's feather (Hofstra et al. 2006). Triclopyr amine (Garlon 360™) has been utilised on parrot's feather at Kongahu, north-west coast, South Island. Control at the site was not universally successful, and parrot's feather has subsequently continued to spread.

Although there are several studies that evaluate the efficacy of triclopyr on alligator weed (e.g., Hofstra and Champion 2010, Roten et al. 2011, Cox et al. 2014) there are mixed results compared with the efficacy of other herbicides. Further trials following the Champion (2008) review demonstrated that triclopyr did not provide any better control of alligator weed than other herbicides in the programme (Hofstra and Champion 2010) and as such triclopyr was no longer advocated for alligator weed control in the Waikato (Champion 2016).

Summary – Restricted herbicides

Availability: Use of the herbicides, metsulfuron-methyl, haloxyfop methyl, imazapyr isopropylamine and triclopyr triethylamine, is possible under regulated conditions (NZ EPA 2012, Decision APP201365), to enable the eradication and control of priority national and regional pest plants.

Legislation: These products are only for use by organisations with biosecurity responsibilities (e.g., MPI, DOC, Regional Councils) and are not permitted for use for other purposes.

Effectiveness: Efficacy on a wide range of target species has been established.

Constraints: See EPA conditions.

Outcomes: Suitable to enable the eradication and control of priority national and regional pest plants.

4.2.3 Biological

Biological control refers to the use of one biological organism (including natural predators, parasites, or pathogens) to control another. Biological control (or biocontrol) may be further defined in terms of classical biological control (CBC) where the target weed, in this case, and the organism have a very specific association such that abundance of the weed and agent closely follow one another, or generalist biocontrol where there may be multiple weeds targeted by the agent.

CBC agents have only been introduced into New Zealand for the control of one species of aquatic weed, alligator weed (Julien 1981). Generalist biocontrol of aquatic weeds can be provided by the herbivorous fish grass carp (*Ctenopharyngodon idella*). These fish consume a wide range of plants in order of the feeding preference of the grass carp (Rowe and Schipper 1985, Hofstra et al. 2014).

Biocontrol agents are generally only suitable for use in weed control programmes where the habitat is saturated (Figure 4).

Classical biocontrol

The aim of classical biological is not to eradicate a weed from a specific area (this would also eliminate the introduced biological control agent) but reduce the spread and density of infestations once established (Petty 2005). Classical biocontrol of aquatic pest plants in NZ is currently limited to the use of arthropods as control agents on alligator weed. A flea beetle, *Agasicles hygrophila*, and a moth, *Arcola* (formerly *Vogtia*) *malloi,* have been widely released in the upper North Island (Stewart et al. 1999; Winks 2007a and b). Flea beetle adults and larvae feed on the leaves and stems of aquatic alligator weed (Winks 2007 a). Caterpillars of the moth graze on and destroy stems of aquatic alligator weed, while the adults are general nectar feeders (Winks 2007b). Flea beetles will naturally disperse from adjacent infestations, if these are close, and if not already present at the site, they could be collected from a source site (ca. 100 adults) and actively released at new alligator weed infestations (Winks 2007a). Likewise, adult moths can move short distances, otherwise stems occupied by caterpillars can be collected in late summer (kept damp and cool) and subsequently introduced to a new alligator weed site (Winks 2007b, de Winton et al. 2013).

These CBC agents are best introduced to large, aquatic beds of alligator weed, where they may contribute to some level of weed suppression (van Oosterhout 2007, de Winton et al. 2013). Neither CBC agents will establish on or control alligator weed growing on land (as opposed to weed growing over water) (Winks 2007a and b). Sites where flowing waters periodically flood over the alligator weed beds are also not suitable for the CBC agents, due to the removal and loss of these agents under those conditions (Winks 2007a and b). Similarly, there is also evidence in Australia that flea beetle is less successful in drains and small, ephemeral waterways than on larger, permanent water bodies (Julien and Bourne 1988). In addition, the strain of flea beetle present in New Zealand and the moth are both limited by temperature, and therefore are not suitable for widespread (Stewart et al. 1999) effective (Hayes 2007) control of alligator weed (de Winton et al. 2013).

Similar constraints have been observed in Australia, where “biological control of alligator weed has been successful in water in areas with mild or warm winters, but not on land” (Sainty et al. 1998), and in the USA. For example, “in the southeastern United States where the alligator weed flea beetle has been introduced, biocontrol success can range from complete to negligible depending on the season, geographic area and habitat” (Cuda 2014a, chapter 8). The alligator weed flea beetle (*Agasicles hygrophila*) was introduced in the USA in 1964 and has provided excellent control of the floating form of alligator weed from southern Florida along the Gulf Coast to southern Texas. The alligator weed flea beetle is not as cold-tolerant as alligator weed and insect populations die out during severe winters in the central and northern parts of the Gulf States. Alligator weed remains a problem in areas such as central and northern Texas, Mississippi, Alabama, Georgia and the Carolinas (Cuda 2014b).

CBC is most appropriate where weed suppression is the goal, as opposed to weed eradication or where targeted removal of specific weed beds is required (e.g., clearance weed from a boat ramp).

This option is less effective than chemical control options but may be more acceptable to the public under some circumstances. There are no consent requirements or health and safety concerns for use of existing CBC agents (de Winton et al. 2013). However, prior to the release of CBC agents there is a rigorous experimental process to assess host-specificity and risks of potential off-target impacts, before permission for release is obtained by EPA under the HSNO Act (New Organisms). This is an important process, because once established in the environment, the 'release' of CBC agents cannot be undone.

Summary – Classical Biocontrol

Availability: CBC agents are only available for alligator weed control.

Legislation: No consent requirements for these agents.

Effectiveness: CBC can provide some weed suppression in warmer regions only.

Constraints: Unpredictable level of weed control.

Outcomes: May be used as part of an integrated weed management plan for nuisance control or weed suppression.

Grass carp

Grass carp (*Ctenopharyngodon idella* Val) are the only biocontrol option that are currently available for submerged aquatic weeds in New Zealand (Hofstra et al. 2014). Grass carp are herbivorous fish, native to Asia (Cudmore and Mandrak 2004). They were brought to New Zealand to assess their potential use for controlling aquatic weeds, with the first consignments of grass carp arriving in 1966 (Chapman and Coffey 1971), and again in 1971 (Edwards and Hine 1974). Initial studies focussed on feeding preferences (Edwards 1973; 1974, Rowe and Schipper 1985). Grass carp were subsequently released for a variety of field studies in small waterbodies to assess their potential impacts (Edwards and Moore 1975, Mitchell 1980, Schipper 1983, Rowe 1984). These initial studies provided data on the potential use of grass carp for weed control in temperate New Zealand environments and addressed the potential impacts of grass carp in New Zealand lakes (Rowe and Hill 1989). Issues with respect to containment arose after some fish escaped into the lower Waikato River (McDowall 1984), and this event resulted in the production of an Environmental Impact Assessment (EIA) to formally address the use of this fish for weed control in New Zealand (Rowe and Schipper 1985). The report analysed the potential impacts of grass carp, and uses, including their potential to eradicate certain problem weed species in lakes. It also confirmed the lack of suitable habitat for grass carp to form a self-sustaining population in New Zealand waterways. It was followed by public consultation and an internal report (Rowe et al. 1985) seeking the formal release of these fish for weed control. This was subsequently granted by the New Zealand Government subject to conditions (e.g., the use of sterile triploid fish) and control by the Department of Conservation and the Ministry of Fisheries (now MPI) (Conservation Act 1987).

The Conservation Act 1987 (Sections 26ZM, 26ZQA) requires Ministerial approval to possess, transfer and release new fish, including grass carp to environments where they have not been recorded before. An application must be made to the Department of Conservation (DOC) for the transfer of grass carp to a new location and DOC may require an impact assessment. Under the Freshwater Fisheries Regulations (1983) consent may be required from the Fish and Game Council with local jurisdiction before fish are liberated (part 8 r59), and releases of grass carp following the initial release need to be approved by Ministry for Primary Industries (MPI).

In 1993, the use of triploid grass carp was reviewed and public feedback on options for future management, including the use of diploid fish, were sought (Coffey 1993). Following the review and the feedback obtained, the use of diploid fish for weed control was approved.

The feeding preference of grass carp, is one of the most studied aspects of grass carp biology, although some contradictory preferences have been listed for several plant species that the fish consume (Mehta and Sharma 1972, Edwards 1973; 1974, Cassani 1981, Rowe and Schipper 1985, Swanson and Bergersen 1988, Pine and Anderson 1991, Spencer 1994, Stewart and Boyd 1999, Masser 2002, Kirkagac and Demir 2006, Dibble and Kovalenko 2009). In general terms grass carp consume most plants that are accessible to them in order of their preference. Grass carp preference is for softer leaved species (e.g., charophytes and pondweeds) before comparatively tougher plants (e.g., hornwort and milfoil) or 'blister raising' species (e.g., *Ranunculus* spp.) (Rowe and Schipper 1985). Grass carp feeding preference has been attributed to the chemical/nutritional properties of the plant, the ease of mastication (Wiley et al. 1987, Bonar et al. 1993, Pipalova 2002), and the source of the plants (Chapman and Coffey 1971).

Not all waterbodies are suitable for grass carp, site considerations must include factors such as water quality (e.g., pH and oxygen) and temperature, and the ability to contain the fish. Given that other water quality parameters are acceptable to freshwater fish in general, grass carp feeding, the rate of plant consumption and fish growth are driven by water temperature (Spencer 1994). In general, grass carp feeding in New Zealand is maximal during summer months and minimal during winter, and water temperatures over 20°C for at least a month are considered necessary to enable weed control by grass carp (Hofstra et al. 2014).

Containment is essential to maintain grass carp stocking density and efficacy and prevent non-target (off site) impacts. The feasibility of grass carp use in a given waterbody must consider the ability to contain the grass carp, including the suitability of existing structures, or installation of barriers to restrict grass carp movement at all inflows and outflows (Hofstra et al. 2014). Grass carp have strong migratory instincts (Wells et al. 2000) and will seek a passage from stocked sites (Rowe and Schipper 1985). Escape and death of grass carp would represent a loss in grazing pressure and weed control, and with escape the potential for off-target impacts (i.e., outside of desired area) (DOC may require an impact assessment). The potential for catchment impacts relates to the number of fish and opportunity for escape (Hofstra et at 2014).

Succinctly stated, the use of grass carp for weed control can result in one of three outcomes, with high stocking resulting in the elimination of all aquatic vegetation (including eradication of target weeds), and low stocking resulting in either selective reduction of vegetation, with preferred species grazed first (Blackwell and Murphy 1996, Bonar et al. 1993, Chilton and Magnelia 2008) or in no control at all (Cassani 1996, Hofstra 2011). In Hofstra et al. (2014) it was recommended that a stocking rate of 100 grass carp/vegetated ha be adopted as a high stocking rate for New Zealand waters (to achieve rapid removal of palatable submerged aquatic vegetation), while a density of 22 standard-sized grass carp/vegetated ha is adopted as a slow stocking rate for New Zealand waters.

Grass carp can be utilised for weed eradication and to provide effective long-term control of aquatic weeds. However, the site suitability, values, functions and management goals (e.g., level of weed reduction and target plants) for a waterbody require consideration when determining the appropriateness of grass carp as a weed control tool (Hofstra et al. 2014). For example, because grass carp are preferential browsers, plants species will be consumed in order of palatability, and the access that grass carp have to them. Although grass carp stocking density and water temperature largely determine the rate of plant removal, stocking density, particularly in large or deep waterbodies, cannot be readily manipulated to refine grazing pressure (Hofstra 2014). The average lifespan of a fish is reportedly 10 years (Wells et al. 2000) yet fish may live for much longer and partial weed control in a sustainable form (over that timeframe) is rarely, if ever, achieved (Hofstra 2014). In this context, partial weed control is defined as a desired level of reduced weed volume (other than total weed removal - eradication). However, it is also important to note that the desire for targeting weed removal at specific locations within a waterbody, such as water ski or rowing lanes is problematic. There is currently no method to restrict grass carp grazing in such targeted locations whilst retaining the amenity value (Hofstra et al. 2014).

A decision support system for the use of grass carp in New Zealand is provided in Hofstra et al. (2014).

Summary - Grass carp

Availability: Grass carp the only biological control tool for submerged aquatic weeds.

Legislation: An application must be made to DOC for the transfer of grass carp to a new location, and subsequent releases need MPI approval. Consent may also be required from the Fish and Game Council with local jurisdiction.

Effectiveness: Grass carp are suitable for the control of large scale submerged weed infestations.

Constraints: Grass carp consume a wide variety of plants and do not provide targeted control, are difficult to remove (post-weed control), containment is essential and not all waterbodies are suitable.

Outcomes: Partial weed control is rarely achieved. Grass carp can be used for eradication of submerged weeds.

4.3 Approaches – integration and adaptation

The following two broad approaches to aquatic weed management describe the integration of different methodologies, and the need to adapt or tailor management as a weed control programme progresses.

4.3.1 Integrated management

An integrated approach, as the name suggests, refers to a combination of tools to provide the weed control outcome that is sought. As with each of the methods described above (Section 4.2) selecting an integrated approach with more than one method requires consideration of key factors such as the amount of weed biomass, both in terms of the density and area, the goals of the weed control programme and the utility of the control tool (Figure 4).

For example, an integrated approach using surveillance and hand-weeding are feasible tools for low density and early weed incursions. This approach is being used in Lake Wanaka for eradication of lagarosiphon populations in designated areas ("incursions beyond the containment line"), while suction dredging and hand weeding is advocated for amenity control at water-intakes and boat ramps (de Winton and Clayton 2016).

As well as different tools being used within a lake, spatial variability in the selection of tools, the combination of tools in an integrative approach may also vary or change over the timeframe of the weed control programme. For example, herbicide may be appropriate for large scale weed control, but as weed beds are diminished (over time), benthic barriers or suction dredging may become feasible, and subsequently hand-weeding. This type of weed reduction over the longer term was illustrated by the lagarosiphon control works in Lake Wanaka during the last 10 years, where adjustments of the “containment line” mean that eradication is now considered feasible along a much greater extent of shoreline (de Winton and Clayton 2016). Further, how biocontrol agents interact with herbicides management strategies need to be considered to enable effective weed management.

4.3.2 Adaptive management

An adaptive management approach is based on appropriate monitoring within the control programme, that alongside efficiencies or refinement of control tools, informs next steps. For example, in maintenance control operations, pre- and post-spray monitoring of weed beds provides valuable information on the amount the weed bed was reduced, which in turn informs the length of time before weeds are likely to again reach nuisance levels. Monitoring of herbicide efficacy in field operations, and subsequent research lead to tool refinements such as the ‘dirtiness’ scale that informs when diquat is unlikely to be effective on target weeds and should not be used (Clayton and Matheson 2010).

Increasing the effectiveness of control and improving cost-effectiveness is usually an important objective of a weed management programme. Hence there is a need to adapt tools and techniques as progress is made, new knowledge becomes available, or efficiencies are identified (de Winton and Clayton 2016).

4.4 Environmental monitoring

Environmental monitoring can be described in three key categories (i) monitoring the effectiveness of the weed control operations, (ii) monitoring to assess potential off-target impacts, and (iii) compliance monitoring.

4.4.1 Monitoring effectiveness

Monitoring the effectiveness of weed control operations is used to inform progress towards goals and to adapt, where necessary the approach or control methods being used to optimise the outcome. The monitoring requirements will vary depending on the weed management goal and the control method(s) that are being used. The timeframe between monitoring events and the type of data collected (e.g., area, or height of the weeds, occurrence of individual plants) should reflect the outcome that is sought. For example, to quantifying the effect of control operations on plant abundance within a maintenance programme, a single post-control survey at a timeframe relevant to the control method (e.g., days after harvesting or a month after diquat herbicide treatment) may be sufficient. For an eradication programme, the viability of remaining plant parts (e.g., root crowns, defoliated stems, underground propagules) will require evaluation. Sites should be monitored over relevant timescales, which is species dependent, but should be sufficient to have observed recovery of viable propagules (Hofstra and Champion 2018). Appropriate techniques or methods to detect target weeds at relevant scales (e.g., individuals or populations) also requires considered (see section Tool 2: Incursion detection).

4.4.2 Assessing potential off-target impacts

This is a broad category that covers both the direct and indirect potential off-target impacts. Examples of direct impacts include the potential for herbicide symptoms on non-target plants, or aquatic fauna that are removed (and killed) with weeds in a harvesting operation.

To minimise the potential for off-target impacts selective methods or application techniques can be used where feasible. Examples include the use of rhodamine dye, prior to herbicide application, to illustrate water movement patterns and inform subsequent herbicide application, or the use of a herbicide at a rate that is efficacious on the target weed(s) but not on desirable native plants (if present). In contrast some control options may not be suitable when risks to non-target organisms are unacceptable.

Direct off-target impacts are often seen as negative or detrimental but the direct effects or the influence of a weed control operation on non-target organisms can also be beneficial. Examples include the application of diquat or a benthic barrier that removed submerged weeds and resulted in recolonisation of the lake bed by native plants (milfoils and pondweed in Lake Okareka (Hofstra 2017), *Isoëtes* in Lake Wanaka (de Winton et al. 2018)). Monitoring native plant recovery may also be aligned with weed control goals.

Examples of in-direct impacts include the influence of weed beds and their removal on dissolved oxygen (DO) which in turn effects habitat for aquatic fauna. The collapse of weed beds following herbicide application and the potential for a drop in DO has been raised as a concern when the use of an aquatic herbicide is proposed (Hofstra and Champion 2018). However, it is also recognised that DO in dense weed beds may decline to low levels diurnally (Sand-Jensen 1989, Schwarz and Howard-Williams 1993) also inhibiting fauna. While under canopies of floating leaved macrophytes DO may be severely limiting for more extended periods due to plant decay and poor water circulation (Carpenter and Lodge 1986, Hofstra et al. 2013, Madsen 2014), and in degraded habitats DO may remain well below the level considered acceptable for healthy aquatic life (ecological habitat standard of 80% saturation) (Hofstra and Champion 2018). To protect aquatic life, constraints on the area of a waterbody to which herbicide can be applied may be in place (e.g., no more than 33% for static waterbodies, (see section Restricted herbicides)) and/or monitoring of DO may be required pre- and post-application to document changes, as a consequence of the control works (Hofstra and Champion 2018).

In recognising the degraded nature of some aquatic habitats, the application of 'restricted use herbicides' does not limit the area of a waterbody that can be treated at any one time if the average dissolved oxygen level for the static water body is less than 4 mg/L at the time of application (see Section 4.2.2).

4.4.3 Compliance monitoring

Compliance monitoring could include either or both, of the monitoring categories above, but specifically refers to monitoring requirements in legislation or resource consents. An example is the application of restricted herbicides (see Section 4.2.2) that require a resource consent.

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6 Glossary of abbreviations and terms

ai	Active ingredient.
ae	Acid equivalent.
AWRAM	Aquatic Weed Risk Assessment (Champion and Clayton 2000).
Benthic barrier	Lining the sediment with matting to smother and kill submerged plants by shading.
BMP	Best Management Practice for aquatic weed management.
BRT	Boosted Regression Tree, modelling using machine learning.
CBC	Classical biological control, using herbivorous species that feed specifically on the target weed.
CTO	Chief Technical Officer appointed under the Biosecurity Act 1993.
Delimitation	Finding the geographical extent of an incursion.
DOC	Department of Conservation.
Drawdown	Lower water level in a water body to expose and kill submerged plants
EDRR	Early Detection and Rapid Response.
EPA	Environmental Protection Authority set up under HSNO Act 1996.
ERMA	Environmental Regulatory Management Authority (now EPA).
Eradication	Complete removal of the target plant including all propagules.
GBIF	Global Biodiversity Information Facility.
GPS	Global Positioning System.
Grass carp	*Ctenopharyngodon idella*, herbivorous fish.
HSNO	Hazardous Substances and New Organisms Act 1996.
Incursion	New detection of a weed in a region or water body.
Integrated control	A combination of tools to provide the weed control outcome that is sought.
LINZ	Land Information New Zealand.
Maintenance control	Reduction in target weed biomass, cover, or abundance so that the desired values (e.g., biodiversity, amenity, utility) are maintained.
MPI	Ministry for Primary Industries.
NPDPM	National Policy Direction for Pest Management 2015 (New Zealand Government 2015).
NPPA	National Pest Plant Accord.
ppb	Parts per billion (e.g., µg/L).
ppm	Parts per million (e.g., mg/L).
Propagule	Dispersal organs (including seed and vegetative reproduction).

Scuba	Self-Contained Underwater Breathing Device.
Suction dredging	Diver operated venturi suction pump used to remove submerged plants including underground parts.
Surveillance	Targeted search for new incursions in a water body.
WAT	Weeks after treatment, such as treatment with herbicide.

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Appendix A Legal status of aquatic weeds

Legal status of aquatic weeds under the Biosecurity Act 1993, National Pest Plant Accord (NPPA) and inclusion in Department of Conservation consolidated list of environmental weeds (Howell 2008).

Species	Common name	Legal Status	DOC environmental weed
Acorus gramineus	Japanese rush	None	
Alnus glutinosa	alder	None	yes
Alternanthera philoxeroides	alligator weed	Unwanted organism, NPPA	yes
Apium nodiflorum	water celery	None	
Aponogeton distachyos	Cape pondweed	None	
Azolla pinnata	ferny azolla	None	yes
Bidens frondosa	beggar's ticks	None	yes
Butomus umbellatus	flowering rush	None, eradicated	
Cabomba caroliniana	cabomba	Unwanted organism	
Carex leporina	oval sedge	None	yes
Carex pendula	drooping sedge	Unwanted organism, NPPA	
Ceratophyllum demersum	hornwort	Unwanted organism, NPPA	yes
Cuscuta campestris	golden dodder	None	
Drosera capensis	Cape sundew	Unwanted organism, NPPA	
Egeria densa	egeria	Unwanted organism, NPPA	yes
Eichhornia crassipes	water hyacinth	Notifiable organism, NPPA	yes
Eichhornia paniculata		None, eradicated	
Elodea canadensis	elodea	None	yes
Epilobium hirsutum	Giant willowherb	Unwanted organism	
Equisetum arvense	field horsetail	Unwanted organism, NPPA	yes
Equisetum hyemale	rough horsetail	Unwanted organism, NPPA	yes
Erythranthe guttata	monkey musk	None	yes
Eupatorium cannabinum	hemp agrimony	None	yes
Glyceria maxima	reed sweet grass	None	yes

Species	Common name	Legal Status	DOC environmental weed
Gunnera tinctoria	Chilean rhubarb	Unwanted organism, NPPA	yes
Gymnocoronis spilanthoides	Senegal tea	Unwanted organism, NPPA	yes
Houttuynia cordata	houttuynia	Unwanted organism, NPPA	yes
Hydrilla verticillata	hydrilla	Unwanted organism, NPPA	yes
Hydrocleys nymphoides	water poppy	Unwanted organism, NPPA	
Iris pseudacorus	yellow flag iris	Unwanted organism, NPPA	yes
Juncus squarrosus	heath rush	None	yes
Lagarosiphon major	lagarosiphon	Unwanted organism, NPPA	yes
Lilaeopsis mauritianus		None	
Ludwigia peploides subsp. *montevidensis*	primrose willow	Unwanted organism, NPPA	
Lycopus europaeus	gypsywort	None	
Lythrum salicaria	purple loosestrife	Unwanted organism, NPPA	yes
Menyanthes trifoliata	bogbean	Unwanted organism, NPPA, eradicated	
Myriophyllum aquaticum	parrot's feather	Unwanted organism, NPPA	yes
Myriophyllum variifolium	Australian milfoil	None	
Nasturtium microphyllum	water cress	None	
Nasturtium officinale	water cress	None	yes
Nuphar lutea	yellow water lily	Unwanted organism, NPPA	
Nymphaea mexicana	Mexican water lily	Unwanted organism, NPPA	yes
Nymphoides montana	marshwort	Unwanted organism, NPPA	yes
Nymphoides peltata	fringed water lily	Unwanted organism, NPPA, eradicated	
Oenanthe javanica	Vietnamese parsley	None	
Osmunda regalis	royal fern	Unwanted organism, NPPA	yes
Ottelia ovalifolia	swamp lily	None	
Paspalum distichum	Mercer grass	None	yes
Paspalum vaginatum	saltwater paspalum	None	yes
Phalaris arundinacea	reed canary grass	None	
Phragmites australis	phragmites	Notifiable organism, NPPA	yes

Species	Common name	Legal Status	DOC environmental weed
Phragmites karka	tropical phragmites	None	
Pinguicula grandiflora	butterwort	None	
Pistia stratiotes	water lettuce	Notifiable organism, NPPA	
Potamogeton crispus	curled pondweed	None	yes
Potamogeton perfoliatus	clasped pondweed	Unwanted organism, NPPA, eradicated	yes
Rotala rotundifolia	rotala	None	
Sagittaria montevidensis	arrowhead	Unwanted organism, NPPA	yes
Sagittaria platyphylla	sagittaria	Unwanted organism, NPPA	
Sagittaria sagittifolia	arrowhead	Unwanted organism, NPPA	
Sagittaria subulata	mud sagittaria	None	
Salix cinerea	grey willow	Unwanted organism, NPPA	yes
Salix x*fragilis*	crack willow	Unwanted organism, NPPA	yes
Salvinia molesta	salvinia	Notifiable organism, NPPA	yes
Saururus cernuus	lizard's tail	None	
Schinus terebinthifolius	Christmas berry	Unwanted organism, NPPA	yes
Schoenoplectus californicus	Californian bulrush	Unwanted organism, NPPA	
Spartina spp.	spartina	Unwanted organism	yes
Typha latifolia	greater reedmace	Unwanted organism, NPPA, eradicated	
Utricularia arenaria	bladderwort	Unwanted organism, NPPA	
Utricularia gibba	humped bladderwort	Unwanted organism, NPPA	yes
Utricularia livida	bladderwort	Unwanted organism, NPPA	
Utricularia sandersonii	bladderwort	Unwanted organism, NPPA	
Vallisneria australis	eelgrass	Unwanted organism, NPPA	
Zizania latifolia	Manchurian wild rice	Notifiable organism, NPPA	yes
Zizania palustris	annual wild rice	None, eradicated	

Appendix B Current management of aquatic weeds

Management of aquatic weeds by Ministry for Primary Industries ((National Interest Pest Response (NIPR) and other incursion responses (IR)), Department of Conservation (DOC) control programmes and Regional Council Management.

N – Northland; A – Auckland; Wk – Waikato; BP – Bay of Plenty; HB – Hawkes Bay; Hz – Horizons; GW – Greater Wellington; M – Marlborough; T – Tasman/Nelson; WC – West Coast; C – Canterbury; O – Otago; S – Southland. Management categories for the National Policy Direction for Pest Management 2015 (Prog Ctmt – Progressive Containment; Sust Cntl – Sustained Control)

Species	Common name	MPI	DOC	Regional Council Management				
				Exclusion	Eradication	Prog Ctmt	Sust Cntl	Site-led
Acorus gramineus	Japanese rush							Wk
Alnus glutinosa	alder		yes					
Alternanthera philoxeroides	alligator weed			C	BP, Hz	Wk	N	
Apium nodiflorum	water celery							
Aponogeton distachyos	Cape pondweed							GW
Azolla pinnata	ferny azolla							
Bidens frondosa	beggar's ticks							C
Cabomba caroliniana	cabomba	IR			A			
Carex leporina	oval sedge		yes					
Carex pendula	drooping sedge					C		
Ceratophyllum demersum	hornwort						N, BP	Hz, BP
Cuscuta campestris	golden dodder		yes					
Drosera capensis	Cape sundew				C			
Egeria densa	egeria		yes		WC	C	BP	N, GW
Eichhornia crassipes	water hyacinth	NIPR			N, A, BP, GW			
Elodea canadensis	elodea							BP
Epilobium hirsutum	Giant willowherb	IR			C			
Equisetum arvense	field horsetail			N, C	S			
Equisetum hyemale	rough horsetail			N	WC			
Erythranthe guttata	monkey musk		yes		N			
Eupatorium cannabinum	hemp agrimony							

Species	Common name	MPI	DOC	Regional Council Management				
				Exclusion	Eradication	Prog Ctmt	Sust Cntl	Site-led
Glyceria maxima	reed sweet grass				T	HB	M	WC
Gunnera tinctoria	Chilean rhubarb				N, Hz, S			GW
Gymnocoronis spilanthoides	Senegal tea			T	N, A, Wk, BP, Hz			
Houttuynia cordata	houttuynia			N	A			
Hydrilla verticillata	hydrilla	NIPR			HB			
Hydrocleys nymphoides	water poppy			N	A, Wk, BP			
Iris pseudacorus	yellow flag iris				N	Wk, WC		Hz, GW
Juncus squarrosus	heath rush		yes	Hz				
Lagarosiphon major	lagarosiphon					C, WC	BP	N, Wk, HB, O
Lilaeopsis mauritianus								
Ludwigia peploides subsp. *montevidensis*	primrose willow							N, Hz
Lycopus europaeus	gypsywort							N
Lythrum salicaria	purple loosestrife				A, BP, HB, T, S	C, WC	M	Hz
Myriophyllum aquaticum	parrot's feather				C, S	WC	M	GW
Myriophyllum variifolium	Australian milfoil							
Nasturtium microphyllum	water cress		yes					
Nasturtium officinale	water cress							
Nuphar lutea	yellow water lily			HB	C			
Nymphaea mexicana	Mexican water lily							Wk
Nymphoides montana	marshwort			Wk	BP, C			
Nymphoides peltata	fringed water lily			Wk				
Oenanthe javanica	Vietnamese parsley							
Osmunda regalis	royal fern		yes		N, A		BP	Wk
Ottelia ovalifolia	swamp lily							
Paspalum distichum	Mercer grass							HB
Paspalum vaginatum	saltwater paspalum							Wk
Phalaris arundinacea	reed canary grass		yes					

Species	Common name	MPI	DOC	Regional Council Management				
				Exclusion	Eradication	Prog Ctmt	Sust Cntl	Site-led
Phragmites australis	phragmites	NIPR			HB, C			
Phragmites karka	tropical phragmites				A			
Pinguicula grandiflora	butterwort		yes					
Pistia stratiotes	water lettuce							
Potamogeton crispus	curled pondweed							
Rotala rotundifolia	rotala							
Sagittaria montevidensis	arrowhead				A, Wk, BP, Hz			
Sagittaria platyphylla	sagittaria				A, Wk, BP			
Sagittaria sagittifolia	arrowhead				A, Wk			
Sagittaria subulata	mud sagittaria				A			
Salix cinerea	grey willow		yes					A, Wk, HB
Salix xfragilis	crack willow		yes					Wk, HB, Hz
Salvinia molesta	salvinia	NIPR			N, A, BP, GW			
Saururus cernuus	lizard's tail							
Schinus terebinthifolia	Christmas berry							N
Schoenoplectus californicus	Californian bulrush				Hz		N	
Spartina spp.	spartina		yes		N, Wk, BP, Hz, T, O, S	A, C		GW
Typha latifolia	greater reedmace			A				
Utricularia arenaria	bladderwort							
Utricularia gibba	humped bladderwort			Hz				
Utricularia livida	bladderwort							
Utricularia sandersonii	bladderwort							
Vallisneria australis	eelgrass				N, Wk, GW		M	Hz
Zizania latifolia	Manchurian wild rice	NIPR			A, Wk, GW	N		

Appendix C Weed Risk Assessments of aquatic species

Weed Risk Assessments of aquatic species using Champion and Clayton (2000), ranked from highest to lowest score.

Aquatic Species	Common Name	AWRAM
Phragmites australis	phragmites	75
Hydrilla verticillata	hydrilla	74
Zizania latifolia	Manchurian wild rice	68
Ceratophyllum demersum	hornwort	67
Eichhornia crassipes	water hyacinth	67
Egeria densa	egeria	64
Alternanthera philoxeroides	alligator weed	63
Lagarosiphon major	lagarosiphon	60
Nymphoides peltata	fringed water lily	58
Typha latifolia	greater reedmace	58
Gymnocoronis spilanthoides	Senegal tea	57
Salvinia molesta	salvinia	57
Myriophyllum aquaticum	parrot's feather	56
Potamogeton perfoliatus	clasped pondweed	55
Azolla pinnata	ferny azolla	54
Butomus umbellatus	flowering rush	54
Lythrum salicaria	purple loosestrife	54
Spartina spp.	spartina	54
Utricularia gibba	humped bladderwort	54
Cabomba caroliniana	cabomba	53
Sagittaria sagittifolia	arrowhead	53
Iris pseudacorus	yellow flag iris	52
Ludwigia peploides subsp. *montevidensis*	primrose willow	52

Aquatic Species	Common Name	AWRAM
Sagittaria platyphylla	sagittaria	52
Glyceria maxima	reed sweet grass	51
Houttuynia cordata	houttuynia	51
Vallisneria australis	eelgrass	51
Phragmites karka	tropical phragmites	48
Apium nodiflorum	water celery	47
Erythranthe guttata	monkey musk	47
Nymphaea mexicana	Mexican water lily	47
Oenanthe javanica	Vietnamese parsley	47
Elodea canadensis	elodea	46
Nymphoides montana	marshwort	46
Sagittaria montevidensis	arrowhead	46
Hydrocleys nymphoides	water poppy	45
Menyanthes trifoliata	bogbean	45
Paspalum distichum	Mercer grass	45
Zizania palustris	annual wild rice	45
Potamogeton crispus	curled pondweed	44
Aponogeton distachyos	Cape pondweed	43
Myriophyllum variifolium	Australian milfoil	43
Nuphar lutea	yellow water lily	43
Sagittaria subulata	mud sagittaria	43
Paspalum vaginatum	saltwater paspalum	42
Pistia stratiotes	water lettuce	42
Schoenoplectus californicus	Californian bulrush	42
Lycopus europaeus	gypsywort	41
Nasturtium microphyllum	water cress	40
Nasturtium officinale	water cress	40
Saururus cernuus	lizard's tail	37

Aquatic Species	Common Name	AWRAM
Rotala rotundifolia	rotala	32
Ottelia ovalifolia	swamp lily	28
Lilaeopsis mauritianus		21
Acorus gramineus	Japanese rush	20
Eichhornia paniculata		18

Appendix D Weed Risk Assessments of wetland species

Weed Risk Assessments of wetland species using Pheloung et al. (1999), or subjective assessments where no assessment could be sourced, ranked from highest to lowest score.

Wetland Species	Common Name	Weed Risk Assessment
Cuscuta campestris	golden dodder	22
Equisetum hyemale	rough horsetail	22
Equisetum arvense	field horsetail	21
Schinus terebinthifolia	Christmas berry	18
Salix cinerea	grey willow	16
Salix x *fragilis*	crack willow	14
Drosera capensis	Cape sundew	10
Gunnera tinctoria	Chilean rhubarb	10
Phalaris arundinacea	reed canary grass	high
Alnus glutinosa	alder	high
Epilobium hirsutum	Giant willowherb	high
Juncus squarrosus	heath rush	high
Osmunda regalis	royal fern	high
Bidens frondosa	beggar's ticks	moderate
Eupatorium cannabinum	hemp agrimony	moderate
Carex pendula	drooping sedge	moderate
Carex leporina	oval sedge	low
Pinguicula grandiflora	butterwort	low
Utricularia arenaria	bladderwort	low
Utricularia livida	bladderwort	low
Utricularia sandersonii	bladderwort	low