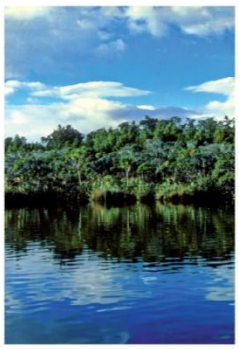

Feasibility of biocontrol of *Lagarosiphon major* in New Zealand

Envirolink grant 1248-HZLC93

Landcare Research
Manaaki Whenua

Feasibility of biocontrol of *Lagarosiphon major* in New Zealand

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Contents

Summary

Project and Client

- A study to investigate the potential for biological control of the aquatic weed *Lagarosiphon major* was undertaken for Horizons Regional Council. This study was funded by an Envirolink Medium Advice Grant 1248-HZLC93.

Objectives

The objectives of this report are to:

- Summarise the literature and current information available from biological control of weeds researchers worldwide on the current status of classical biological control of *Lagarosiphon major* (lagarosiphon).
- Assess the likelihood of success of such a programme in New Zealand.
- Review the steps necessary for a biological control programme for lagarosiphon in New Zealand and propose a realistically costed programme for Horizons Regional Council and other agencies to consider implementing.

Methods

- The global literature was accessed and experts familiar with the weed were consulted to obtain up-to-date information regarding the natural enemies of lagarosiphon.
- The latest plant phylogenies were examined in order to develop a test plant list that included key New Zealand plant species.
- The impact of biocontrol was predicted according to a prioritisation tool developed by Landcare Research and the cost of developing biocontrol for New Zealand was estimated.

Results

- Lagarosiphon belongs to the family Hydrocharitaceae (subfamily Anacharidoideae), which is placed in the Order Alismatales. No native New Zealand plants belong to this family, which simplifies host-range testing as relatively few test plants need to be included in the host-range test plant list.
- A collaborative project between University College Dublin (UCD), Inland Fisheries Ireland (IFI), and Rhodes University (South Africa) began in 2008 to investigate the prospects for biocontrol of lagarosiphon. Surveys of lagarosiphon have been conducted in the native range and a number of candidate arthropod agents have been identified, including a leaf-mining fly (*Hydrellia lagarosiphon*) a shoot-tip mining midge (cf. *Polypedilum* sp.). Host-range testing of these agents is well progressed and the fly appears to be sufficiently specific for release in New Zealand, although additional host-range testing is required to confirm this. More extensive testing would be required to determine the suitability of the midge for release in New Zealand.

- Lagarosiphon is an aquatic plant that is not considered to be weedy in its native range and reproduces asexually in New Zealand. Biocontrol is predicted to have a major impact according to the analysis by Paynter et al. (2012), who investigated the impact of biocontrol in relation to plant traits.
- It was estimated that the cost of developing the fly as a biocontrol agent for New Zealand would be in the region of $115,000–$125,000 and the cost of developing both the fly and the midge would be ~$235,000–$255,000. This compares with an annual estimated cost of $1,459,000 spent on control of lagarosiphon in New Zealand.
- There are some potential objections to using biocontrol that may need to be addressed in order to gain approval to release biocontrol agents into New Zealand: 1) there is a risk that Biocontrol may increase fragmentation making eradication harder in eradication/containment areas (although this risk has already been addressed for *Hydrellia lagarosiphon* which has been shown to reduce fragment viability); 2) Anglers may object to biocontrol if the habitat for fish is reduced and; 3) Lagarosiphon is one of the few plants which can withstand the degraded conditions in some fresh waters so its removal may further degrade the habitat. Additional interventions may be required to restore such lakes prior to/in tandem with the release of biocontrol agents.

Conclusions

- The prospects for biological control of lagarosiphon appear to be high as a potentially specific and damaging agent (*Hydrellia lagarosiphon*) has already been identified and other invertebrate herbivores have been found that also have potential for use as biocontrol agents.

Recommendations

- A pre-release survey of the natural enemies of lagarosiphon should be conducted in New Zealand. This is likely to cost in the region of $80,000. Pre-release surveys of the target weed are normally required before a biocontrol programme is commenced (see Appendix 1). This ensures that candidate agents are not already present, for example, the bridal creeper rust, *Puccinia myrsiphylli*; a biocontrol agent of the weed *Asparagus asparagoides*, was a candidate agent for release in New Zealand, but was discovered to be already present in New Zealand during a routine pre-release survey of the weed (Waipara et al. 2006). Pre-release surveys can also assist agent prioritisation, for example, by allowing the risk of agent parasitism to be predicted (Paynter et al. 2010).
- Host-range testing of *Hydrellia lagarosiphon* should be completed using New Zealand test plants and could be completed within 2–4 months. The cost of completing the tests in a containment facility in Ireland was estimated at (€6,000 ~=NZ$ 10,000; J-R Baars, pers. comm.). This would require New Zealand test plants to be sourced in New Zealand and shipped to Ireland and may require phytosanitary certificates (estimated cost c. $5,000–$10,000 depending on how much time and travel is required to obtain and ship New Zealand native aquatic test plants). Alternatively, a starter colony of the fly could be shipped to New Zealand and the testing carried out by Landcare Research at either of the Auckland or Lincoln containment facilities (this would likely cost more than conducting the testing in Ireland as there would be costs associated with establishing and maintaining a colony in New Zealand that were not

factored into the Irish estimate). Assuming the fly is adequately specific to be considered for release in New Zealand, then an application would be made to the Environmental Protection Authority (EPA), which would cost c. NZ$50,000 (sum of cost of preparing an application, EPA processing costs and the cost of attending a hearing, should a hearing be required). All up, the cost of completing host-specificity testing and obtaining EPA approval for release is likely to be in the region of $65,000–$85,000. Agent mass-rearing and release would be in addition to this.

- Releasing more than one agent increases the probability that a biocontrol programme will succeed. Indeed, the midge has larvae that can swim so it should, therefore, be capable of attacking lagarosiphon growing in deeper water than the fly can exploit (the fly oviposits on vegetation growing at the water's surface). Given the damage of the shoot-tip mining midge (cf. *Polypedilum* sp.) is purportedly even more harmful than *H. lagarosiphon*, it is recommended that host-range testing of the shoot-tip mining midge should also proceed, provided the results of the host-range testing to be conducted in Ireland in 2013 indicate that it is likely to be sufficiently specific for New Zealand. The cost of the host-range testing and EPA approval would be similar to before, but may cost $10,000–$20,000 more if longer-term multi-generational tests are required to demonstrate adequate specificity.
- Research should address the potential negative impacts of biocontrol, particularly in degraded lakes where removal of lagarosiphon may cause further environmental degradation.

1 Introduction

Fifty-two exotic aquatic weeds have naturalised in New Zealand, excluding wetland species that are normally only flooded for part of their lifecycle (Champion & Clayton 2000). Some of these species have serious detrimental impacts on native aquatic fauna and flora, recreational activities (such as angling, boating and swimming), disrupt hydro-electric dams, restrict irrigation, and block drainage causing flooding (Champion & Clayton 2000).

The submerged aquatic plant *Lagarosiphon major* (Ridley) Moss ex Wager (henceforth lagarosiphon) is one of several species of exotic Hydrocharitaceae that have established in New Zealand. There are no native members of this family in New Zealand (De Lange & Rolfe 2010). The origin, distribution and impacts of lagarosiphon in New Zealand have previously been reviewed (McGregor & Gourlay 2002) and are summarised briefly below:

Lagarosiphon, native to southern Africa, has become invasive in parts of Europe as well as in New Zealand. It was first recorded in New Zealand in 1950 and is now patchily distributed throughout most of the country, where it is a national surveillance plant pest, causing a range of problems. Lagarosiphon does not produce seeds in New Zealand (lagarosiphon is dioecious and male plants are unknown outside South Africa) but is likely to spread further as vegetative fragments are transferred between water bodies by boating, fishing, weed harvesters and float planes. Lagarosiphon replaces native vegetation, and dense infestations restrict the passage of boats and limit recreational activities like swimming and angling; storms can tear loose the weed and deposit large masses of rotting vegetation on beaches, spoiling their amenity value; and detached stems may block water-intakes of power stations, impeding electricity generation.

Current control methods for water weeds in New Zealand include mechanical control, herbicides and inundative biological control using grass carp *Ctynopharyngodon idella* (Valenciennes) (Chisholm 2006). Most non-chemical methods have been of limited value in controlling or eradicating aquatic weeds (Chisholm 2006). Even with aquatic herbicides, it can be difficult to control submerged species effectively, due to inadequate plant exposure and uptake (Chisholm 2006). Nevertheless, use of herbicides is easier and cheaper than mechanical methods, and many are harmless to aquatic organisms at concentrations required for aquatic weed control. The main disadvantage is that a chemical is in water as residue for a period of time. Therefore, not all herbicides can be used in aquatic environments (Chisholm 2006) and public opposition to the use of approved pesticides is growing (e.g. Champion et al. 2002).

In New Zealand, Diquat, which is applied to the weed in gel form, is used to control aquatic weeds (http://www.linz.govt.nz/crown-property/biosecurity/biosecurity-control-programmes/aquatic-weeds#control). Weed control by mechanical and chemical means can be extremely expensive (Table 1). Chisholm (2006) described how Hydrogel was used to administer herbicide to a hornwort infestation over 0.68 Ha of Moutere Stream, Nelson. This treatment cost $4,500 (i.e. c. $6,617 per hectare) and resulted in the eradication of this infestation.

Grass carp are a cheaper weed control option (Table 1) and, as they are unlikely to breed in New Zealand waterways, are unlikely to become a pest. However, they do pose problems for

native aquatic plant conservation, as they are not selective in the plants they eat (Clayton & Wells 1999; Chisholm 2006).

Table 1 Comparative costing of aquatic weed control techniques in New Zealand. Figures are from Chisholm (2006)

Method	Approx. Cost/ha ($NZ)
Hand-weeding	7,000 – 10,000
Mechanical digger	1,000 – 3,500
Rototiller	2,000 – 5,000
Weed cutter	2,000 – 4,000
Suction dredging	15,000 – 20,000
Nutrient control	6,000 – 10,000
Shading	5,000 – 15,000
Grass carp	750
Herbicide	1,400

The annual cost of controlling lagarosiphon in New Zealand was recently estimated to be $1,458,928 (Deloitte 2011). Of this, approximately $340k per annum is spent on the Benmore catchment alone by Meridian Energy and Land Information New Zealand (Joe Wheeler, Meridian Energy, pers. comm.).

Classical biological control (henceforth biocontrol and defined in Appendix 1) is a management option for aquatic pest plants that can potentially replace chemical usage, which is now increasingly unpopular in riparian areas as well as mechanical control and inundative biological control (i.e. the release of overwhelming numbers of a mass-produced biological control agent in the expectation of achieving a rapid reduction of a pest population without necessarily achieving continuing impact) with grass carp. Biocontrol of weeds is an environmentally sound and effective means of reducing or mitigating weed impacts through the use of natural enemies. A definition of biocontrol and the steps involved in a biocontrol programme are given in Appendix 1. A great advantage of biocontrol is that once implemented, it provides permanent weed suppression, which makes it very cost-effective. Several economic analyses have reported impressive cost:benefit ratios for biocontrol. For example, it was reported that overall (including failed programmes), the benefit:cost ratio of Australian weed biocontrol programmes was 23:1 (Page & Lacey 2006). An analysis by van Wilgen et al. (2004) indicated that the benefit:cost ratios of programmes targeting 6 weeds in South Africa ranged from 34:1 for lantana to 4333:1 for golden wattle. Culliney (2005) report the cost:benefit analyses of a range of programmes including the USA (e.g. St Johns wort *Hypericum perforatum*, for which the benefit:cost ratio was 4000:1).

To date, biocontrol has only been utilised against one aquatic weed in New Zealand (alligator weed *Alternanthera phylloxeroides*). It was previously assumed that biocontrol of aquatic weeds is difficult because most aquatic insect herbivores/pathogens have wide host ranges (Cummins 1973; Resh & Houp 1986). However, the average impact of biocontrol programmes against aquatic and wetland weeds was recently shown to be higher than that of

programmes targeting terrestrial weeds (Paynter et al. 2012), indicating that previous concerns regarding a paucity of adequately damaging and specific agents are unfounded. Indeed, dense floating mats of alligator weed are well controlled by the beetle *Agasicles hygrophila* in warmer parts of New Zealand (Roberts et al. 1984).

2 Background

This report updates a previous report (McGregor & Gourlay 2002) as considerable research has been conducted on the natural enemies of lagarosiphon since then. This research includes surveys in the native range that resulted in the identification and host-range testing of candidate agents for the biocontrol of lagarosiphon in Ireland, where it is also an introduced weed (Baars et al. 2010). Due to the difficulty, expense and possible adverse effects of currently used control methods, the feasibility of a classical biological control programme for lagarosiphon in New Zealand was investigated by Landcare Research for Horizons Regional Council.

3 Objectives

The objectives of this report are to:

- Summarise the literature and current information available from biological control of weeds researchers worldwide on the current status of classical biological control of *Lagarosiphon major*.
- Assess the likelihood of success of such a programme in New Zealand.
- Review the steps necessary for a biological control programme for lagarosiphon in New Zealand and propose a realistically costed programme for Horizons Regional Council and other agencies to consider implementing.

4 Methods

4.1 Selecting a test-plant list for host-range testing of biological control agents

Host-specificity testing is used to discard potential weed biological control agents that are likely to cause significant undesirable non-target damage to either native or valued exotic plants. The simplest tests are extremely robust ‘no-choice’ tests where arthropods are confined on a particular test plant and either feed or die, or, for pathogens, inoculation is attempted to see if infection can result. No-choice tests define the fundamental host-range of a particular species (all the plant species it can survive/complete development on; Van Klinken & Heard 2000). However, for many herbivorous insects this fundamental host range is broader than the realised host range under natural conditions (i.e. they will eat plants when forced to in captivity that they would never attack in the field), so more complex and costly tests, such as field cage oviposition tests, may be required.

A centrifugal phylogenetic method (Wapshere 1974) has long been used to determine the host-range of a potential biological control agent by sequentially testing plant taxa most

closely related to the target weed followed by increasingly distantly related taxa until the host-range has been circumscribed. This approach is supported by recent advances in molecular techniques: host-shifts in lineages of specialist phytophagous insects are strongly linked to the evolution of host-plant lineages, and in particular plant chemistry. Such insects show a strong phylogenetic conservatism of host associations (Briese 1996; Briese & Walker 2002). This pattern of strong phylogenetic conservatism in diet indicates the non-target plants at greatest risk are those closely related to known hosts (Futuyma 2000), and this has been validated by recent reviews of non-target attack by insect (Pemberton 2000; Briese & Walker 2002; Louda et al. 2003; Paynter et al. 2004) and fungal (Barton 2004) weed biological control agents.

The scientific literature regarding the taxonomic position of lagarosiphon and the most recent checklist of native New Zealand plants (De Lange & Rolfe 2010) were consulted to identify the New Zealand plant species that are most closely-related to lagarosiphon in order to compile a list of plants for inclusion in host-range testing. To do this the Web of Science® database and the angiosperm phylogeny website (http://www.mobot.org/MOBOT/research/APweb/) were searched for information regarding the phylogeny of the genus *Lagarosiphon*. Nevertheless, given that the aquatic lifestyle is a highly specialised one, relying totally on taxonomic position without due consideration of habitat may be risky (for example, a more distantly related submerged aquatic is likely to be at greater risk of non-target attack than a more closely related terrestrial plant), so information on the habitat preference of related plants was also recorded.

4.2 Identifying candidate biocontrol agents of lagarosiphon

Information regarding fungi associated with lagarosiphon was sought by searching computer databases and Internet sites including the USDA Fungus-host database (http://nt.ars-grin.gov/fungaldatabases/fungushost/FungusHost.cfm), the Fungal Records Database of Britain and Ireland (FRDBI; http://www.fieldmycology.net/FRDBI/assoc.asp), the IMI fungal herbarium (http://www.herbimi.info/herbimi/searchassorg.htm), and the NZFUNGI database (http://nzfungi.landcareresearch.co.nz). Google searches using the key words "*Lagarosiphon"* and "pathogen" or "fungi" were also made.

Identifying candidate arthropod biocontrol agents of lagarosiphon was more difficult than identifying pathogens because there is no equivalent of the FDSM or FRDBI databases for all arthropod herbivores. However, the Natural History Museum's world listing of Lepidoptera host plants was searched (http://www.nhm.ac.uk/research-curation/projects/hostplants/). CAB Abstracts and Google were searched for 'lagarosiphon' and "invertebrate*" or "herbivore". The abstracts were then examined and relevant pests added to the list.

To determine whether any of the pest species recorded feeding on/infecting lagarosiphon already occur in New Zealand, checklists of New Zealand fauna were referred to.

As noted in the introduction, above, a biocontrol programme that targets lagarosiphon infestations in Ireland is underway (e.g. Baars et al. 2010). In addition to the literature searches, key personnel working on the lagarosiphon biocontrol programme in South Africa were contacted for up-to-date information on progress towards identifying candidate biocontrol agents.

4.3 Determining the likelihood of success

Paynter et al. (2012) recently developed a framework that allows the best and worst weed targets for biocontrol to be identified on the basis of a few easily determined plant traits: whether a plant is reported to be common/weedy in the native range; habitat (aquatic/wetland versus terrestrial); mode of reproduction (sexual versus asexual); presence of native or valued exotic congeneric species; and, if they have been performed, the past success of biocontrol programmes against the target weed in other countries. Relevant data to parameterise Paynter et al.'s (2012) scoring framework were acquired by using international scientific literature (e.g., CAB Abstracts®), regional floras, relevant websites (e.g. Wikipedia http://www.wikipedia.org/) and by consulting with regional experts.

5 Results

5.1 The taxonomy of lagarosiphon

Lagarosiphon belongs to the family Hydrocharitaceae (subfamily Anacharidoideae), which is placed in the Order Alismatales (Fig. 1). No native New Zealand plants belong to this family, but several exotic species have become naturalised (Howell & Sawyer 2006), namely:

- *Egeria densa* Planchon
- *Elodea canadensis* Michaux
- *Ottelia ovalifolia* (R. Br.) L.C.Rich, which also belongs to the subfamily Anacharidoideae
- *Hydrilla verticillata* (L. f.) Royle and *Vallisneria* spp., which belong to the subfamily Hydrilloideae.

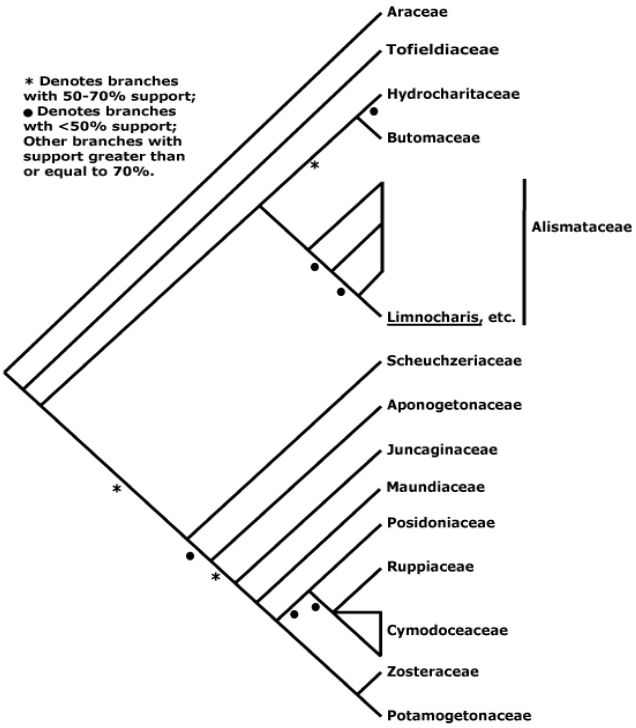

Figure 1 Phylogeny of the Alismatales (from the Angiosperm Phylogeny Website: http://www.mobot.org/mobot/research/APweb/).

The Butomaceae and the Alismataceae, which are the most closely related families to the Hydrocharitaceae (Fig. 1), are also absent from the native New Zealand flora: the sole representative of the Butomaceae *Butomus umbellatus* was declared an unwanted organism and targeted for eradication in New Zealand, following the discovery of plants that had not been propagated for sale on the premises of one grower in New Zealand (Champion et al. 2007). Two genera of the Alismataceae have become naturalised in New Zealand, namely *Alisma* spp., and *Sagittaria* spp.

The families Tofieldaceae, Scheuchzeriaceae and Aponogetonaceae are also absent from the New Zealand native flora (and only one species that belongs to these families has become naturalised, namely *Aponogeton distachyos*). Native representatives of the Alismatales are found in the following more distantly related families: Araceae, Juncaginaceae, Ruppiaceae, Zosteraceae and Potamogetonaceae (Table 2).

Table 2 Alismatales native to New Zealand

Family and species	Habitat in New Zealand
Araceae	
Lemna minor	Floating aquatic
Wolffia australiana	Floating aquatic
Juncaginaceae	
Triglochin palustris	Montane wetlands, growing along the sides of slow flowing streams, on tarn and lake margins and in sphagnum bogs
Triglochin striata	Wetlands: Damp, water-logged situations, usually in the margins of ponds

	and lagoons, salt marshes
Ruppiaceae	
Ruppia megacarpa	Submerged aquatic. Coastal habitats in brackish or saline water
Ruppia polycarpa	Submerged aquatic. Both estuarine water and freshwater lakes and streams
Zosteriaceae	
Zostera muelleri	Marine: mainly estuarine sand flats
Potamogetonaceae	
Lepilaena bilocularis	Submerged aquatic herb of lakes, brackish water, or slow-flowing rivers. Usually found in shallow freshwater habitats not far from the coast
Potamogeton cheesemanii	Submerged freshwater aquatic (with floating leaves)
Potamogeton ochreatus	Submerged freshwater aquatic
Potamogeton suboblongus	Commonly found in shallow, muddy hollows in forest, and colonising tarns and alpine soaks and pools that may partially dry out in summer

5.2 Developing a host-specificity test plant list for lagarosiphon

The following recommendations are based on utilising a centrifugal phylogenetic method (Wapshere 1974) to determine the host-range. Adopting this approach requires that exotic Hydrocharitaceae and Alismataceae should be included in specificity testing (even if they are undesired weeds) before any native plants are tested, as their inclusion should help to delimit the host-range of candidate biocontrol agents.

In addition to phylogenetic information, the ecology of the potential test plants should also be considered. For example, arthropod herbivores that feed on lagarosiphon should be adapted to being submerged in freshwater, so it is assumed that submerged freshwater aquatics that occur in similar habitats to lagarosiphon are potentially at greater risk of non-target attack than plants that are not submerged freshwater aquatics, even if the latter are more closely-related to lagarosiphon. For example, the saltmarsh plant *Triglochin striata* (Juncaginaceae) and the marine eelgrass *Zostera muelleri* (Zosteriaceae) are less likely to be suitable hosts for a lagarosiphon herbivore than the more distantly related *Potamogeton cheesemanii* (Potamogetonaceae), which is a submerged freshwater aquatic. Indeed, given the habitat requirements of New Zealand native plants that belong to the Zosteriaceae and the Juncaginaceae, it is recommended that it is not necessary to include these species in host-range testing.

5.2.1 Recommended test-plant list

Hydrocharitaceae: at least one representative of the naturalised genera in this family (*Egeria, Elodea, Hydrilla, Ottelia* and *Vallisneria*) should be included in host-range testing. All of these species are submerged freshwater aquatics.

- Alismataceae: Representatives of each of the two genera that have become naturalised in New Zealand (*Alisma* and *Sagittaria*) should be tested.
- Aponogetonaceae: *Aponogeton distachyos*.

- Araceae: *Lemna minor*, *Wolffia australiana.*
- Ruppiaceae: *Ruppia polycarpa* (*Ruppia megacarpa* occurs in brackish or saline water).
- Potamogetonaceae: *Lepilaena bilocularis*, and at least one representative of the native *Potamogeton* spp. (Table 3).

5.3 Identifying candidate biocontrol agents of lagarosiphon

5.3.1 Fungal pathogens

None of the database or internet searches found any examples of fungal pathogens reported to attack lagarosiphon. This could indicate a dearth of survey work, although Gassmann et al. (2006) noted that plant pathogens appear to be poor candidates for use against submerged weeds. Indeed, some survey work has looked for pathogens in the native range, but a pathogen collected on *L. major* at only one site in the native range could not be cultured for identification (Baars 2011).

5.3.2 Arthropod herbivores

A collaborative project between University College Dublin (UCD), Inland Fisheries Ireland (IFI) and Rhodes University (South Africa) began in 2008 to investigate the prospects for biocontrol of lagarosiphon. Surveys of lagarosiphon have been conducted in the native range and a number of candidate arthropod agents have been identified, including a leaf-mining fly (*Hydrellia lagarosiphon*) a shoot-tip mining midge (cf. *Polypedilum* sp.), defoliating moths (prob. *Synclita* sp. and prob. *Parapoynx* sp.), and leaf- and shoot-feeding weevils (*Bagous* sp.) (Baars et al. 2010; http://www.fisheriesireland.ie/Lagarosiphon-major/using-insects-to-wage-the-war-against-our-invasive-plants.html).

Host-specificity testing is continuing, but results to-date (J-R Baars, University College Dublin, pers. comm.) have indicated that the defoliating moths are polyphagous and one of the *Bagous* weevils collected was subsequently found to feed on *Juncus* and is not associated with lagarosiphon. The second *Bagous* weevil collected is considered likely to be associated with lagarosiphon but has not been collected in subsequent surveys. Work, therefore, has focused on the potential of *Hydrellia lagarosiphon* and the shoot-tip mining midge (cf. *Polypedilum* sp.) although work on the weevil could be revisited at a later date, if this is considered necessary.

The fly *H. lagarosiphon* has been tested on nearly 50 plant species using no-choice and paired-choice trials and 1st and 3rd instar larvae; the host-range testing has not yet been completed but the results to-date are very promising (J-R Baars, pers. comm.). Work on *H. lagarosiphon* also indicates that this fly is highly damaging, reducing biomass by 50–70% after 134 days exposure to *H. lagarosiphon* herbivory, and that sustained damage induced by consecutive generations of *H. lagarosiphon* negatively affected rooted plants at both low (1 per shoot) and medium (3 per shoot) larval densities (Mangan & Baars, in prep.). Sustained herbivory, over multiple generations, reduced shoot biomass production by approximately 100% when plants were exposed to larvae compared with the control shoots (Mangan % Baars, in prep). The generation time of this fly varies according to temperature and it was estimated that *H. lagarosiphon* could complete two generations per year in Ireland and up to

14.7 generations per year in southern Europe (Mangan & Baars 2013). Mangan and Baars (in prep.) also investigated the impact of herbivory on the viability of lagarosiphon stem fragments and found that when they planted stem fragments, those that had been exposed to herbivory by *H. lagarosiphon* had significantly reduced establishment rates, compared with those that had not been exposed to herbivory.

Work on the midge (cf. *Polypedilum* sp.) has shown that it is extremely damaging as the larvae burrow into the shoot after spending some time damaging the meristem tissue. In the field it was only found on *L. major*, despite searches on a related species *Lagarosiphon muscoides*, at sites where it occurred in isolation or co-occurred in equal abundance with *L. major*. While choice-specificity tests indicated that it was specific (J-R Baars, pers. comm.), in no-choice tests it completed its life cycle on several *Potamogeton species* and also *Elodea canadensis*, but does not seem to attack *Hydrilla* and *Najas*; but more trials are needed to confirm this. Lengthy multi-generation trials are being planned in Ireland, as there is some indication that adults that emerge on other species are smaller, some are infertile, and populations may not be able to be sustained on these sub-optimal hosts over time (J-R Baars, pers. comm.). Studies are underway in Ireland to assess the impact, but the damage is certainly more impressive than the fly, and the reproductive potential is also much better (J-R Baars, pers. comm.).

5.4 Determining the likelihood of success

Biocontrol agents have not yet been released against lagarosiphon. Agents, including *Hydrellia* spp., similar to those found on lagarosiphon have, however, been released on a related aquatic weed *Hydrilla verticillata* in the USA (Buckingham & Grodowitz 2004; Grodowitz et al. 2004) where weed monocultures were replaced by a mixture of species (Fig. 2)

Figure 2 *Hydrilla* at Lake Seminole in 1994 before biocontrol (a) and in 1999, after biocontrol (b) (from Grodowitz et al. 2004).

Moreover, the predictive framework developed by Paynter et al. (2012) indicates that lagarosiphon should be a good target for biocontrol: it is not reported to be weedy in the native range, New Zealand populations are clonal, and it is an aquatic plant. The mean reduction in plant density due to biocontrol programmes against weed species with this combination of traits is 93% (Table 3), although it should be noted that the predictions made by Paynter et al. (2012) were based on a relatively small dataset and this level of control is by no means guaranteed.

Table 3 Predictions of the proportion reduction achieved by biocontrol for each of the eight combinations of the predictor variables (Paynter et al. 2012)

Major weed in native range	Reproduction	Ecosystem	Mean percentage reduction from biocontrol
No	Asexual	Aquatic/wetland	93
No	Sexual	Aquatic/wetland	77
No	Asexual	Terrestrial	80
No	Sexual	Terrestrial	50
Yes	Asexual	Aquatic/wetland	69
Yes	Sexual	Aquatic/wetland	36
Yes	Asexual	Terrestrial	41
Yes	Sexual	Terrestrial	15

5.5 Potential objections to biocontrol of lagarosiphon

Lagarosiphon has some uses: it provides habitat for aquatic fauna, large patches increase sedimentation (which is helpful in some areas), it can coexist with native aquatic plants in some areas, and it is one of the few plants which can withstand the degraded conditions in some fresh waters so its removal may further degrade the habitat (McGregor & Gourlay 2002). It is unclear how fast the candidate agents for lagarosiphon are likely to disperse if introduced into New Zealand, but *Hydrellia pakistanae*, a biocontrol agent of Hydrilla, dispersed 400 km in just 13 years in the USA (Grodowitz et al. 2004) indicating that agent dispersal has the potential to be quite rapid. Biocontrol agents released against lagarosiphon may spread to areas where it is valued for these roles and thus potentially be detrimental.

During a workshop on aquatic weeds, the potential for objections to biocontrol was discussed (Quentin Paynter, unpublished notes). Three potential objections were put forward:

- Anglers may object to biocontrol
- Biocontrol may increase fragmentation making eradication harder in eradication/containment areas

- Biocontrol could contribute to eutrophication, potentially 'flipping' lakes into new stable states

The first of these objections is considered unlikely to influence the outcome of an EPA decision because of the large economic impacts of lagarosiphon and the likelihood that some vegetation will persist for fish to shelter in.

The issue of fragmentation was addressed by research which indicated that fragmentation by the *Hydrellia* fly was associated with low fragment viability (see section 5.3.2 above), so this is unlikely to be a problem.

The final concern would require a thorough review of the literature and, potentially, experimental work to determine the potential outcomes of biocontrol. For example, Körner and Dugdale (2003) noted that re-establishing stable submerged vegetation is considered an important tool to restore shallow eutrophic lakes. Therefore, interventions such as planting native macrophytes in lakes dominated by lagarosiphon may be required to achieve biodiversity goals in some locations. However, one advantage of biocontrol over other control methods, such as the use of herbicides, is that changes brought about by biocontrol should be relatively gradual, allowing time for managers to make interventions. For example, decline of *Hydrilla verticillata* at Lake Seminole, USA was noticed in 1999, some nine years after it was first released there (Grodowitz et al. 2004; Center et al. 1997).

6 Conclusions

The prospects for biological control of lagarosiphon appears to be high as a potentially specific and damaging agent (*Hydrellia lagarosiphon*) has already been identified and other promising candidate agents have been found that also have potential for use as biocontrol agents.

7 Recommendations

- A pre-release survey of the natural enemies of lagarosiphon should be conducted in New Zealand. This is likely to cost in the region of $80,000. Concurrent research should address the potential negative impacts of biocontrol, particularly in degraded lakes where removal of lagarosiphon may cause further environmental degradation.
- Host-range testing of *Hydrellia lagarosiphon* should be completed using New Zealand test plants, and could be completed within 2–4 months. The cost of completing the tests in a containment facility in Ireland was estimated at (€6,000 ~=NZ$ 10,000; J-R Baars, pers. comm.). This would require New Zealand test plants to be sourced in New Zealand and shipped to Ireland, and may require phytosanitary certificates (estimated cost c. $5,000–$10,000 depending on how much time and travel is required to obtain and ship New Zealand native aquatic test plants). Alternatively, a starter colony of the fly could be shipped to New Zealand and the testing carried out by Landcare Research at either of the Auckland or Lincoln containment facilities (this would likely cost more than conducting the testing in Ireland as there would be costs associated with establishing and maintaining a colony in New Zealand that were not factored into the Irish estimate).

- Assuming the fly is adequately specific to be considered for release in New Zealand, then an application would be made to the Environmental Protection Authority (EPA), which would cost c. NZ$50,000 (sum of cost of preparing an application, EPA processing costs and the cost of attending a hearing, should a hearing be required). All up, the cost of conducting surveys of lagarosiphon in New Zealand, completing host-specificity testing and obtaining EPA approval for release is likely to be in the region of $145,000–$165,000. Agent mass rearing and release would be in addition to this.

Releasing more than one agent increases the probability that a biocontrol programme will succeed. Indeed, as the midge has larvae that can swim it should be capable of attacking lagarosiphon growing in deeper water than the fly can exploit (the fly oviposits on vegetation growing at the water's surface). Given the damage of the shoot-tip mining midge (cf. *Polypedilum* sp.) is purportedly even more damaging than *H. lagarosiphon*, it is recommended that host-range testing of the shoot-tip mining midge should also proceed, provided the results of the host-range testing to be conducted in Ireland in 2013 indicate that it is likely to be sufficiently specific for New Zealand. The cost of the host-range testing and EPA approval would be similar to before, but may cost $10,000–$20,000 more if longer-term multi-generational tests are required to demonstrate adequate specificity.

Table 4 A 5-year work plan for biocontrol of lagarosiphon in New Zealand. *Note: costs associated with gaining EPA approvals for both agents could potentially be reduced if the application to release *Hydrellia* were to be delayed for a year so that both agents could be included on the same application.

Year	Fly (*Hydrellia lagarosiphon*)	Midge (cf. *Polypedilum* sp.)
1	Conduct survey of natural enemies of lagarosiphon in New Zealand ($80,000)	
2	Complete *H. Lagarosiphon* host-range testing (~$15,000–$35,000)	Liaise with J-R Baars regarding progress of host-range testing & the suitability of cf. *Polypedilum* sp. for release in New Zealand
3	If host-range testing results indicate adequate specificity, apply for permission from the EPA to release *H. Lagarosiphon* in New Zealand (~$50,000)*	If results in Ireland are promising, complete cf. *Polypedilum* sp. host-range testing ($25,000–$55,000)
4	Assuming permission is forthcoming, mass-rear & release *H. Lagarosiphon* (~$30,000)	If host-range testing results indicate adequate specificity, apply for permission from the EPA to release cf. *Polypedilum* sp. in New Zealand (~$50,000)*
5	Mass-rear & release *H. Lagarosiphon* (~$30,000)	Mass-rear & release cf. *Polypedilum* sp. (~$30,000)

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Appendix 1 – The steps in a biocontrol project

Classical biological control (or biocontrol) of weeds is defined as "The intentional introduction of an exotic, usually co-evolved, biological control agent for permanent establishment and long-term pest control". A classical biocontrol programme typically works through the following steps, usually in a sequential manner, but some activities may occur concurrently.

1. Explore the feasibility of project. If project looks feasible, proceed.
2. Survey weed in places where biocontrol is desired. If any potential agents are found explore ways to maximise them. If any likely impediments are found look for ways to mitigate them.
3. Undertake molecular studies of the weed to help narrow down the best place in the native range to find natural enemies.
4. Unless natural enemies are already well known, survey weed in native range. Identify and study life cycles of natural enemies found.
5. Determine host range for potential agents. Abandon any species that do not appear to be safe or effective enough.
6. Apply to authorities for permission to release agents.
7. If permission is granted import, clear through containment, and develop rearing techniques for new agents (if not already known)
8. Mass rear and release agents over several years.
9. Monitor establishment success and dispersal of agents over several years.
10. Harvest and redistribute agents
11. Evaluate success of project. Decide if further agents are needed.