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Executive Summary

It is almost four years since *Lagarosiphon* was first reported in a bay on the western side of upper Lough Corrib. Since that time, this aggressive invasive plant has rapidly expanded its geographical range and its overall standing crop within this large water body. Between 2005 and 2008 focused research programmes have endeavoured to identify the factors that confer such a competitive advantage on this species over indigenous macrophytes. Studies on the life cycle of this southern African plant under Irish conditions have revealed growth, reproduction and dispersal strategies that differ significantly from those inherent in our native species. Furthermore, a wide range of control methods, including mechanical, chemical, environmental and biological approaches, have been targeted against this invasive weed. It is clear that a great deal more research must be conducted if viable, long-term control of *Lagarosiphon* in Lough Corrib is to be achieved.

Lough Corrib is the second largest lake in Ireland (*circa* 17,000 ha). Its ecological and conservational importance is considerable, supporting 14 habitats and six species that are listed on Annex I and Annex II, respectively, of the Habitats Directive. Lough Corrib is an internationally renowned wild brown trout fishery, supporting significant stocks of wild salmonid fish. As a consequence, the lake is a nationally recognised recreational angling resource for the local tourist industry. The environmental, social and economic status of Lough Corrib will continue to be compromised as this aggressive invasive plant continues to expand its range within the lake.

Survey work conducted in 2008 revealed that *Lagarosiphon* is continuing to spread rapidly through the upper and middle lakes. In 2007, 64 *Lagarosiphon*-infested sites were identified in Lough Corrib. A further 49 sites were recorded in 2008, giving a total of 113 infested sites in the lake at the time of writing. In the middle lake, the plant is gaining an increased foothold and is continuing to spread downstream towards the shallower, lower lake.

Significantly, no *Lagarosiphon* has yet been recorded from the entire lower lake. While this is a positive finding, it is clear from the distribution studies conducted in recent years that the plant is progressively moving southward towards this large expanse of relatively shallow water (average depth - 3 m). Every effort must be made to ensure that the progress of the plant in this direction is halted and that any sighting of viable populations in this watercourse is met with urgent and dramatic action.

Results from biological surveys of the macrophyte, macroinvertebrate and fish populations that were conducted in Lough Corrib in 2008 demonstrated the significant alteration that *Lagarosiphon* can impose on the ecology of this infested water. Macrophyte surveys clearly illustrated a dramatic reduction in diversity in areas where *Lagarosiphon* was well established. Furthermore, macroinvertebrate abundances were significantly greater in the invasive *Lagarosiphon* than in the indigenous Charophyte vegetation, although fewer species and taxa contributed to this abundance. Of significant concern is the fact that *Lagarosiphon* appears to be providing a habitat that favours the establishment and proliferation of the invasive Zebra mussel (*Dreissena polymorpha*).

A total of seven fish species and one hybrid were recorded on Lough Corrib in 2008. There was a clear dominance of coarse fishes in the nets surveyed. Perch and roach were the predominant species present. Smaller fish of both species were associated with *Lagarosiphon*-dominated habitats, suggesting that the invasive macrophyte represents an important predator refuge for these juvenile fishes. Despite the status of Lough Corrib as an internationally important salmonid angling location, brown trout was poorly represented in the samples. However, the sampling protocol was selective towards smaller fish size classes and would not be expected to representitive of the natural brown trout population in the lake. Despite this, it is clear that the habitat created by the tall and dense *Lagarosiphon* vegetation favours coarse fish species and communities, probably to the detriment of native salmonid species. The continued expansion of this invasive species, clearly, will negatively impact on these more sensitive salmonid groups.

Significant progress has been made with weed control initiatives in 2008 and a total of 29 hectares of *Lagarosiphon*-infested lake has been mechanically cleared over a six month period. This has resulted in the removal from the lake of approximately 4,700 tonnes of invasive plant material. Regrettably, this constitutes only a small fraction of the weed in the lake and control operations will have to be intensified in the long-term in order to make a serious impact on the overall weed population.

On the positive side, field observations supported by empirical data from artificial growth chambers have shown that *Lagarosiphon* is susceptible to the deep cut that is applied using trailing knives or V-blades, and that ‘deep cut’ plants rarely regrow. This suggests that the cutting method currently in operation in Lough Corrib, while slow and labour intensive, has the potential to provide long-term control. Furthermore, research conducted into the life cycle of the plant has shown that there are two distinct morphological forms of the plant. The ‘erect’, canopy-forming stage proliferates during the colder winter months, while the ‘collapsed’ stage is most common through the summer time. This finding has influenced the course of the mechanical cutting programme as it has been demonstrated that far greater yields, in terms of *Lagarosiphon* biomass removed from the lake, are attained for a similar effort when the cut is applied to erect, buoyant plants. Thus, cutting during the winter months will be far more productive than cutting in the summer time.

Further advances with weed control techniques have been made, particularly in the area of environmental control, and specifically light exclusion. The use of a biodegradable, jute geotextile was piloted in 2008 and, while trials are at an early stage, the method is showing considerable promise. The jute material is far easier to handle and to accurately place over designated *Lagarosiphon* stands than was the plastic geotextile that was trialed in 2007. When secured in position by divers, this material rarely moves and never interferes with boat traffic or recreational use of the lake. Interestingly, it has been discovered that some of the more diminutive, native *Chara* species are capable of growing through the fine pores in the material, thus reducing the necessity to transplant native macrophytes on the geotextile sheets. No *Lagarosiphon* plants have managed to grow through the material. In addition, although relatively labour intensive to apply, it is believed that, once laid, this material will remain in position for a sufficiently long time to completely eradicate the underlying *Lagarosiphon* plants.

Other weed control approaches currently receiving attention include the use of an approved herbicide (dichlobenil) and hand removal of *Lagarosiphon* plants by divers. The application of chemical control within carefully selected and localised areas, normally where alternative approaches are unsuitable, has proved to be quite successful.

The possibility of ultimately releasing one or more biocontrol agents onto *Lagarosiphon* in Lough Corrib is being carefully considered. Field studies in South Africa have identified a number of potential candidate agents that will be examined in detail over the coming years by a team of experts in UCD. No releases will be countenanced until there is certainty that the released agents will not find a suitable host among the native macrophytes in or around Lough Corrib.

There are a considerable number of avenues still to pursue in order to fully understand the complex biology of *Lagarosiphon*, the factors that favour its establishment and growth in Lough Corrib, its impact on the broad ecology of the lake, and how best to control and eradicate it. Efforts to advance and optimise the weed control methods currently being used will continue. However, it will be necessary to develop alternative and novel approaches to controlling the plant and to investigate mechanisms or strategies that will best exploit any vulnerable life cycle stages.

Recent work on *Lagarosiphon* in Lough Corrib has used the combined resources of a number of State and semi-State agencies. This has significantly benefited the project by providing additional manpower, but it has also aided in the development of field technique and control strategies. Furthermore, direct collaboration with expert teams from UCD, QUB and from GMIT has bolstered the research effort and provided a greater insight into the inner workings of this complex invasive species. This work will continue into the future, with the primary objective of restoring the high ecological and conservation status for which Lough Corrib is renowned.

1 Introduction

The national importance of Lough Corrib as an area of significant natural heritage and conservation is, at present, adversely compromised by the presence and expansion of the aggressive invasive macrophyte, *Lagarosiphon major*.

Lagarosiphon major is an invasive, non-native, aquatic plant species that was first recorded in a natural aquatic habitat in Ireland in 2005. At that time, the dense growth of *Lagarosiphon* covered an area of 12 ha in one of Lough Corrib's northern bays - Rinerroon Bay (Figure 1). This thick, matted canopy precluded angling or recreational boating in the bay and impacted indigenous floral and faunal communities that were previously resident in the area.

Figure 1: *Lagarosiphon* in Rinerroon Bay, 2005.

Lagarosiphon major (African curly-leaved waterweed, African elodea, oxygen weed) is a native to southern Africa (Obermeyer, 1964) and is a member of the Family Hydrocharitaceae, which includes the more commonly known species such as *Elodea* and

Hydrilla. This perennial, submerged aquatic plant can be distinguished most easily from closely related species by the distinct, alternately spiraled position of the leaves along the stems (Bowmer *et al*., 1995). The leaves are also strongly recurved downwards towards the stem and have strongly tapered tips (A more detailed description of the morphological features used to identify *Lagarosiphon* can be found in Caffrey and Acevedo, 2007.) The specific growth pattern of this plant leads to repetitive surface stem branching. This produces extremely dense mats on and immediately below the water surface at times of maximum growth. These mats can be so dense that practically no incident light can penetrate to the lake bed beneath. It is this substantial surface growth form that poses most threats for biodiversity and for recreational exploitation in infested watercourses. Only female plants are known to occur in Ireland (Cook, 1982; National Botanic Gardens, 2007). However, despite this, reproduction and spread of this plant is extremely successful through the alternative asexual methods of fragmentation and vegetative reproduction.

The Corrib Catchment constitutes an environmental resource of major international importance. Lough Corrib itself is the second largest lake in Ireland (*circa* 17,000 ha). Its importance is characterised ecologically by the extensive *Chara*-dominated shallow areas, the clean alkaline waters and the abundance of insect life present in the lake. Lough Corrib is one of the few large alkaline lakes remaining in Western Europe that is capable of supporting significant stocks of wild salmonid fishes.

Further, Lough Corrib is of major conservation importance and supports 14 habitats and six species that are listed on Annex I and Annex II, respectively, of the Habitats Directive (http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm).

In addition to its environmental value, Lough Corrib is a focus for a large local and tourist recreational angling community. The quality wild salmon and brown trout fishing makes Lough Corrib a major national tourist angling destination. This large alkaline lake is regarded as one of the more productive wild brown trout water body in Ireland. This is reflected by the fact that *circa* 16,000 angling boats were present on Lough corrib during the 2008 mayfly fishing season.

Lough Corrib is also a focus for the local tourist industry, with regular cruise tours and a wide range of historically significant sites (e.g. the ancient Hen's Castle (home of the great pirate Queen of Connemara, Grace O'Malley), the 13th century Ashford Castle, the monastic sites on Inchagoill Island, among others) to appeal to visitors from at home and abroad.

Since the recent identification of the highly invasive submerged plant species, *Lagarosiphon major*, its rapid advance through the upper lake has demonstrated its potential to compromise the environmental, social and economic quality of the area.

In this report, the status of the *Lagarosiphon* problem in Lough Corrib in 2008 is described and results from research undertaken this year are presented. This information is critical in order to reduce and/or reverse the negative impacts already evidenced on the lake and its communities. The long-term aim of the programme is to restore Lough Corrib to its acknowledged status as a fishery of international standing and a nationally important Special Area of Conservation (SAC).

1.1 Funding and Research Objectives

Knowledge of the invasive capacity of *Lagarosiphon*, and the environmental and economic havoc that it has caused over a period of 40 years in New Zealand (e.g. Howard-Williams, 1988; Rattray *et al.*, 1994), gave rise to serious concerns for the conservation status and overall functioning of Lough Corrib. Following its identification in 2005, a *Lagarosiphon* 'Task Force' was convened to coordinate a focused programme that would research the biology and ecology of the plant under Irish conditions and develop an informed and science-based control and eradication plan. The activities undertaken by this group are outlined in Caffrey and Acevedo, 2007.

Initial funding for the project was provided by NPWS in late 2006. In 2007 further funding was jointly provided by NPWS, OPW and WRBD. This culminated in the production of the above-mentioned report, which describes the status of the invasion in

the lake, presents preliminary observations on the biology and ecology of the species under Irish conditions, presents results from the control trials conducted within the lake and issues recommendations for further research and weed management within the lake.
In 2008, the Central Fisheries Board (CFB), in co-operation with the Western Regional Fisheries Board (WRFB), was commissioned to conduct a further, intensive research investigation on *Lagarosiphon* in Lough Corrib. Funding was jointly provided by NPWS, OPW, WRBD and Galway City Council. The specific aims and objectives of the investigation are presented below.

Lagarosiphon *Control*

A range of *Lagarosiphon* control and physical removal operations will be conducted, according to a predetermined schedule. Where possible, operations in different areas of the lake will be conducted contemporaneously. The operations will be scientifically monitored and the results, in terms of areas of lake cleared of *Lagarosiphon*, will be quantified. While tried and tested weed control practices are in progress on the lake, trials to investigate new methods of control will be conducted and assessed.

Hand Removal

In bays and littoral areas where *Lagarosiphon* occupies only small sections of the lake bed (< 20 m^2), the use of scuba divers to hand remove the plants will be employed. This method is time-consuming but can be very effective. It is a widely used practice in *Lagarosiphon*-infested lakes in New Zealand. Using this method, it is possible to totally clear recently infested bays of any *Lagarosiphon* plants. The CFB team will conduct these operations at the same time as cutting and removal operations are in progress elsewhere in the lake by the WRFB.

Light Exclusion

Trials conducted in Lough Corrib in 2007 using black geotextile to exclude incident light showed that the method was most effective where the *Lagarosiphon* was cut prior to laying the material. Work in 2008 will determine the optimum area of weed to be treated. In 2007 the trial sites were each 2,500 m^2. This was too large an area to effectively cover. It is estimated that sites measuring *circa* 400 m^2 will prove more manageable. Trials will determine the length of time that the geotextile should remain in place to effectively kill the *Lagarosiphon*. In the coming seasons, a number of different material types will be used to determine their relative efficiencies. At least one biodegradable product will be tested.

Herbicide

Trials conducted using dichlobenil (applied as Casoron G) at a number of *Lagarosiphon*-infested sites throughout the country, including a small marina in Rinerroon Bay, Lough Corrib, revealed the susceptibility of *Lagarosiphon* to this herbicide. This control method will probably prove most useful in restricting or precluding the regrowth of viable fragments in mechanically cut sections. Trials to assess the efficacy of this herbicide in different situations will be conducted and evaluated in the coming season.

Biocontrol

A desk study will be conducted, in conjunction with UCD, to investigate the possibility of finding biological agents that might specifically control *Lagarosiphon* in Irish watercourses.

Distribution in Lough Corrib

The status and spread of *Lagarosiphon* in the upper and middle lake will be monitored in 2008. The CFB scientific team, with the support of the WRFB, will continue to survey bays and littoral areas with a view to updating the 2007 distribution map for these lake areas. Surveys will continue on the lower lake, where no *Lagarosiphon* has yet been recorded.

Life Cycle Traits of Lagarosiphon

For the duration of the project on Lough Corrib, scientific staff will continue to observe and record features pertinent to the life cycle of *Lagarosiphon*. This is a most important aspect of any weed control programme as an understanding of the life cycle of a species may unveil weak links that can be specifically targeted for control.

Where time and resources permit, specific studies will be conducted to quantify the biomass development of the plant in established and in developing stands. In addition, information will be collected on factors that might influence the growth and performance of this invasive weed in Lough Corrib (e.g. depth, temperature, light, pH and substrate).

Impact on Indigenous Biotic Communities

It is clear that the growth and spread of *Lagarosiphon* in Lough Corrib has adversely impacted indigenous floral and faunal species and communities. This loss of natural biodiversity will continue as *Lagarosiphon* expands its range within the lake. Studies will quantitatively determine the nature and extent of the loss of macrophyte, macroinvertebrate and fish species, as well as specific habitat types, as a consequence of this invasion.

Recolonisation of Treated Sites

Efforts to determine the nature and rate of natural, indigenous recolonisation in locations that have been cleared of *Lagarosiphon* will be made. Depending on the natural rate of recolonisation, it may be necessary to expedite the process by transplanting native plant species from adjacent bays.

PR and Education

Information gathered during the course of the project will be used to mount ongoing PR and education campaigns in order to raise awareness of the problem in Lough Corrib. The media will be encouraged to maintain a watching brief and will be provided with whatever information they require to make good copy.

1.2 Threat of Non-Native Invasive Species

Non-native species introduction is acknowledged to be one of the major causes of species extinction in freshwater ecosystems (Lodge, 2001). This impact may be mediated by competitively excluding or out-competing the less robust native species, by preying on native species or by altering the natural aquatic or riparian habitat in which they reside. Invasive species can also adversely impact the recreational and amenity use of infested watercourses by restricting angling, boating, swimming and other water-based leisure pursuits. They pose a significant threat to economic interests such as agriculture, forestry, fisheries and tourism. A consequence of the above can be a significant financial cost to the economy. Recent estimates suggest that the global economic cost of invasive species is so significant that it is impossible for any country to ignore the current expanding threat. Specifically, Pinmentel *et al*, (2001) estimated that the total global economic cost of invasive species is approximately $1.4 trillion, which equates to almost 5% of the total global economy.

1.3 Status of Lagarosiphon in Lough Corrib since 2005

The presence of the highly invasive aquatic plant *Lagarosiphon major* was confirmed in Lough Corrib's Rinerroon Bay, north of Oughterard, in April 2005. In the months that followed, investigations to determine the status of *Lagarosiphon* in Lough Corrib were conducted. At that time *circa* 55% of the area of this bay (*c*. 12 ha) was overgrown with *Lagarosiphon*. With a mean fresh weight biomass of 13.8 kg m^{2}, this represented an estimated overall weed biomass in this bay of 1,650 tonnes.

The field surveys in 2005 revealed that the invasive plant had established viable populations at eight other locations in the upper lake, primarily in shallow bays along the more sheltered western shore. Only one population was recorded on the eastern shore of the upper lake and no specimens were reported from the middle or lower lake. Further surveys of the weed population and its spread within the lake were undertaken during 2006. These revealed that the weed was continuing to spread and had established new populations on the northern and western shores of the upper lake, and had spread down into the middle lake. A total of 24 infested sites were recorded in 2006. In 2007, an intensive distribution survey was undertaken from mid-June to the end of September.

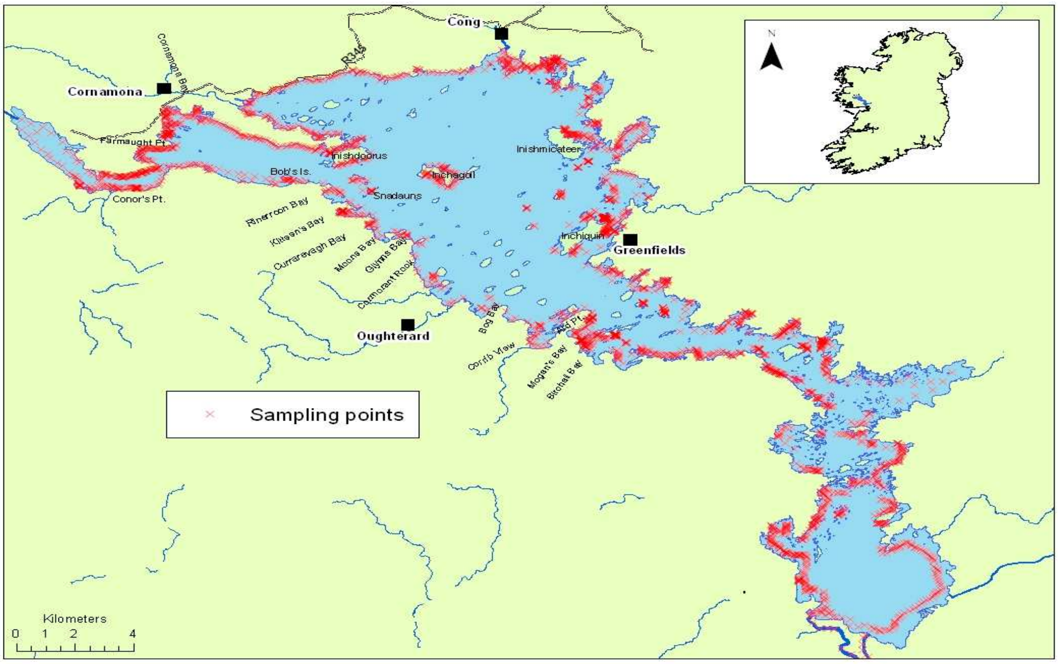


Figure 2: Sampling sites (2,658) surveyed for the presence of *Lagarosiphon major* between mid-June and late September 2007.

Despite poor weather conditions, a total of 2,058 sites in the upper, middle and lower lakes were sampled in this period (Figure 2). The results revealed that *Lagarosiphon* had expanded its range considerably and occupied a total of 64 sites at the end of this survey period (Figure 3).

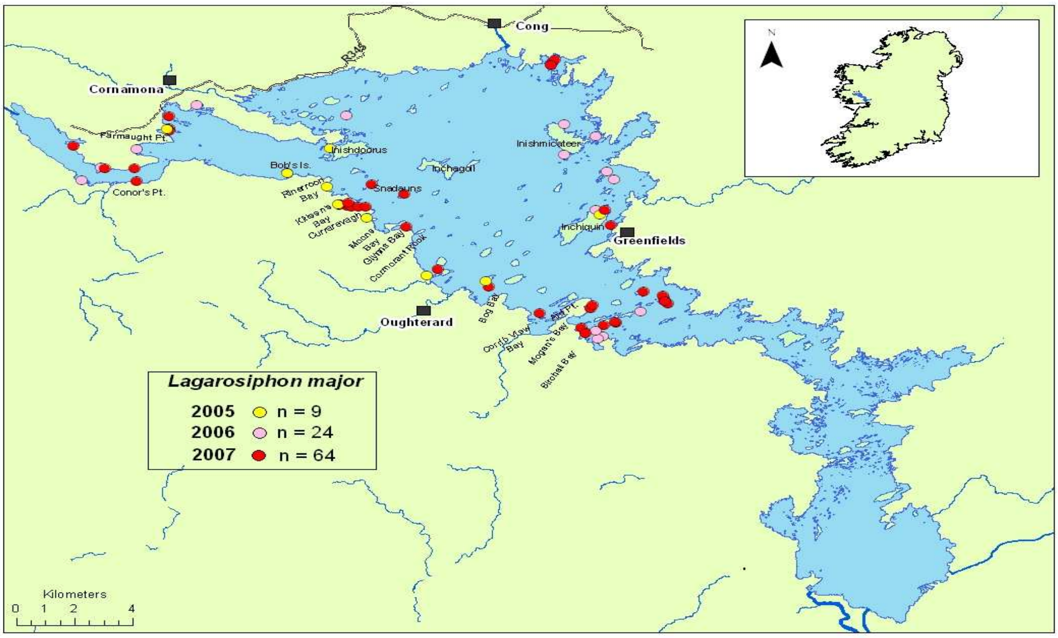


Figure 3: Map showing distribution of *Lagarosiphon major* populations in Lough Corrib in 2005, 2006 and 2007.

The majority of the new sites from which the plant was recorded in 2007 were along the western shore of the upper lake and in the middle lake. However, a number of new sightings were recorded on the eastern and northern shores. This suggests that dispersal may have been significantly influenced by boats or wind action.

The 2007 survey also estimated the broad abundance of *Lagarosiphon* associated with 41 of the 64 sites that had been identified. This provided baseline information against which data collected in 2008 could be compared, giving a quantitative figure for the extent of spread of the weed at a given site over a 12-month period.

Preliminary surveys conducted in Rinerroon Bay demonstrated the potential for rapid expansion that the weed was capable of over a short temporal period. In 2005 it occupied an area of 12 ha, but by 2007 the *Lagarosiphon* bed had expanded to an area of 19.45 ha. This represented an expansion of 7.45 ha in just 2 years. It was estimated that the fresh weight biomass for *Lagarosiphon* in Rinerroon Bay, recorded in 2005, was 13.8 kg m^2 or 138 tonnes per ha (Caffrey, 2006; 2007). The increased biomass or standing crop of vegetation over the two year period, assuming the same biomass level, was 1,028 tonnes.

2 Materials and Methods

2.1 Staffing

The first of two Research Officers (RO) employed by the CFB on the 2008 *Lagarosiphon* research and control programme commenced work at the end of June 2008. The second RO was recruited in August. During the summer, two students from GMIT were recruited for a 10-week period to assist with field sampling.

The WRFB upgraded one of their permanent staff members to supervisor status and assigned him, full-time, to the *Lagarosiphon* project. Three additional WRFB staff members were dedicated to the mechanical weed cutting programme. Additional personnel were provided to the programme by the Office of Public Works (OPW), who assigned two staff members to aid in the weed cutting and harvesting operation.

Constant support was provided to the field operations by scientific staff from CFB and from permanent staff members within the WRFB.

2.2 Collaboration

The Freshwater Ecology Research Group, from University College Dublin (UCD), has established experimental stations in the upper lake to quantitatively monitor the impact that *Lagarosiphon* is having on indigenous macroinvertebrate communities. In addition, a team from Queens University, Belfast (QUB) has received funding under the EPA-sponsored STRIVE programme to study the dynamic interactions between *Lagarosiphon* and native biological communities in Lough Corrib. Fisheries Board staffs are intimately involved with both projects. Work on these collaborative programmes will continue into 2009.

2.3 Distribution and Growth

2.3.1 Distribution

In 2007 some 2,058 sites were examined over a four month period as part of the *Lagarosiphon* distribution study. In 2008 it was not possible to devote as much resource to this aspect of the study because the primary focus was on actual weed removal. However, a considerable amount of sampling was conducted and a significant number of new sites were recorded.

A number of methods were employed to collect information on the distribution of *Lagarosiphon* in the lake. Snorkeling was the most effective method used during the survey. Grapnel sampling, diving and viewing through a glass-bottom tube were methods also employed. Sampling was generally conducted from a 16 ft flat-bottomed boat powered by a 25 hp engine. Members of the WRFB staff, who know the lake intimately, accompanied the survey team during most of the sampling operations. All of the sample sites where *Lagarosiphon* was recorded were positioned with a Global Positioning System (GPS).

Survey assessments were conducted while snorkeling along transect lines positioned across designated bays and also by snorkeling the perimeter of islands. Grapnel surveys were conducted using a standardised, 8- pronged grapnel attached to a length of rope. The grapnel was retrieved when a sufficient body of weed had been trapped by the prongs. The weed was examined for the presence of *Lagarosiphon*. Observations by anglers and other lake users were also logged, following verification by the scientific team.

2.3.2 Life-Cycle Studies

The biology and ecology of *Lagarosiphon* in Lough Corrib was examined in order to identify phases of the plant's life cycle that may be vulnerable to specific control measures. It is essential to understand, in detail, the life processes that confer such a strong competitive advantage on this submerged plant and the environmental factors that favour its establishment and proliferation in certain habitats.

During 2008, the seasonal growth habits and vegetative performance of the weed were examined *in situ* while conducting scuba diving surveys. Further assessments were made during the course of separate studies on the impact that *Lagarosiphon* has on macroinvertebrate and other biotic communities.

2.3.3 Fragmentation Experiments

This phase of the study aimed to examine the viability and potential for establishment and growth of a range of *Lagarosiphon* fragment types. Mature *Lagarosiphon* plants were collected from random locations within the established Bob's Island population (Figure 4). From these, fragments for use in the experiments were prepared.

Figure 4: *Lagarosiphon* plants used in the fragmentation experiments.

Designated parts of the *Lagarosiphon* stems were cut to produce the fragment types required. These fragments represented the different plant parts that would normally become detached or released from the parent plant stand. For this investigation, the following fragment types were used (Figure 5):

- 'mid-stem' sections (10 plants, each 30 cm long),
- 'stem crown' sections (10 plants, each 30 cm long), and
- 'rooted stem' sections (6 plants, each 30 cm long), i.e. mid-stem sections with adventitious or aerial roots.

Figure 5: *Lagarosiphon* stem fragment types used in the experimental aquaria. Stem sections used were (from the left) a) unbranched mid-stem (from upper part of plant), b) unbranched stem crown and c) stem crown with adventitious roots. All fragments were 30 cm long.

At the commencement of the experiment, fragment lengths were measured and the number of roots (if any) was counted. Five 60 litre plastic aquaria were filled to a depth of 10 cm with mesotrophic sediment collected from an area of lake that supports an abundant population of *Lagarosiphon*. To reduce the potential for variation from natural conditions, the plastic aquaria were filled with lake water and stored in the open, close to the lake shore (Figure 6).

The fragments were placed in the aquaria and no attempt was made to plant them into the hydrosoil. All plant fragments were placed in the aquaria on 4th September 2008. The fragments were monitored at *circa* 3 week intervals for the first half of the settlement period (up to day 59). Measurements of stem and new branch elongation were made *in situ*, but root sections were left undisturbed to avoid causing any disturbance to the growth of the fragments.

Figure 6: Plastic aquaria with sediment and water from Lough Corrib.

At the end of the experimental period, some 102 days after it commenced, all of the rooted fragments were removed from the aquaria, ensuring that no roots or stems were broken. Adhering sediment was washed from the roots and the following measurements were made:

- number of new branches,
- branch length,
- number of new adventitious roots,
- rooting success, and
- length of subterranean roots.

2.3.4 Plant Cutting Experiment

The potential for plant regrowth following mechanical cutting of different severity was investigated under experimental conditions. Mature *Lagarosiphon* plants were again collected from the Bob’s Island population. Scuba divers were used to carefully collect the plants as it was important to ensure that both roots and the stem were undamaged. For this experiment, two treatments were used. With one set of plants, a cut was applied 10 cm above the root crown (Figure 7). The other plants were more severely cut and only 1 cm of green stem tissue remained above the root crown (Figure 8).

At the commencement of the experiment (4th September 2008), the total wet weight of each rooted plant was recorded in order to determine biomass change over time. Plants were then placed in the experimental aquaria. Plant growth was monitored at 3-weekly intervals for the first 59 days to provide information on early activity. At the end of the experiment (on the 16th December, 2008, a total of 102 days after initial commencement), the plants were removed and the following measurements were taken in order to provide information on relative growth success:

Figure 7: *Lagarosiphon* root sections with 10 cm of above-ground stem material before being planted in the experimental aquarium.

- total wet weight biomass (g),
- number of new branches, and
- new branch length (cm).

Figure 8: *Lagarosiphon* root sections with 1 cm of above-ground stem material before being planted in the experimental aquarium

2.4 Biological Research

It is clear that the growth and spread of *Lagarosiphon* in Lough Corrib has adversely impacted indigenous floral and faunal species and communities. This loss of natural biodiversity will continue as *Lagarosiphon* expands its range within the lake. It is important to quantitatively determine the nature and extent of the loss of macrophyte, macroinvertebrate and fish species, as well as the alterations in specific habitats, as a consequence of this invasion.

2.4.1 Physico-Chemistry

A YSI multi-meter was employed to record values for temperature (°C), dissolved oxygen (DO) concentration (mg/l) and pH. Readings were taken at 15 sites (from the upper, middle and lower lake). Readings were taken in summer and autumn of 2008 (three replicates in total). Sampling was undertaken over a two-day period in order to minimise variance to measurements. Measurements of water temperature were also recorded over a 4-month period using two data loggers positioned approximately 0.6 m above the substrate of two infested northern sites.

2.4.2 Macrophytes

Detailed macrophyte surveys at specific locations in Lough Corrib were undertaken in order to compile quantitative information on native macrophyte population in un-impacted bays. Further surveys were conducted to determine the impact that the establishment and spread of *Lagarosiphon* in the lake has on indigenous macrophyte species and assemblages (Figure 9). A total of 15 sites were surveyed in 2008.

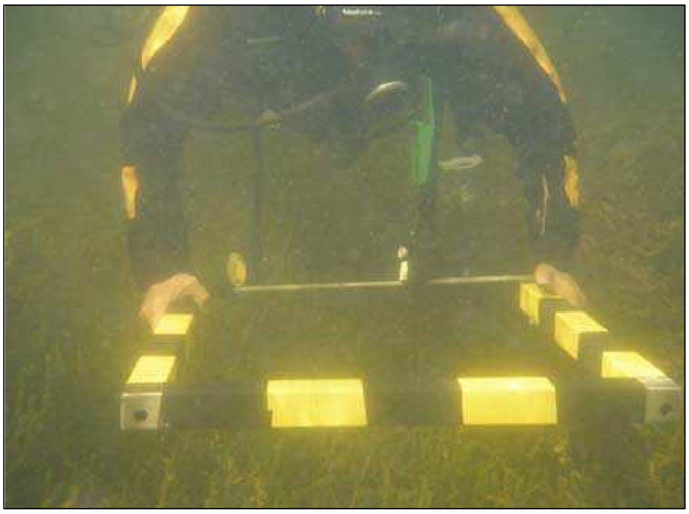


Figure 9: Locations of the sites surveyed for macrophyte species and communities. At each location a minimum of three transect lines was examined.

Comparisons were made between sites where *Lagarosiphon* had successfully invaded and sites yet to be infested. Further, within individual bays, surveys were undertaken in areas of different *Lagarosiphon* abundance to quantify the effect that *Lagarosiphon* density had on native macrophyte species. Surveys were undertaken to encompass the main lacustrine habitat types (e.g. shallow, steeply sloping, sheltered or exposed, east or west facing, etc.) present within Lough Corrib.

Macrophyte abundance and species assemblages were examined by divers along transect lines measuring 150 m in length. Surveys were undertaken using a minimum of two divers and one snorkeler. Each transect line was laid from the shoreline towards the centre of the designated bay. Along each transect line, the plant species and their relative abundance values were recorded from within three 0.5 m^2 quadrats (Figure 10) that were placed at every 0.5 m depth interval (Figure 11). This provided a detailed profile of macrophyte species present at different depths within the bays.

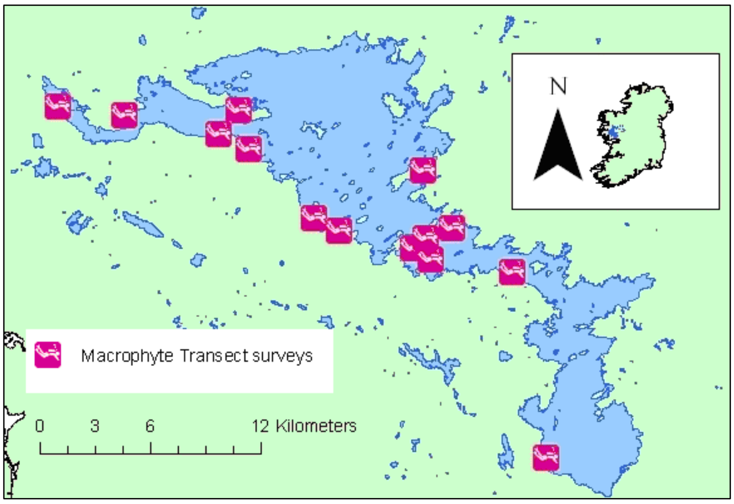


Figure 10: Quadrat (0.5 m^2) deployed by a scuba diver to estimate the percentage bottom cover of aquatic plant species in Lough Corrib.

Within each quadrat, the percentage cover of each macrophyte species was estimated. The results were recorded on waterproof writing slates. Any species that could not be identified on site were passed to the snorkeler to be bagged and a label assigned. These samples were returned to the field station for specific identification. The quadrats were placed randomly within each depth zone. This reduced the chances of positive bias towards specific macrophyte species.

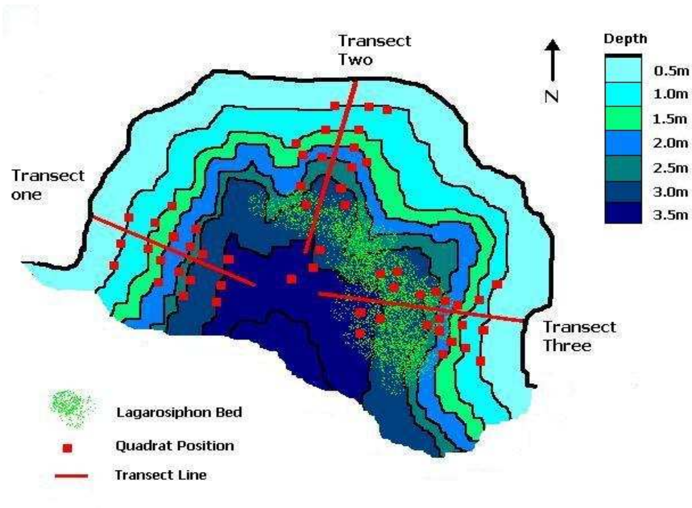


Figure 11: Diagrammatic representation of transect lines and quadrat points within a sample bay.

2.4.3 Macroinvertebrates

A study of the changes to the macroinvertebrate fauna of littoral habitats induced by the invasive species *Lagarosiphon major* was conducted between June and November 2008 by the Freshwater Ecology Research Group from University College Dublin (UCD), in cooperation with the CFB. The methods applied to this study are detailed in Baars, J-R., Keenan, E.A., O'Callaghan, P. and Caffrey, J.M. (see Appendix I).

2.4.4 Fish

Fish stock assessments were conducted on three different occasions and by three different scientific teams, working in close cooperation, in 2008. The broad objectives of the surveys were to accurately determine the current status of fish stocks present in this large watercourse and to determine the influence of a variety of macrophyte-based habitat types on resident fish populations. In early June 2008, an extensive survey that encompassed the whole of the lake was conducted by the CFB in order to provide information on fish species that is required under the Water Framework Directive (WFD).

WFD surveys deployed nets overnight for a 4 day period. The lower lake was surveyed in mid-June. Six gangs of Dutch fykes, 24 benthic multimesh monofilament gill nets (14 at 0-2.9 m and 10 at 3-5.9 m) were deployed at 30 sites. The netting effort was supplemented using 6 benthic braided gill nets (62.5 mm mesh knot to knot) at an additional 6 sites. The upper lake was surveyed from 19th to 27th June by deploying nets over five nights. Nine sets of Dutch fykes, 51 benthic multimesh gillnets (12 at 0-2.9 m and 12 at 3-5.9 m, 12 at 6-11.9, 6 at 12-19.9, 7 at 20-34.9 and 3 at 35-49.9 m) and 8 surface monofilament gill nets were deployed. The netting effort was supplemented using 11 benthic braided nets and 2 surface braided nets (F. Kelly, pers. comm.).

Figure 12: Multimesh nets being deployed in *Lagarosiphon* stand.

In September and November, teams from the CFB and WRFB deployed three sets of multimesh monofilament nets and one gang of Dutch fyke nets (Figure 12), similar to those used for the WFD surveys, in four different macrophyte-based habitat types. The habitat types included: a) within *Lagarosiphon* stands, b) at the outer edge of *Lagarosiphon* stands, c) in and above native Charophyte beds, and d) within native, tall *Potamogeton* stands (Figure 13).

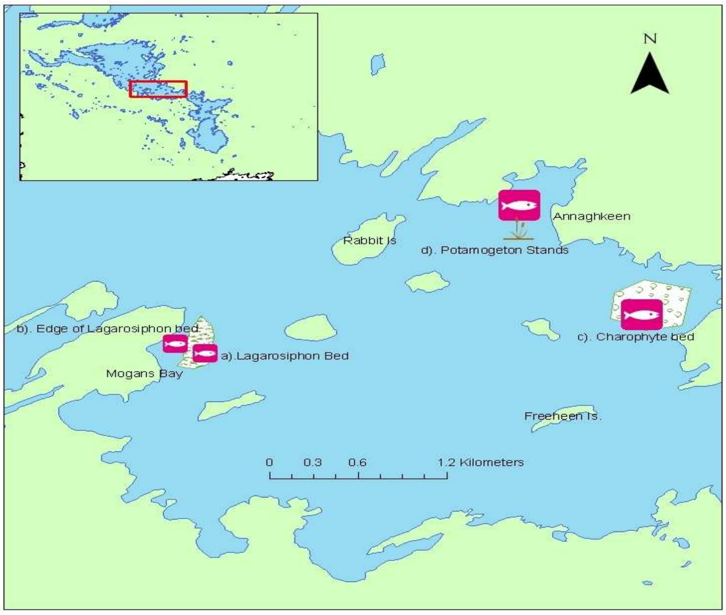


Figure 13: Location of sites where CFB fish surveys were conducted in September and November 2008. The habitat types investigated included a) within dense *Lagarosiphon* beds, b), the outer edge of *Lagarosiphon* beds, c) in and above low-growing Charophyte meadows, and d) within tall-growing *Potamogeton* stands.

Consistent with the WFD surveys, nets were deployed overnight, for approximately 24 hours. At each site, the area for deployment of nets was chosen randomly. The angle of each net in relation to the shoreline was also randomised. All of the fish captured in the nets were carefully removed, measured (fork length, to the nearest centimeter), counted, identified (to species level) and, where possible, returned alive to the water.

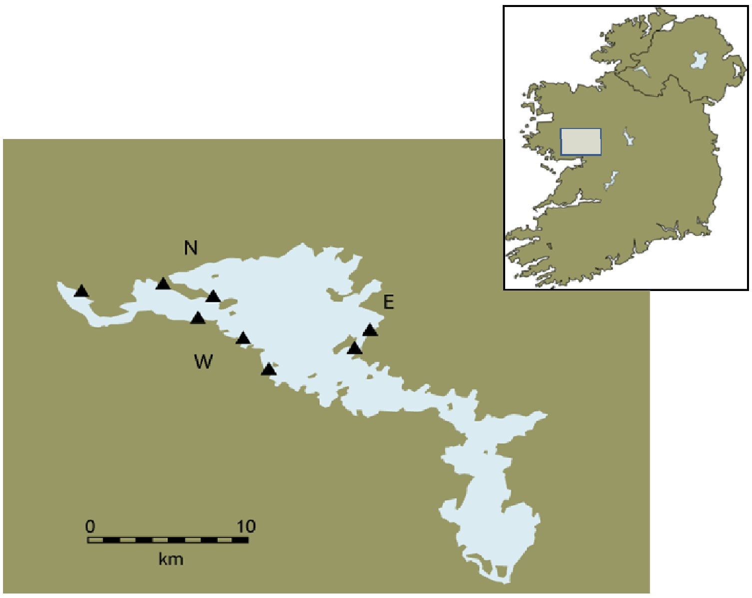


Figure 14: Location of Lough Corrib (inset) and the eight sites sampled to examine the ecological impact of *Lagarosiphon* on the fish communities in the upper lake.

A third fish stock survey was conducted by the scientific team from Queens University Belfast (QUB), working in close collaboration with the CFB, as part of the EPA-funded STRIVE project. Eight sites situated on the north, west and east shores of the lake were selected for study. These comprised three *Lagarosiphon*-dominated or 'invasive' sites, three Charophyte-dominated or 'native' sites and two sites that are currently *Lagarosiphon*-dominated but that are due to be mechanically cut (Figure 14). The latter two sites were sampled in order to examine the post-cutting response by fish. The sites were sampled on three occasions in 2008 (3 to 13 June, 24 to 30 August and 17 to 24 October 2008).

All three of the fishing surveys undertaken (WFD, CFB and STRIVE) used multimesh sampling protocols aimed primarily at achieving population information on the smaller size classes of fish.

Figure 15 and Figure 16 show the sampling protocol followed during the survey. This protocol was designed to compare fish communities at Charophyte- and *Lagarosiphon*-dominated bays. The *Lagarosiphon* in two of the bays on the north and west shores is to be mechanically cut.

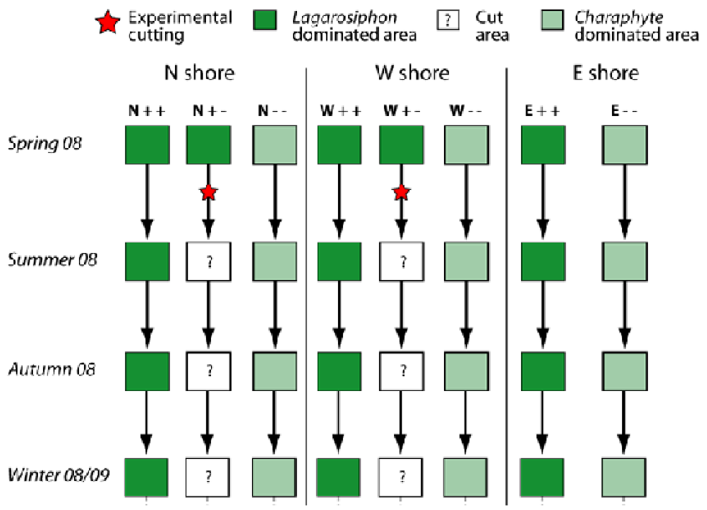


Figure 15: Sampling protocol used for fish stock survey on Lough Corrib in 2008.

The fish community was sampled at each of the eight sites using a single overnight set of three standard Collins multi-panel gill nets (60 m x 1.5 m) (Figure 16). Two gillnets (one surface and one bottom set) and the fyke net trains were fished adjacent to the area sampled for Charophytes and

Lagarosiphon. A further surface-set gillnet sampled pelagic fishes from deeper water located adjacent to the *Chara*/*Lagarosiphon* area.

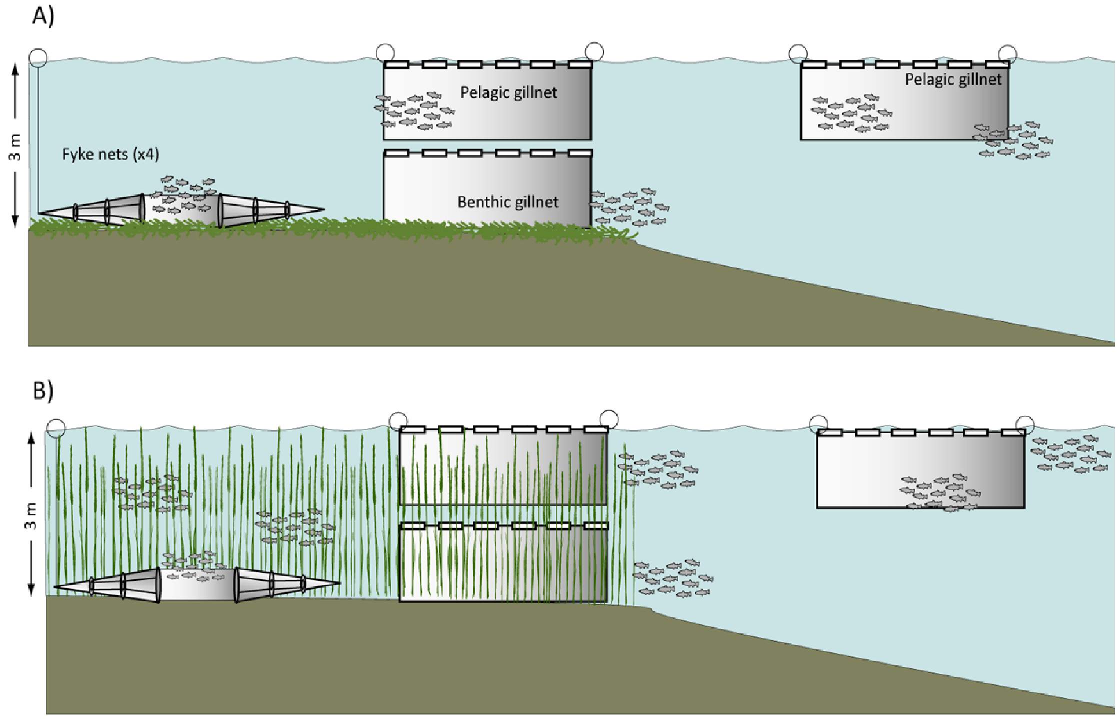


Figure 16: Fish sampling protocol followed in A) native (*Chara*) and B) invaded (*Lagarosiphon*) habitats in Lough Corrib in 2008.

Fish removed from nets were identified to species and measured. Due to the typically large catches in gill nets a size-based representative subsample of each species was selected, where necessary, from each net and processed in the field. The remaining fish were frozen for subsequent processing at QUB. Fish from the sub-sample were weighed prior to the removal of ageing structures: scale samples from below the dorsal fin in cyprinids, salmonids and pike, and from below the lateral line in perch. The left operculum was also removed from perch and pike, and otoliths were collected from eels.

Fish were dissected allowing sex to be recorded and stomach/gut contents to be collected for preservation in 70% alcohol for further analysis. A 5 mg sample of dorsal muscle tissue was excised and frozen at -20°C for stable isotope analysis (SIA) of carbon and nitrogen ($\delta^{13}C$ and $\delta^{15}N$) (C. Harrod, internal report).

2.5 *Lagarosiphon* Control

2.5.1 Mechanical Cutting

In 2008, a new weed cutting boat, funded by NPWS, was purchased for *Lagarosiphon* control on Lough Corrib. WRFB and OPW staffs were trained in its use and have been dedicated to weed cutting operations since the boat was comminisioned. The OPW provided a harvesting boat to support the weed removal operation and, likewise, dedicated two staff members to the project.

Figure 17: Weed cutting boat within the weed containment nets set in Rinerroon Bay in 2008.

Weed cutting commenced on the upper lake in July 2008 and has been ongoing to date (Figure 17). Bays in the upper lake have been targeted for initial treatment and it is planned to work progressively downstream. In this manner, it is hoped that cleared areas will not be recolonised by floating weed fragments (the primary direction of flow being from the upper towards the lower lake). Areas suitable for cutting were demarcated with buoys by the research diving team. Prior to cutting in a designated bay or area, large containment nets were set in place (Figure 18). These collect drifting plant fragments and reduce the risk of further spread consequent of the weed cutting activities.

Figure 18: Containment nets placed at the mouth of Rinerroon Bay prior to commencement of weed cutting activities.

Considerable effort was focused on the development of an effective containment net. The system currently in place on Lough Corrib is capable of containing the maximum amount of drifting vegetation. The nets are cleared of *Lagarosiphon* after each day's cutting. The efficacy of the cutting and removal operations is monitored by the research team, while diving. Where weed stands have been missed during the cutting operation, they are marked using floating buoys and retreated.

The weed cutting boat is fitted with a pair of deep-cutting V-blades (also known as trailing knives) trailed on an 8 m-length of chain (Figure 17). The edges of the blade are blunted and are designed to pull or rip the vegetation by the roots rather than to cut it cleanly. This approach increases the chances of removing the root system of the plant and significantly reduces the rate of regrowth. The cut weed is immediately collected by weed harvesting boat (Figure 19). The plant material is removed from the lake to a team onshore. From here, the weed is moved to a suitable deposit area distant from any natural watercourses.

Figure 19: Weed harvesting boat removing cut *Lagarosiphon* from Rinerroon Bay on Lough Corrib.

Biocontrol

A survey for natural predators and/or parasites of *Lagarosiphon major* in South Africa, its country of origin, was undertaken in 2008. This exploratory field survey was tasked with searching for potential candidate biocontrol agents and was conducted by the Freshwater Ecology Research Group, from University College Dublin (UCD), in association with specialists from the University of Grahamstown, SA. The survey methodology is presented in Baars, J-R., Coetzee, J., Martin, G., Hill, M.P. and Caffrey, J.M. (see Appendix II).

2.5.2 Light Exclusion

In recent years a considerable amount of research has been focused on developing a practical method for excluding incident light from submerged *Lagarosiphon* stands. The method that is currently showing most promise involves the use of biodegradable geotextile material (Figure 20). The textile used is made from the organic material, known as jute or hessian. Jute is a long, soft, shiny vegetable fiber that is spun into coarse, strong threads. It is produced from plants in the genus *Corchorus*, family *Tiliaceae*. Jute is one of the cheapest natural fibres and is second only to cotton in amount produced and the variety of uses. Jute fibres are composed primarily of a ligno-cellulosic fibre that is partially textile and partially wood. Importantly, due to the fact that this material is of organic origin, it is subject to decomposition with time and, therefore, should not need to be removed from the lake bed after the *Lagarosiphon* has been eliminated.

Figure 20: Jute geotextile currently used to exclude incident light from submerged *Lagarosiphon* stands in Lough Corrib.

The material works by blocking a high percentage of the incident light from penetrating and reaching the submerged plants. Using this approach, it should be possible to disrupt the life-giving photosynthetic process and to eradicate the target vegetation. Trials using the material are at an early stage and, so far, three *Lagarosiphon*-dominated areas have been covered with the material (Figure 21). Monitoring will continue at sites already treated and geotextile will be applied to further sites, as resources permit.

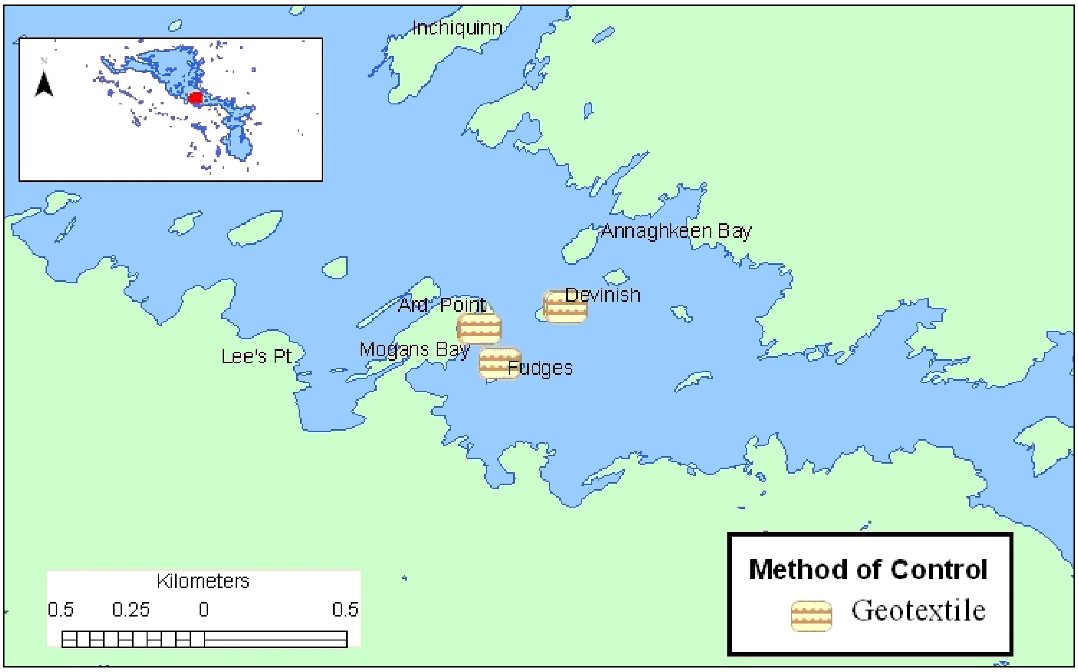


Figure 21: Map showing the three areas in Lough Corrib that were treated using geotextile in 2008.

Three small-scale experimental applications of the geotextile were made in August 2008 in order to determine the potential for control using this method and to develop a methodology for placing the material in the lake. The first site treated was approximately 20 m offshore from the eastern side of Devinish Island. This was one of the more established *Lagarosiphon* beds in the middle lake. The *Lagarosiphon* population at this location measured *circa* 10 x 5 m. A section of geotextile measuring 15 x 10 m was deployed by small boat and a team of divers. The boatman fed the geotextile to the divers who held position directly over the target weed. The material rapidly saturated on contact with the water and sank within minutes.

In order to treat larger and more expansive *Lagarosiphon* stands, a strategic up-scaling of the geotextile laying process was undertaken. Following a number of attempts using different approaches and different lengths of the 5 m-wide geotextile roll, it was decided that 100 m lengths (x 5 m wide) were most manageable. The geotextile was secured to the sediment by divers using prepared weights. This required significant modification to be made to the boat (undertaken by members of the Western Region Fisheries Board). To accommodate the large sections of bulky geotextile (Figure 22), a purpose-built platform was constructed. This enabled the boat to retain and easily deliver the geotextile. In preparation for delivery onto the boat, 100 x 5 m lengths of geotextile were rolled onto iron bars and transported, by road, to the lake shore adjacent to the site of the weed infestation. The rolls were then loaded onto the rigging constructed on the boat. From here the material was fed directly over the pre-marked, buoyed *Lagarosiphon* bed to the team of divers (Figure 22). The divers expedited the process by pulling the material underwater and ensuring that it completely covered the *Lagarosiphon* bed. To reduce the risk of the geotextile folding in the water and to aid the sinking of the material, the corners of the textile were weighted using specially designed weights with flexible wire hooks. These were attached to the edges of the geotextile sheet, at intervals of approximately five meters, as the material was fed from the boat. The divers ensured that the material accurately covered the area of invasive vegetation.

Figure 22: Large-scale geotextile placement operation at Mogan's Bay. The photograph shows a 5 m-wide by 100 m-long roll of geotextile being deployed from the boat.

Weather conditions, and specifically wind, play an important role in the success of this operation. The operation itself can be quite labour intensive and may require the use of three boats and a minimum of two divers. As this is a new and developing method, modification to the deployment strategy are continuously being made.

2.5.3 Hand Removal

A number of sites that were recently infested with *Lagarosiphon* were located during 2008 while snorkeling and diving. Many of these sites supported single plants or small colonies of the invasive weed. In each instance, the specific locations were captured using GPS and the numbers of plants present were counted. Following these surveys, divers painstakingly removed these plants and their roots. Further, hand removal was also employed at the perimeter of small sites where geotextile had been laid in an effort to remove any outlying plants that may not have been covered by the light occluding material.

2.5.4 Chemical Control

While it is acknowledged that Lough Corrib is an SAC and that its species and habitats must be protected, as a priority, it is also accepted that *Lagarosiphon* poses a major threat to these same protected species and habitats. It must also be borne in mind that Lough Corrib is an important drinking water supply to the city of Galway and to a number of private users around the lake. It is, therefore, important that any mitigation or control measures implemented as part of the *Lagarosiphon* management programme must pay due cognizance to these factors.

Chemicals represent an important tool in the armory of any weed control manager. In fisheries and water management throughout the country, approved herbicides are used to control nuisance or potentially hazardous weed problems. These are normally used locally, under strict supervision and by certificated operators. One such approved herbicide is dichlobenil, a herbicide that has been used to good effect in watercourses throughout the country. The impacts of this herbicide on water quality, non-target plants, macroinvertebrates and fish has been studied by CFB scientists and the results have been published in peer reviewed international scientific journals (e.g. Caffrey, 1993). The results demonstrate that, when used correctly, the herbicide is effective in treating a range of rooted, submerged weeds. Further, the application is highly directional and targeted, and has no obvious adverse impact on associated species or communities. The product is granular, with the herbicide infused into an inert dolomite granule. On application, the granule sinks to the lake or river bed, from which the active ingredient (dichlobenil) is removed by adsorption onto the soil particles. From here it is taken up by the target plants *via* root uptake. There is little of no lateral diffusion of the chemical and, hence, only the specific area on which the granules were sprayed will be impacted.

Dosage was calculated by depth and area, at approximately 4 g/m^3. The herbicide is fed into the tank attached to the knapsack and the granules are expelled by air generated from the petrol-driven engine through an extended flexible pipe (Figure 23).

Acknowledging that the supervised use of this herbicide in a small number of localised areas would not represent a risk to the drinking water supply or to protected species and habitats in the lake, NPWS agreed that isolated trials could be conducted. These aimed to test the efficacy of the chemical in controlling *Lagarosiphon* in Lough Corrib. Initial trials in Rinerroon Bay demonstrated the capacity of the chemical to kill this species, particularly where it had been cut before herbicide application (Caffrey and Acevedo, 2007). The cut permitted the maximum amount of chemical to reach the site of activity – the substrate. In 2008 the herbicide was used to treat a small harbour area in Rinerroon Bay. The frequent movement of angling boats to and from the site and the relatively shallow depth (approx 1.5 m) of the site would have made the use of geotextile impractical. Therefore, it was decided that chemical control would be the most suitable and efficient approach.

Figure 23: Apparatus used for the application of the herbicide dichlobenil.

The product was also applied at a small, isolated, rocky area in the upper lake where *Lagarosiphon* is known to have established but where access to the weed cutting blades was obstructed. The chemical was applied in October, 2008. The efficacy of the treatment was monitored in November 2008 and monitoring will continue through 2009.

3 Results

3.1 Distribution and Status

It is clear from the survey work conducted in the latter part of 2008 that *Lagarosiphon* is continuing to spread rapidly through the upper and middle lake. Sixty-four *Lagarosiphon*-infested sites were identified in the lake in 2007. A further 49 sites were recorded in 2008, giving a total of 113 infested sites and a 55.4% increase in new sites recorded (Figure 24).

Neither time nor resources were available this year to conduct an absolute survey of all areas of the lake. This reflected the fact that physical weed removal was a first priority. During the survey to determine the spread of *Lagarosiphon* to new locations in the lake, it was decided to prioritise the middle lake, where the southerly migration of *Lagarosiphon* was of particular interest. This was because no *Lagarosiphon* had yet been recorded in the adjacent lower lake.

Despite the time limitations imposed on the survey in 2008 (compared to that of 2007), a substantial number of new sites were recorded. In the middle lake, the plant is gaining an increased foothold and is continuing to spread downstream towards the shallower, lower lake. In 2008 the number of new sites in this section of Lough Corrib increased by more than 50%. It is noteworthy that the growth of the plant within the shallower middle lake is not only confined to bays, but is recorded across the width of this narrow water body.

The most southerly site at which *Lagarosiphon* has yet been recorded is Kilbeg pier (Figure 24). This site is *circa* 3.8 kilometers farther south than the most southerly point from which the invasive weed was recorded in 2007.

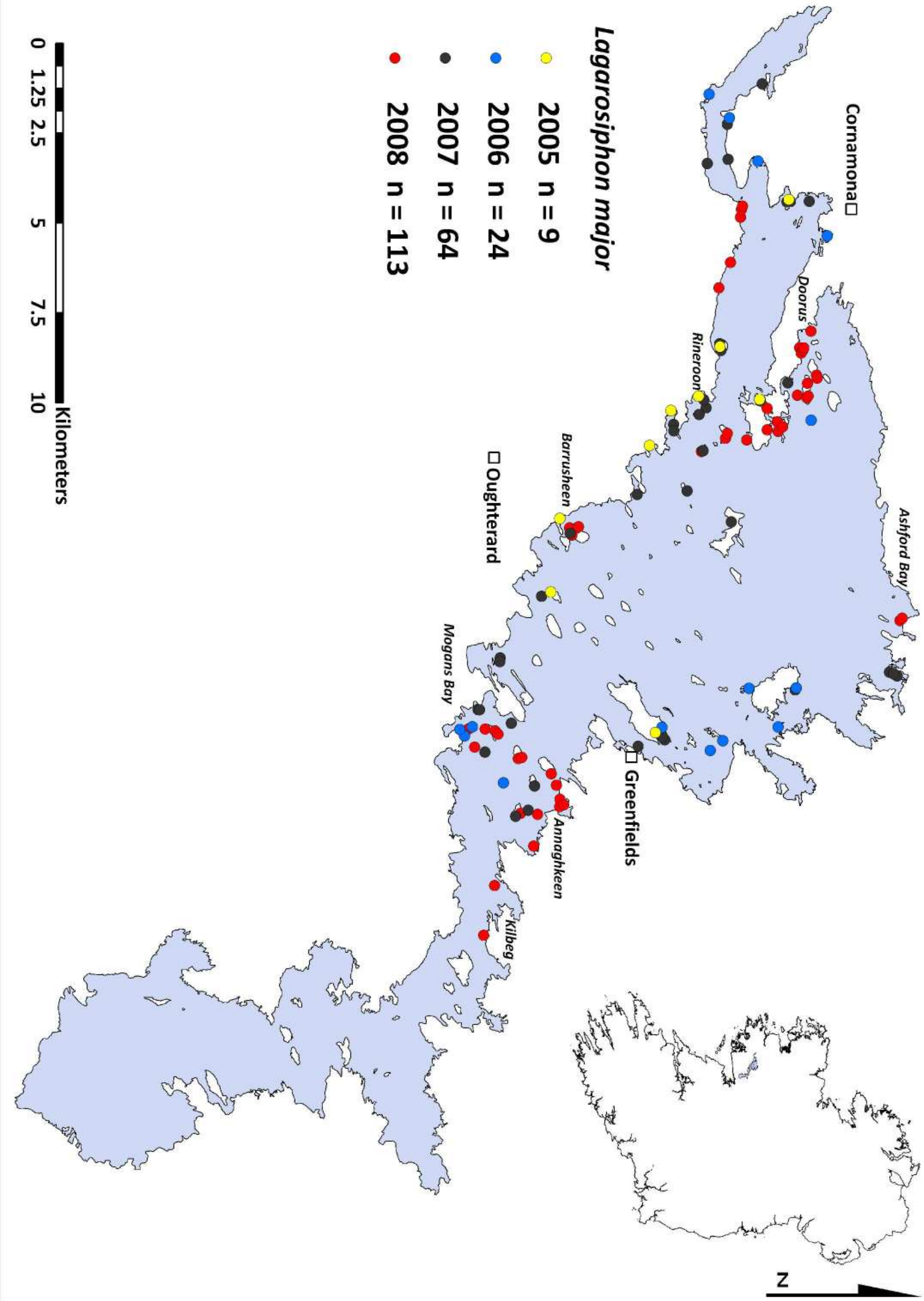


Figure 24: Distribution of *Lagarosiphon major* in Lough Corrib between 2005 and 2008.

A number of dense, newly colonised *Lagarosiphon* stands were recorded in 2008 on the western shore of the middle lake (in the area of Barrusheen). This new focus of sites is south of those previously identified areas associated with, and proximate to, Rinerroon Bay. This would suggest a southerly migration of the *Lagarosiphon* infestation along the western shore, towards areas very popular with anglers. These individual sites are well established and have no barriers to prevent them from spreading and merging into single very large infestations. A number of new sites were recorded on the eastern arm of the Doorus peninsula, in the northern sector of the upper lake (Figure 24). The majority of these sites consisted of isolated patches and small stands, often measuring less than 10 m^2. No other sites had previously been recorded along the eastern shoreline of this peninsula. This demonstrates that the distribution of new sites is not necessarily confined to areas proximal to those of existing infestations.

A number of the *Lagarosiphon*-infested sites that were present in 2007 were re-surveyed in 2008 and significant vegetative expansion was generally recorded. The spread of *Lagarosiphon*, in all cases, was at the expense of indigenous aquatic plant species and communities that were unable to compete with this aggressive coloniser. This is clearly illustrated in Figure 25, which shows the expansion of one *Lagarosiphon* bed in a single year in the area adjacent to Ard Point (middle lake). In 2007, the *Lagarosiphon* bed measured 1,630 m^2. By 2008, the outermost perimeter of the bed had increased to 73,518 m^2 (Figure 25). This not only represents a dramatic increase in the area of lake bed colonised, but also means that this site now represents an important potential feeder-site for *Lagarosiphon* fragments,

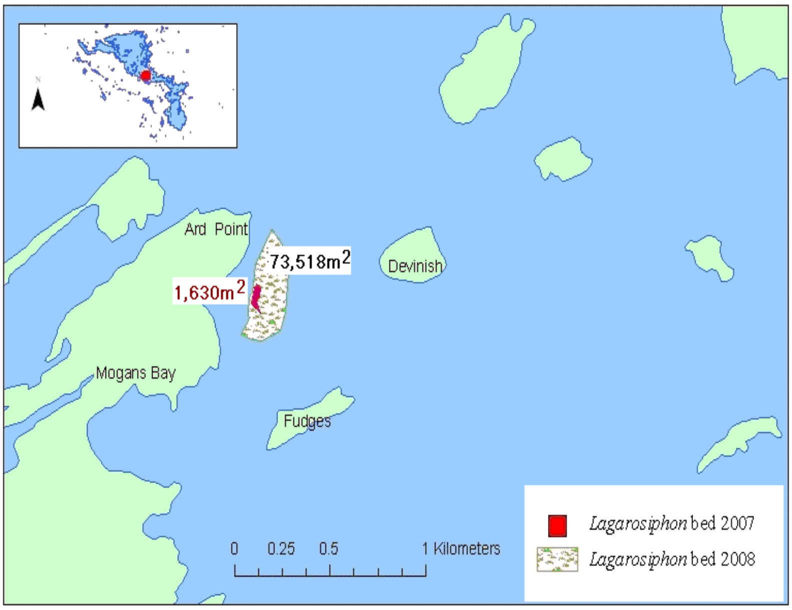


Figure 25: Location of an expanding *Lagarosiphon* infestation, south of Ard Point, in 2007 and 2008.

posing a great threat to the surrounding bays and to the lower lake. For this reason, the site was prioritised for weed control in 2008.

Despite extensive surveys, only a small number of *Lagarosiphon*-infested sites were recorded on the north shore of the upper lake in 2007 (Caffrey and Acevedo, 2007). In 2008, however, a number of new sites were identified in this area. Of particular interest was one of the larger sites, at Cassidy's Bay. No records of *Lagarosiphon* had been recorded from this site previously and yet, when surveyed in 2008, a stand measuring 9,676 m^2 was present (Figure 26). It is possible that *Lagarosiphon* was present here when surveyed in the past but was overlooked. However, it is also possible that this site demonstrates the rapid growth potential of new colonies of this invasive species.

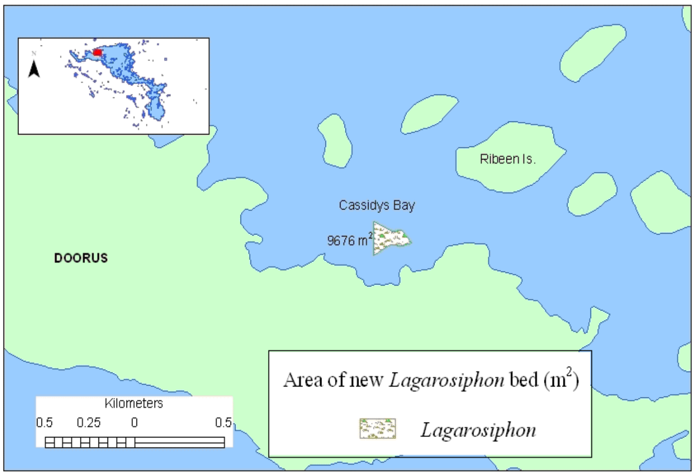


Figure 26: Map showing location of a large *Lagarosiphon* bed at Cassidy's Bay, upper Lough Corrib, in 2008.

The area of lake bed occupied by *Lagarosiphon* at 28 sites was estimated in 2007 (Figure 27). In order to assess the expansion potential of mature *Lagarosiphon* stands, 19 of these sites were resurveyed in 2008.

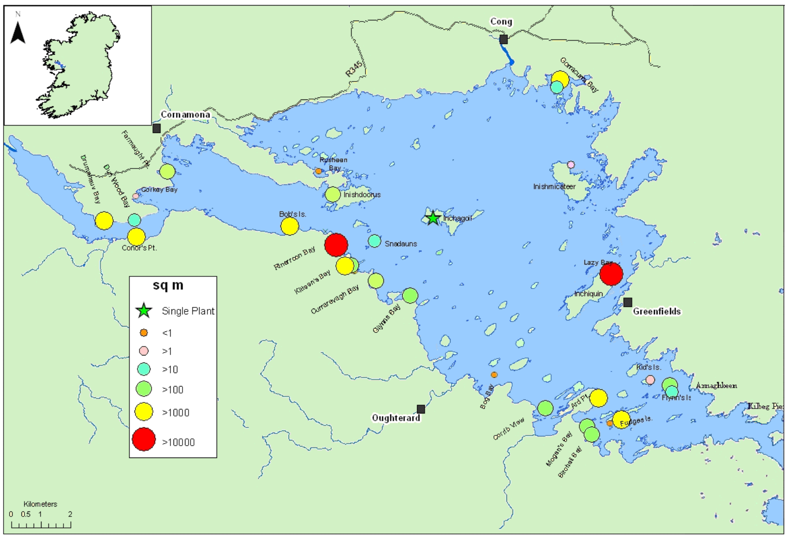


Figure 27: Map showing the relative abundance, as percentage bottom cover (m^2), of 28 *Lagarosiphon* populations in upper and middle Lough Corrib in 2007 (Caffrey & Acevedo, 2007).

It is clear that a significant level of expansion has occurred in this relatively short time period (Figure 28). Using this comparison clearly illustrates the considerable expansion of existing invasive weed stands that has occurred in the middle and upper lake in just one year. Based on this assessment, new *Lagarosiphon* sites that were first recorded in Lough Corrib in 2008 have been graded by the extent of infestation and a proposed action plan for each site has been prepared (Table 1).

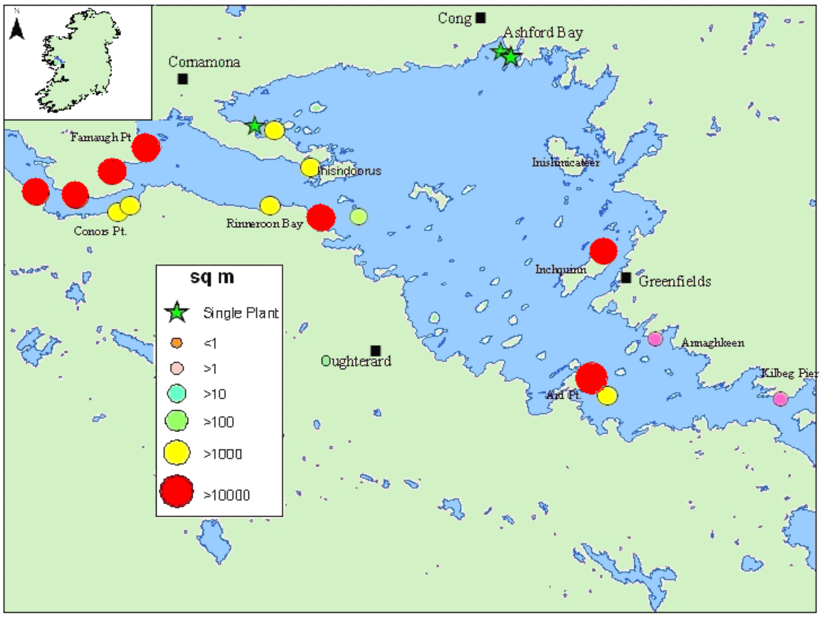


Figure 28: Map showing the relative abundance, as a percentage bottom cover (m^2), of 19 (of the 28 sites originally measured in 2007) *Lagarosiphon* populations in the upper and middle Lough 2008

Table 1: Locations of new *Lagarosiphon*-infested sites recorded in Lough Corrib in 2008. The scale of the infestation, the treatment status and the proposed treatment to be undertaken are presented. The scale of infestations is grades by number: 1- Single strands, 2- Strands in isolated patches, 3- Small bed (10-100m^2), 4– moderate stand (100-1000m^2) and 5– large stand (>1000m^2). √ indicates treated sites; X indicated sites awaiting treatment.

Location	Scale of infestation	Treatment status	Action / Treatment
Glann shore	2	x	Small scale geotextile
Glann shore	1	x	Small scale geotextile
Glann shore	2	x	Small scale geotextile
Glann shore	2	x	Small scale geotextile
Glann shore	2	x	Small scale geotextile
Vinlush	1	√	Hand removal
Cassidys Bay	3-4	x	Mechanical Cut
Cassidys Bay	3-4	x	Mechanical Cut
Cassidys Bay	3-4	x	Mechanical Cut
Cassidys Bay	3-4	x	Mechanical Cut
Ribeen Island	2	x	Hand removal
Ribeen Island	2	x	Hand removal
Caffeys Island	2	x	Hand removal
Inish Thee	1	x	Small scale geotextile
Inish Thee	2	x	Small scale geotextile
Inish Thee	2	x	Hand removal
Caol	3	x	Geotextile
Lords bay	1	x	Small scale geotextile
Lords bay	2	x	Hand removal
Lords bay	2	x	Hand removal
Doorus	1	√	Hand removal
Canaver	1	√	Hand removal
Canaver	1	√	Hand removal
South of Doorus	1	x	Hand removal
The Snaudauns	3	x	Mechanical Cut
The Snaudauns	3	x	Mechanical Cut
Roeillaun	3-4	x	Mechanical Cut/Geotextile
Roeillaun	3-4	x	Mechanical Cut/Geotextile
Barrusheen	3-4	x	Mechanical Cut/Geotextile
Barrusheen	3-4	x	Mechanical Cut/Geotextile
Ashford Bay	1	√	Hand removal
Ashford Bay	1	√	Hand removal
South Fudges	3-4	x	Geotextile
South Fudges	3	x	Geotextile
North Fudges	3	√	Geotextile
North Fudges	3	√	Geotextile
South Fudges	2	x	Geotextile
Devinish	3	√	Geotextile
Devinish	2	√	Geotextile
Rabbit Island	2	x	Hand removal
Annaghkeen	2	x	Hand removal
Annaghkeen	1	x	Hand removal
Annaghkeen	2	x	Hand removal
Annaghkeen	1	x	Hand removal/Geotextile
Annaghkeen	2	x	Hand removal
Flynn Island	2	x	Hand removal
Mouth of Canal	3	x	Geotextile
Clydagh Bay	1	x	Handremoval
Kilbeg	2-3	x	Geotextile

3.2 Growth and Recruitment Experiments

3.2.1 Life Cycle

The biology and ecology of *Lagarosiphon* in Lough Corrib is being examined in an effort to identify phases of the plant's life cycle that may be vulnerable to specific control measures. It is essential to understand, in detail, the life processes that confer such a strong competitive advantage on this submerged plant and the environmental factors that favour its establishment and proliferation in certain habitats.

Observations were made on *in situ Lagarosiphon* populations during survey visits to infested sites across the upper and middle lake throughout 2008. These observations are part of the ongoing investigation into growth patterns, morphological variation and life-cycle traits of *Lagarosiphon* within Lough Corrib, and have been in progress since the invasive species was first reported in early 2005.

From these observations, it is clear that the growth habit and morphological status of *Lagarosiphon* can alter significantly throughout the season. The change in morphology can be dramatic and single plants can undergo cyclic patterns of variation between differential states. Broadly, these states can be described as 'erect' and 'collapsed'. However, there are also a number of intermediate stages between these two morphologies.

Erect Phase

Plant growth and biomass is at its maximum when *Lagarosiphon* is in this growth phase. When erect, *Lagarosiphon* is characterized by tall buoyant stems that grow directly from the subterranean roots or from lateral, basal stems at the sediment. Although the vertical stems grow unbranched from the basal growth points, multiple and extensive branching occurs at the uppermost part of the vertical stem (at 0.5 to 1 m below the water surface). This upper stem branching habit results in the production of a broad and dense surface canopy that is normally visible at the water surface (Figure 29). Where a large bed of *Lagarosiphon* has established, the canopy formation can cover extensive areas, sometimes occupying tens of hectares (e.g. Rinerroon Bay).

The dense canopy (Figure 29) causes significant light exclusion in the water column below. Those native macrophyte species present that have not achieved a surface growth before the light-occluding canopies form are afforded little opportunity to compete. This vigorous surface growth, and resulting light exclusion, confers a distinct competitive advantage on *Lagarosiphon*.

A further competitive advantage conferred on the invasive *Lagarosiphon* by the surface canopy relates to the ease with which viable stem fragments are released, often as a result of wave action, boat movements or other factors. These fragments, many of which are capable of establishing new populations, are commonplace in the vicinity of canopy-forming *Lagarosiphon* beds.

Figure 29: Surface canopy of *Lagarosiphon* in winter 2008.

Collapsed Phase

At the height of this phase in the plant's seasonal cycle, growth and performance of *Lagarosiphon* is minimal. The stems are no longer buoyant and tend to collapse to the lake bed. At this stage, the majority of the stems are leafless (Figure 30), or what leaves remain are discoloured and unhealthy. There is minimal vertical growth and, hence, there is little evidence of the plants existence at the water surface. The density of these collapsed stems on the lake bed is commonly such that it precludes the development of any native macrophyte

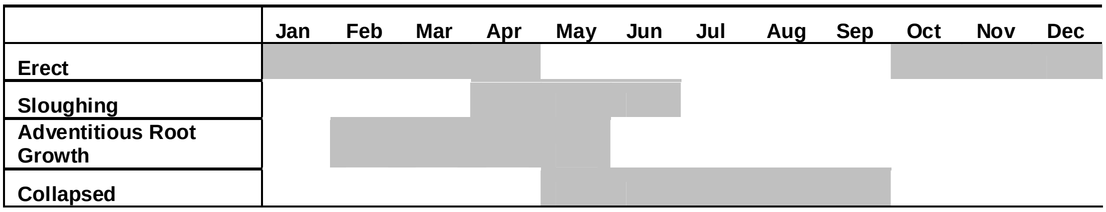
Figure 30: *Lagarosiphon* in 'collapsed' state during summer 2007.

populations and the collapsed stems cover an area of the lake floor that is greater than when the stems stand erect in the water column.

Growth patterns

These two morphological states occur in cyclic succession, with a number of intermediate stages. Much research is still required to fully understand the factors that stimulate the development of these different growth phases. However, there appears to be a strong seasonal influence. In the broadest sense, observations have revealed that, with the advent of winter (*circa* October to April/May), there is the greatest increase of vertical growth and surface branching (Table 2). As a result, dense and conspicuous canopies become evident at infested areas across the upper and middle lake during these colder winter months. In fact, in the three years since this invasive plant was first discovered (2005), no collapsed *Lagarosiphon* populations were observed during the winter period.

Table 2: Typical life cycle stages of *Lagarosiphon* based on observations made between 2005 and 2008.



The collapsed phase is, by comparison, most common during the warmer summer period (roughly May to October) (Table 2). Although occasional erect plant stands are present in the lake during this period, they tend to be site-specific and are commonly limited to smaller areas (e.g. small stands within larger weed beds). Further, the density of the canopy produced by these plants is often significantly less than that produced during the winter period. Interestingly, the period of any summer canopy growth is relatively short (*circa* one month), whereas the more pronounced erect stage present in winter can persist for the entire season (up to 7 months).

With management activities often dependant on the morphological status of the plant, it is important to understand the factors that influence the change in state of the plant. It is hypothesized that the specific site-to-site duration, timing and extent of morphological variation may be affected by several factors including water temperature, level of incident light, water depth, water clarity and the level of exposure at the site. However, no clear relationship has yet been identified and this important aspect will form the basis of much of the life cycle research to be undertaken in 2009 and subsequent years.

In addition to the two distinct stages described ('erect' and 'collapsed'), there are a number of intermediate stages that occur within this complex life cycle. Most obvious is the period when large numbers of adventitious or aerial roots are produced along the erect stems (Figure 31A). These white, single, unbranched roots vary considerably in length and can be up to 45 cm long (Figure 31B). This root growth occurs after the initial formation of the canopy (Table 2). What variable(s) control the timing and extent of aerial root formation is, at present, unknown. Further investigations are on-going to determine whether the root production stimulates or even causes stem collapse. However, it is clear that the production of this extensive aerial root system must require significant energy resources and, therefore, this change in resource allocation must endow a competitive advantage on the *Lagarosiphon*.

Figure 31: A) *Lagarosiphon* plants in the erect stage, showing the aerial roots; B) *Lagarosiphon* plant with long adventitious roots.

Relating life cycle to dispersal and vegetative reproduction

In April, May or June, a large part of the buoyant canopy vegetation is sloughed off or released from the parent plants (Table 2). There is also the possibility that the often expansive surface canopy simply becomes too heavy and is broken free from the weakened parental stems by wind action, water movement or some other factor. This sloughing effect significantly contributes to the successful dispersal of this invasive species through fragmentation. However, what remains after sloughing of the canopy are weakened stems, some of which now support extensive aerial root systems

On-site observations over a number of seasons suggest that stem collapse may actually represent another crucial part of the vegetative reproduction mechanism used by *Lagarosiphon* in Irish waters. The large-scale collapse of the stems results in a mass of root-bearing plant material settling laterally on the sediment in the area surrounding the rooted parental stems. These circumstances allow for extensive substrate coverage and for subsequent colonization of these lake bed area, often not yet infested, by the collapsed and rooted stems. This mechanism essentially parallels self-layering propagation where a portion of a stem produces adventitious roots while still attached to the parent plant. It then detaches as an independent plant and aids in the lateral expansion of the colony. Layering has evolved as a common means of vegetative propagation for numerous species in natural environments. Natural layering of terrestrial plants typically occurs when an aerial branch touches the ground (Mogie, 2002).

The combination of two methods of asexual reproduction (fragmentation and self-layering) results in an effective propagation mechanism for both proximate (self-layering) and long distance (fragmentation drift) plant dispersal and confers a significant competitive advantage on *Lagarosiphon* over indigenous species in Irish watercourses.

This dual-approach reproduction and dispersal strategy by *Lagarosiphon* means that alternative measures to tackle the different life stages and the different reproduction mechanisms must be developed if the overall efficacy of weed control is to be improved. Ongoing scientific research into the factors that influence plant growth will continue to provide a greater understanding of the plant growth strategy and will inform the approaches that will be adopted to control and remove the *Lagarosiphon* threat.

3.2.2 Fragmentation Experiments

These experiments aimed to determine what constitutes a viable plant fragment (i.e. one that is capable of creating a new *Lagarosiphon* population in areas that may be geographically distinct from the parental population). Specifically, the experiments were designed to determine which plant parts produced the most viable fragments.

The fragment types investigated were those that would naturally occur through biotic and abiotic fragmentation processes. As breakage could happen from most or any part of the plant, and could occur at different morphological stages, different fragment types were used to reflect this. These included 'mid-stem', 'stem crown' and 'stem with aerial root' fragments.

The temporal progress of the fragment growth and settlement process was observed by undertaking four intermittent measurements of growth within the first stage of the experiment. These measurements provide information on growth success at the earlier stages of settlement. Information on initial rooting success was limited as it was not desirable to disturb the fragment during the experiment. Observations revealed significant variation in the success of the different *Lagarosiphon* fragment types in the first stage (day 1 to 59) of the growth study (Table 3).

Table 3: Growth response of different *Lagarosiphon* fragments in artificial aquaria in the first stage (day 1 to 59) of the fragmentation experiment, 2008.

Date	**23/09/2008**	**02/10/2008**	**16/10/2008**	**02/11/2008**
Incubation period (days)	**19**	**28**	**42**	**59**
Stems with aerial root	Aerial roots orientated down in 3 fragments; no new branches	1 fragment produced 2 new branches	Half of fragments have aerial roots (between 2- 5 each)	One fragment rooted in sediment; majority of fragments have new branches (1-5 each)
Stem crown	Crowns pointing up; 2 fragments have new branches	Stems lengthening; fragments appear more robust; all fragments have 1-3 branches	Half of fragments have aerial roots (1-3); all fragments have new branches (1-3)	Two-thirds of fragments show root-sediment infiltration; new branches lengthened (3 - 8 cm).
Mid-stem	5 fragments on sediment, 5 floating; 2 fragments produced new branches.	All fragments have new branches (~1 cm length).	Half of fragments have aerial roots; branches lengthened (2 – 4 cm length)	Branch length increased (mean < 8 cm).

Budding of side branches was the first growth response by all fragment types and rooting appeared to be a secondary strategy. The stem crowns were the only fragment types to produce roots that penetrated into the substrate within the first stage of this experiment (recorded at day 59).

Results from the final measurements, taken at the end of the experimental period (at day 102) showed that all of the fragments remained viable and, it is envisaged, were capable of creating new invasive species populations. These results also revealed significant variation between both rooting and branching success among the fragment types. In respect of new branch production, the most productive fragments were those from the mid-stem and the stem crown. These produced an average of two new branches per fragment (1.8 and 2.1, respectively). The stem fragments with the aerial root exhibited most variation although, on average, they produced fewer new branches (1.3) than the other fragment types (Figure 32).

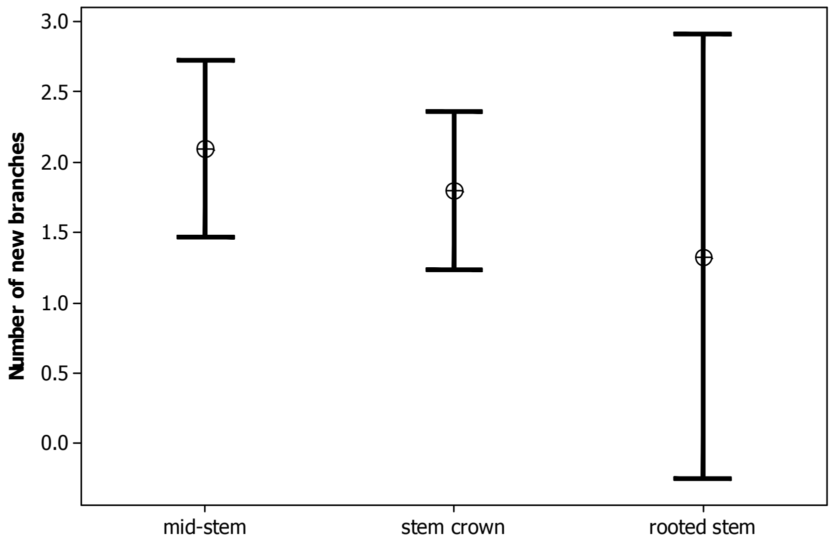


Figure 32: Interval Plot indicating the development of new branches from a range of *Lagarosiphon* fragment types. Plot shows mean ± 95% confidence interval. ANOVA indicates no significant difference between fragments (n = 26, P= 0.361).

When considering new branch elongation (Figure 33), the mid-stem fragments produced the most vertical stem growth (mean of 9.3 cm). This compared with an average of 4.5 and 5.0 cm for the stem crown and rooted stem fragments, respectively. This observation indicates that, where a larger number of new branches are produced by a viable fragment, there is no clear associated reduction in the relative growth rate of these branches.

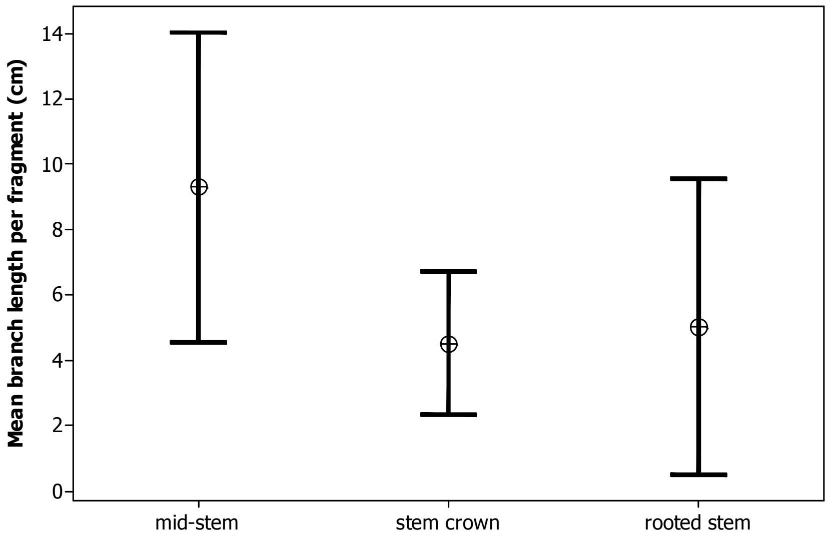


Figure 33: Interval Plot indicating the mean branch length per fragment (cm) for a range of *Lagarosiphon* fragment types. Plot shows mean ± 95% confidence interval. ANOVA indicates no significant difference between fragments (n = 26, P= 0.094).

When considering relative success and the differential viability of *Lagarosiphon* stem fragments, it is considered that one of the primary indicators of success is the ability of fragments to root firmly into the substrate. Having settled to the bottom of the aquaria, all stem fragments eventually produced single, white and unbranched roots from nodes along the stem. The first of these new roots were produced from after approximately five weeks (Table 3).

Although at the mid-stage of the fragmentation experiment (59 days), only the stem crown fragments had produced roots that successfully penetrated the hydrosoil, by the end of the growth period (102 days), most of the fragment types had produced at least one root that rooted in the hydrosoil. These roots varied greatly in length, from 10 to 50 cm and supported a large number of small, laterally protruding root hairs (*circa* 0.5 cm in length) (Figure 34A). These root hairs aid in nutrient uptake but also help to anchor the plant in the soft sediment (Figure 34B).

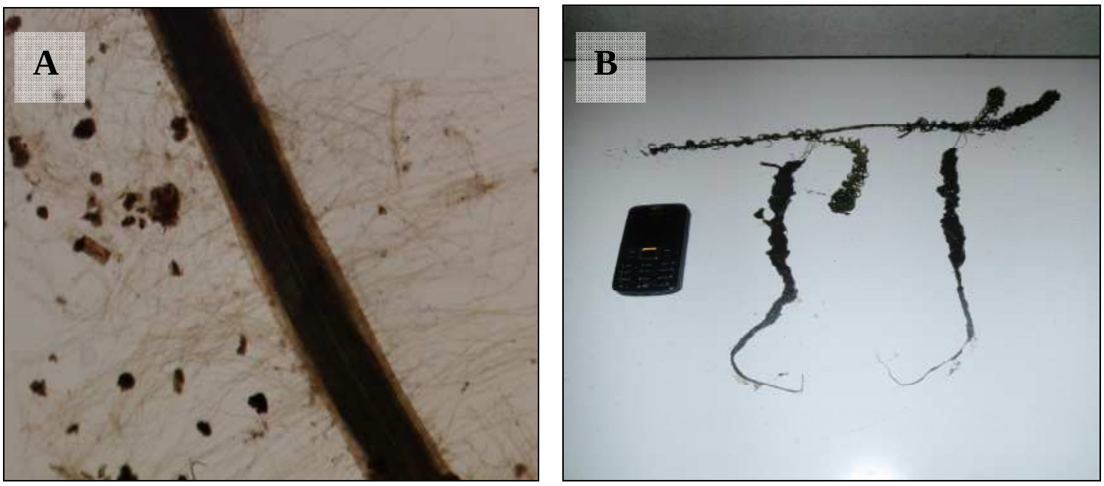


Figure 34: A) Root hairs growing from a single *Lagarosiphon* root; B) Stem sections with new branches and roots after 3 months in the experimental aquaria. Successful rooting is indicated by mud adhering to the roots/root hairs.

Fragment types without aerial roots produced the largest number of new roots (average of 3.0 and 3.6 for mid-stem and stem crown fragments, respectively). By contrast, fragments with existing aerial roots produced only 1.6 new roots over the experimental growth period (Figure 35).

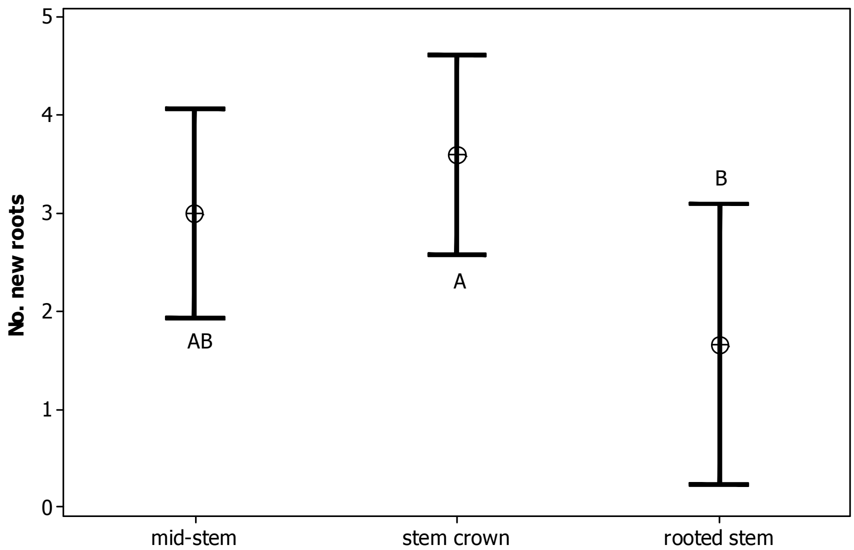


Figure 35: Interval plot showing the numbers of new roots produced by *Lagarosiphon* fragments. ANOVA indicates significant difference between samples (n = 26, P = 0.050). TUKEY test indicates the relative significances between samples (95% confidence interval). Where samples share a common letter, they are statistically comparable.

Further, fragment types without existing roots were the most successful at the end of the growth experiment at securing their newly produced roots in the soft sediment provided in the experimental aquaria, with an average of 1.5 and 2.2 roots per fragment becoming established in the substrate (for mid-stem and stem crown fragments, respectively) (Figure 36). This contrasts the mean of 0.6 established roots for those fragments with existing aerial or adventitious roots. The result indicates that the stem crown sections produced more roots (P= 0.05) and rooted more frequently (P = 0.025) than the fragments with existing roots.

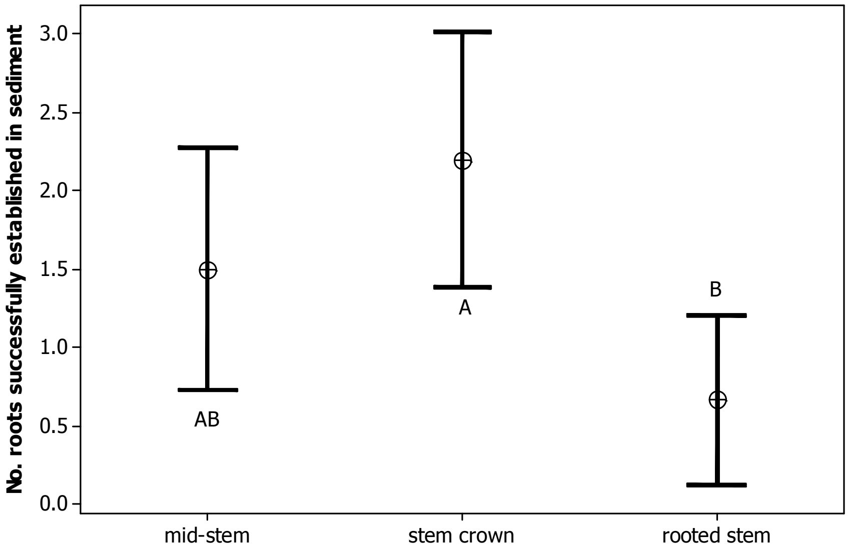


Figure 36: Interval plot showing the numbers of new root that successfully rooted in the experimental aquaria, after 102 days. ANOVA indicates significant difference between samples (n = 26, P = 0.025). TUKEY test indicates the relative significances between samples (95% confidence interval). Where samples share a common letter, they are statistically comparable.

The results from these fragmentation experiments indicate that the fragments with, and without, existing roots have different growth rates for both new branches and new roots. The pre-rooted fragments were the least successful, producing fewer and smaller branches and roots. Stem crown fragments appear to direct energy resources towards root production, but possibly at the expense of branch elongation. It would appear from these preliminary observations that the mid-stem fragments target their resources towards branch production and elongation. Yet, this strategy may be at the expense of root production. A great deal more research needs to be conducted in this area in order to gain a better understanding of the factors that influence fragment establishment and growth, and the implications for future management *Lagarosiphon* programmes.

3.2.3 Cutting Experiment

Rooted and mature *Lagarosiphon* plants were carefully collected from established weed beds in the north of Lough Corrib. These plants were cut with differing severity (to 1 cm and 10 cm above the root crown). The 1 cm or 'deep cut' plants replicate that segment of the stem that remains following mechanical cutting using the V-blades. The 'less deep cut' plants replicate the type of cut that might be achieved using a different and less deep-cutting machine. The experiment aimed to determine the regrowth potential of plants following cuts of different severity.

Table 4: Growth response of *Lagarosiphon* plants with stems cut 1 cm and 10 cm from root crown and grown in artificial aquaria during the first stage (day 1 to 59) of the experiment .

Date	**23/09/2008**	**02/10/2008**	**16/10/2008**	**02/11/2008**
Incubation period (days)	**19**	**28**	**42**	**59**
'Less deep cut' stems at 10 cm	2 out of 3 plants have new branches (~1 cm long)	All plants have new branches (1-3 each, 1-3 cm long)	All plants have average of 3.5 new branches (~ 5-7 cm long).	Branch length in all cases increase (from 5-17 cm).
'Deep cut' stems at 1 cm	No growth	No growth	No growth	No growth

Where the equivalent of a deep cut was applied, no regrowth was recorded throughout the either the initial (Table 4), or latter half of the test period (Figure 37B). The results suggest that the application of a deep cut to *Lagarosiphon* (close to or at the root crown) will significantly reduce, and may totally restrict, the regrowth potential of the plant. It is noteworthy that the root systems of these 'deep cut' plants reduced in length and lost vitality during the experiment (Figure 37B). In fact, there was a mean wet weight loss of 2.8 g among these plants over the duration of the experiment.

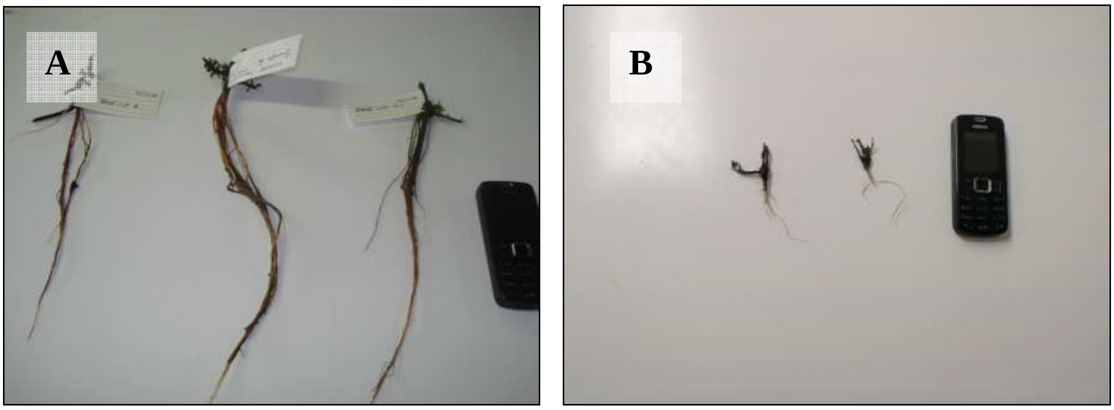


Figure 37: A) 'Deep cut' *Lagarosiphon* plants at the commencement of the experiment (day 1); B) 'Deep cut' *Lagarosiphon* plants after 102 days in the experimental aquaria.

Where a less deep cut was applied to *Lagarosiphon*, the level of regrowth was both rapid and extensive (Table 4 and Figure 38B). This resulted in a mean biomass increase of 3.6 g among these plants. In addition, an average of four new branches, each averaging 10.6 cm in length, was produced by each plant.

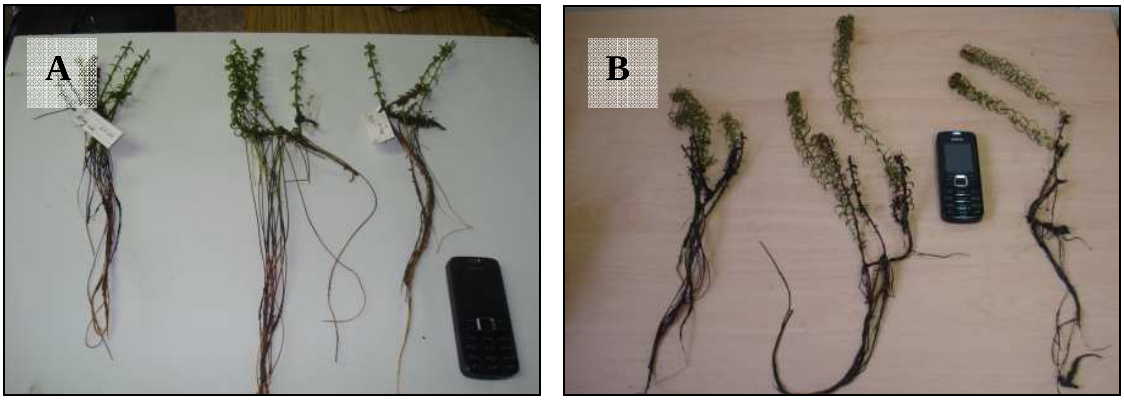


Figure 38: A) *Lagarosiphon* plants to which a 'less deep cut' had been applied at the commencement of the experiment (day 1); B) *Lagarosiphon* plants to which a 'less deep cut' had been applied after 102 days in the experimental aquaria.

This result supports observations in the field during 2007 (Caffrey and Acevedo, 2007) that the deep cut provided by the V-blades currently operating in Lough Corrib will have a significant, long-term negative impact on *Lagarosiphon* growth and expression in treated areas.

3.3 Biological Research

3.3.1 Physico-Chemistry

Water chemistry measurements were made by the CFB and also as part of ongoing collaborative work with UCD (see Appendix I). These measurements involved long-term data logging of water temperature within two infested sites in the northern lake (specifically, Bob's and Currarevagh bays) (Figure 39).

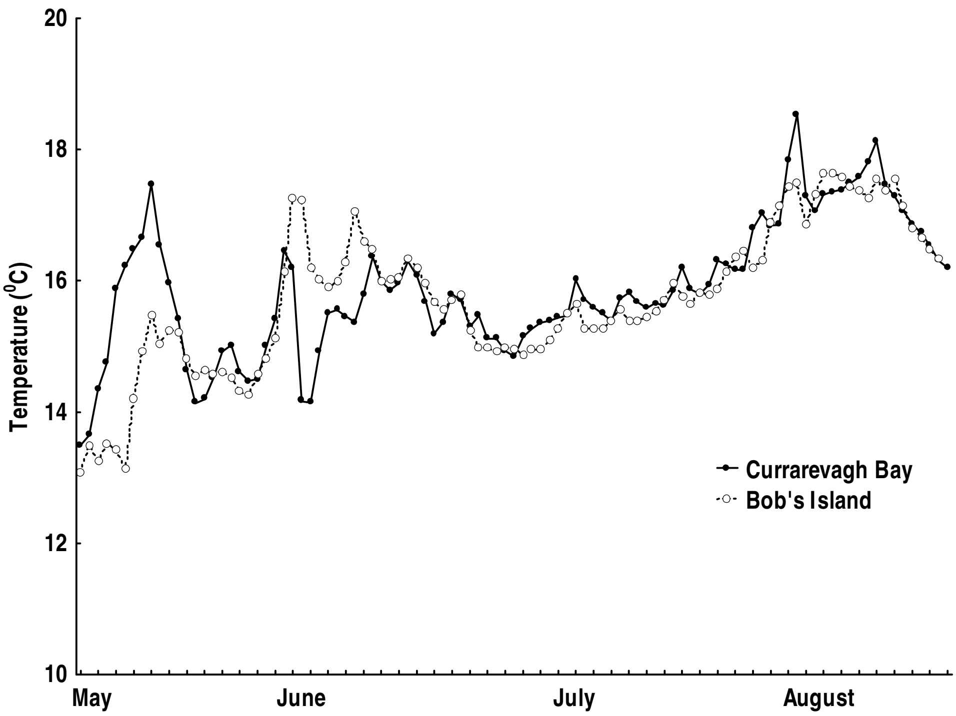


Figure 39: Mean daily temperature recorded within *L. major* stands (circa 0.6m above the lake substrate) at an hourly interval in two bays in Lough Corrib, Bob's Island and Currarevagh Bay, summer 2008 (A full account of the study is presented in Baars, J-R., Keenan, E.A., O'Callaghan, P. and Caffrey, J.M. (see Appendix I).

There was a clear increase in temperatures throughout the summer months at both bays. However, there were often distinct differences in temperature between the two sites, especially during high temperature events.

In addition, water samples were collected for analysis of a number of basic environmental parameters at sites used for macrophyte surveys in summer and autumn of 2008. The results are presented in Table 5.

Table 5: Mean values for environmental parameters recorded at macrophyte survey sites in summer and autumn, 2008. Measurements were made using the YSI multimeter. All measurements were automatically corrected for temperature and consistently taken at a depth of 1.5m. Sites are ordered from the north (top) to south (bottom) of Lough Corrib.

Site	Conductivity µS/cm	pH	% DO
Maam	43	7.98	93.2
School House	115	7.88	95.5
Corker	97	7.64	93.1
Bobs Island	110	7.92	93.9
Rinerroon	155	7.75	93.9
Moons	154	7.56	93
Greenfields (*L. major*)	173	8.36	99.2
Greenfields (*Chara*)	172	8.37	99.6
Creeve	176	8.03	97.8
Devinish	165	8.07	96.6
Annaghkeen	183	8.11	95.1
Mogans North	163	8.07	95.1
Mogans South	165	8.18	93.7
Knockferry	165	8.08	95.7
Moycullen	188	8.11	99.5

Although these measures represent only the mean of three replicate readings, they provide general information about the physical conditions of the sites surveyed. From these initial readings trends suggest that conductivity levels are greater at southern sites (e.g. Annaghkeen to Moycullen) in the lake. Dissolved oxygen levels were high at all sites. However, the extent of variability between the sites may be minimal compared to the potential variation that can arise within a 24-hour period at a single site (due to respiration and photosynthesis of aquatic plants and phytoplankton within the water column). Therefore, only with greater replication of all measurements, can we be fully confident that the trends described represent real site to site variation. Significantly more attention will be paid to analysis of the physico-chemistry and overall water quality of the water throughout the lake in 2009.

3.3.2 Macrophytes

A total of 25 macrophyte species were identified during the transect surveys conducted in the upper, middle and lower lake in 2008. Among these were included five Charophyte and four *Potamogeton* species (Table 6). Of the 47 transects surveyed, the non-native species *Lagarosiphon* was present in 26.

Table 6: List of macrophyte species recorded during transect surveys conducted on Lough Corrib in 2008.

Macrophyte Species	
Callitriche (cf. *obtusangula*)	*Littorella uniflora*
Ceratophyllum demersum	*Lobelia dortmanna*
Chara glomerata	*Myriophyllum alterniflorum*
Chara hispida	*Myriophyllum spicatum*
Chara sp. (cf. *aspera*)	*Nitella sp.* (cf. *translucens)*
Chara sp. (cf. *vulgaris var. denudata*)	*Phragmites australis*
Chara vulgaris var. *vulgaris*	*Potamogeton lucens*
Elodea canadensis	*Potamogeton gramineus*
Equisetum fluviatile	*Potamogeton perfoliatus*
Fontinalis antipyretica	*Potamogeton pusillus*
Isoetes lacustris	*Schoenoplectus lacustris*
Juncus bulbosus	*Sparganium augustifolium*
Lagarosiphon major	

Where Charophytes were the dominant group present, these submerged plants commonly occupied extensive, continuous, low-growing meadows in bays and littoral areas throughout the lake. They reached their greatest expansion in the lower lake where large areas of shallow water provide an ideal habitat for their establishment, growth and expansion (Figure 40).

Figure 40: Charophyte bed (mainly *Chara hispida)* showing a typical monoculture.

The most common Charophyte species present were *Chara hispida and C. glomerata*. There was clear evidence of a depth-related zonation among the Charophytes in the lake. Specifically, *C. hispida* (a relatively tall, to 0.4 m, robust and spiny plant) commonly dominated waters from 1 to 2.5 m deep, while *C. glomerata* (a shorter and finer structured species) formed dense beds at depths between 2 and 4.5 m. Where *Lagarosiphon* had not established large populations, or in areas where only single strands of this invasive species were present, the two *Chara* species, within their respective depth zones, occupied between 75% and 100% bottom cover. However, this habitat type was frequently the first to be colonised by *Lagarosiphon* and it generally proved to be ideally suited to its settlement, growth and expansion. The direct competition between *Lagarosiphon* and the Charophytes has resulted in the loss of large areas of unique *Chara* beds throughout the upper and middle lake.

A number of other native or naturalized species also produced locally dominant stands in the upper, middle and lower lake. These included *Potamogeton lucens, P. perfoliatus, P. pusillus, Myriophyllum spicatum* and *Elodea canadensis*. These species commonly grow in mixed assemblages, where they provide a diverse habitat structure for resident macroinvertebrate and fish species. Further, these species rarely grow with sufficient abundance to competitively exclude, through light occlusion, the dense under-storey of Charophyte vegetation.

Intensive botanical surveys along transects in various sectors and habitats within Lough Corrib have provided empirical data on the impact that established *Lagarosiphon* stands have on native macrophyte communities. Sites at which *Lagarosiphon* is established demonstrate a significant reduction in macrophyte species diversity. These changes to typical community composition are illustrated in Figure 41.

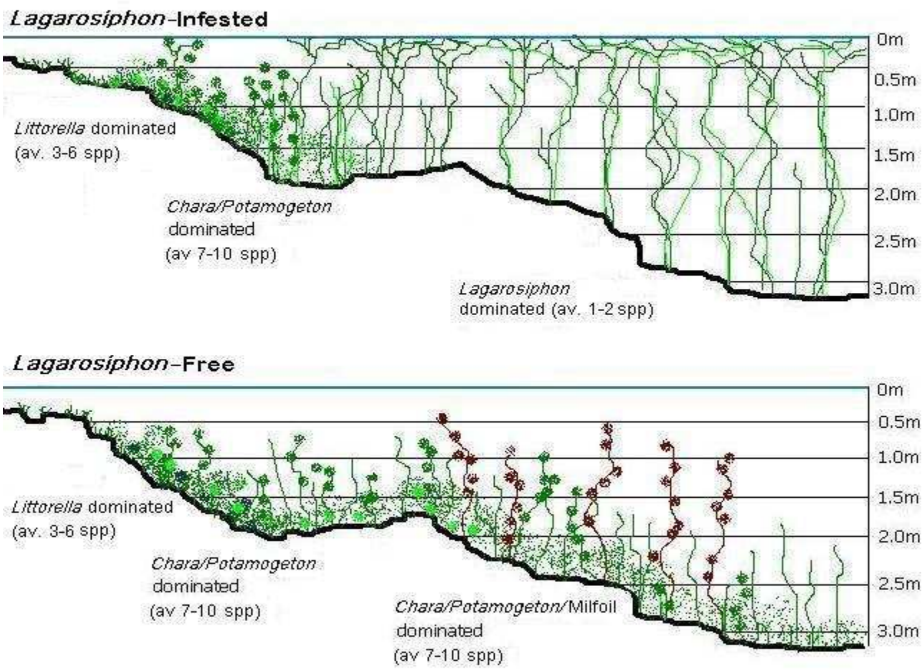


Figure 41: A typical depth profile showing the typical macrophyte species pattern in both *Lagarosiphon*-infested and *Lagarosiphon*-free sites.

The full influence of *Lagarosiphon* growth on indigenous macrophyte diversity is most apparent when the population is well established and capable of producing extensive light excluding canopies. It is apparent from the results recorded that the damaging affects of *Lagarosiphon* were at their greatest when the coverage of the weed occupied 20-40% of the 0.5 m^2 quadrats. Figure 42 illustrates that, at low densities (i.e. small clumps or single strands, with cover <20%), *Lagarosiphon* does not have a significant negative impact on overall macrophyte diversity. However, when the level of the infestation expands (>20% cover), the diversity and community evenness becomes significantly reduced. In areas where *Lagarosiphon* has established over a number of seasons, commonly only monocultures of the invasive weed are present.

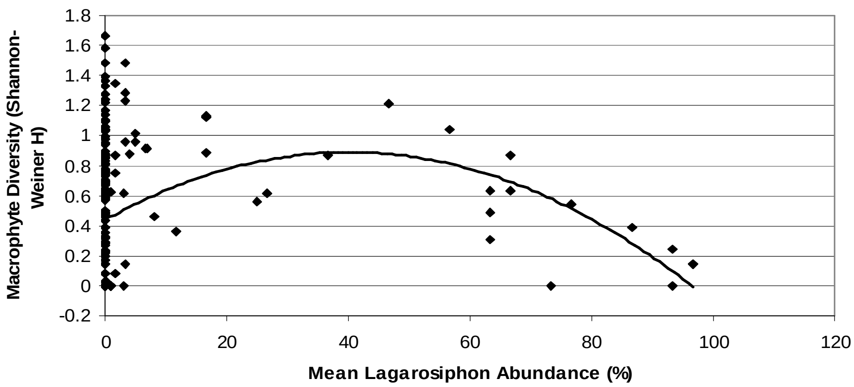


Figure 42: Polynomial curve showing the negative influence of *Lagarosiphon* when present at densities above 20%.

Where quadrats with >20% *Lagarosiphon* cover are examined, there is a significant negative linear effect of reduced macrophyte diversity with increasing *Lagarosiphon* cover (linear regression, P< 0.05) (Figure 43).

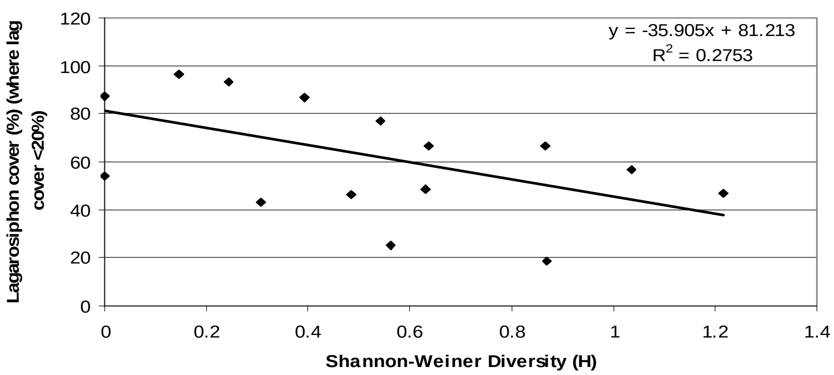


Figure 43: Significant (n = 15, P <0.05 as r =0.524) negative linear relationship between *Lagarosiphon* cover (above 20% only) and overall macrophyte diversity.

By focusing on a typical infested site (e.g. Bob's Island, upper lake), it is clear that *Lagarosiphon* density increases with depth up to 3 m (Figure 44). This increasing *Lagarosiphon* percentage cover is paralleled by decreasing overall macrophyte species richness. This trend was so pronounced that, at what is clearly the optimal depth for *Lagarosiphon* growth at Bob's Island (2.5 – 3.0 m), only this weed was present. At depths greater then 3 m percentage cover of *Lagarosiphon* rapidly decreases (Figure 44).

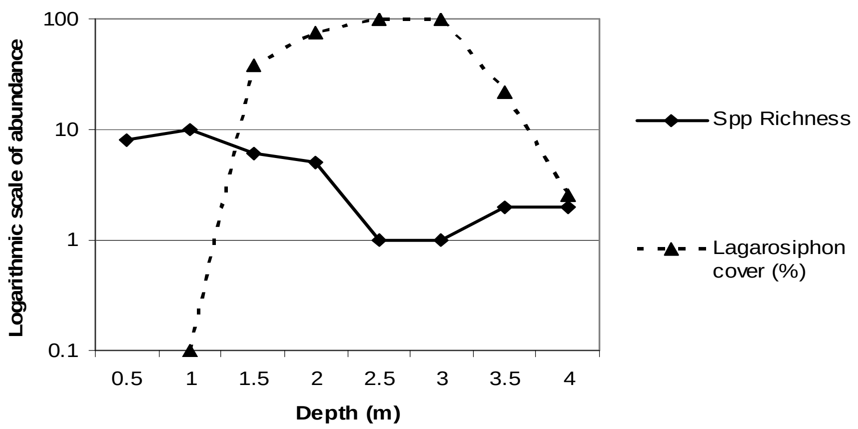


Figure 44: Diversity profile at site where *Lagarosiphon* is well established (Bob's Island).

The results from the transect analyses conducted over the past two years has revealed that *Lagarosiphon* displays a clear preference for lake areas where the depth ranges between 2 and 5 m, although growth has been recorded down to 6.5 m (Caffrey and Acevedo, 2007).

The limitation to a depth of 4 m at Bob's island probably reflects the more turbid nature of this area, where a regular flow of water is recorded. The positive association between water depth and *Lagarosiphon* (Figure 45) indicates that species whose depth preference is also within this range (e.g. *C. glomerata*, *Myriophyllum spicatum* and the tall *Potamogeton* species) are in direct competition with *Lagarosiphon*.

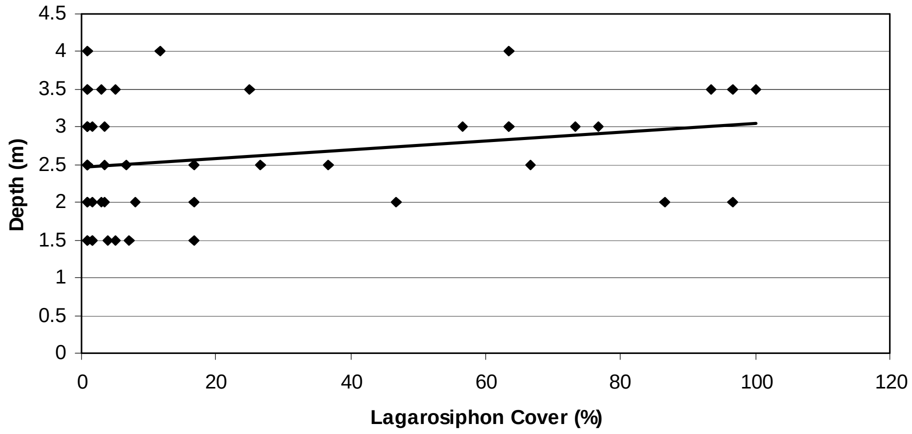


Figure 45: Positive linear relationship between depth and the percent cover of *Lagarosiphon* recorded during 2008.

It is interesting to note that, due to the depth preference exhibited by *Lagarosiphon*, there remains a shallow zone in the lake (<1.5 m) where *Lagarosiphon* does not grow vigorously and, as a consequence, native species can maintain a foothold (see Figure 44).

3.3.3 Macroinvertebrates

A synopsis of the pertinent results to emerge from the study undertaken in Lough Corrib to investigate the impact that the invasion by *Lagarosiphon* has on native macroinvertebrate species and communities is presented below. The study focuses on the differences between macroinvertebrate communities in the invasive *Lagarosiphon* and in native *Chara* vegetation. A full account of the study is presented in Baars, J-R., Keenan, E.A., O'Callaghan, P. and Caffrey, J.M. (see Appendix I).

A total of 100,069 macroinvertebrate individuals were sorted and identified from the samples collected in the three bays in June 2008. These included 51 taxa and many of the macroinvertebrate groups typically found in littoral habitats were represented (see Appendix I). Three groups represented most of the numbers, including non-biting midges Chironomidae (Diptera), crustaceans including *Crangonyx pseudogracilis* and *Gammarus deubeni* (Gammaridae) and several snails (Mollusca), particularly *Bithynia tentaculata* (Bithyniidae) and *Radix balthica* (Lymnaeidae).

The differences in taxon richness varied between the three bays investigated. There was no significant difference in taxa richness between Charophyte and *Lagarosiphon* samples in Bob's Island and Rinerroon Bay, while there were significantly fewer taxa recorded on Charophyte vegetation in Kitteens Bay. In respect of macroinvertebrate communities, there were significant differences in the communities found on the different plant species and also in the different bays. The differences in depth profile, substrate composition, current and temperature in the various bays may account for the latter finding.

Significant differences in macroinvertebrate abundances were recorded between the Charophyte vegetation and *Lagarosiphon* samples in all of the bays examined. When the taxa abundances are assessed in relation to the entire macroinvertebrate abundances (relative abundance and accumulative relative abundances), some interesting patterns are noted. There was a notable consistent difference in the number of taxa that contributed to the significant portion (80%) of the overall macroinvertebrate abundance between the two plants surveyed. In Bob's Island - 8 and 3 species, Rinerroon Bay - 4 and 2 species and in Kitteens Bay - 5 and 3 contributed to >90% of the overall abundances on Charophyte and *Lagarosiphon* plants, respectively. There was a clear spread of species that contributed to the overall abundance on the low-growing Charophyte vegetation, indicating that there were only a few taxa that make up the majority of the macroinvertebrate abundances on *Lagarosiphon*, representing a relatively more uneven community structure on the exotic plant.

A significant observation is that *Lagarosiphon* is providing a substrate that is ideally suited to the veliger and juvenile stages of another highly invasive species, the Zebra mussel (*Dreissena polymorpha*).

3.3.4 Fish

WFD Surveillance Monitoring Fish Stock Survey

A total of seven fish species and one hybrid were recorded on Lough Corrib in June 2008. The species encountered and numbers captured by each net type are shown in Table 7 and Table 8. A total of 1,730 fish were captured during the survey in the lower (612) and upper (1118) lakes, respectively.

Table 7: List of fish species recorded (including numbers captured) during the WFD surveillance monitoring survey on lower Lough Corrib in June 2008.

Scientific names	Common names	Number of fish captured			
		Benthic monos	**Benthic braided**	**Dutch fykes**	**Total**
Salmo trutta	Brown trout	13	6	0	19
Perca fluviatilis	Perch	283	1	1	285
Rutilus rutilus	Roach	266	2	2	270
Esox lucius	Pike	9	7	1	17
Abramis brama	Bream	0	1	0	1
	Roach x bream hybrid	8	0	0	8
Gasterosteus aculeatus	3-spined stickleback	3	0	3	6
Anguilla anguilla	Eel	2	0	4	6

Perch and roach were the most common fish species encountered in the benthic gill nets. Small numbers of brown trout were captured. In total, 35 eels were captured, most in the Dutch fyke nets. No salmon were recorded (adults or juveniles).

Table 8: List of fish species recorded (including numbers captured) during the WFD surveillance monitoring survey on upper Lough Corrib in June 2008.

Scientific names	Common names	Number of fish captured					
		Benthic (mono)	**Benthic (braided)**	**Surface (mono)**	**Surface (braided)**	**Dutch fykes**	**Total**
Salmo trutta	Brown trout	12	0	3	6	0	21
Perca fluviatilis	Perch	706	0	0	0	7	713
Rutilus rutilus	Roach	291	6	0	0	3	300
Esox lucius	Pike	4	3	0	0	3	10
Abramis brama	Bream	14	3	0	0	0	17
	Roach x bream hybrid	22	10	0	0	0	32
Gasterosteus aculeatus	3-spined stickleback	2	0	0	0	0	2
Anguilla anguilla	Eel	1	0	0	0	28	29

Fish abundance was calculated as the mean number of fish caught per meter of net (i.e. mean catch per unit effort - CPUE) and these data, for all fish species per gear type on lower and upper Lough Corrib, are summarized in Table 9.

Table 9: Mean CPUE (mean number of fish per meter of net) on lower and upper Lough Corrib in June 2008

	Mean CPUE (mean number of fish/m of net)							
Gear type	**3-spine**	**Roach**	**Perch**	**Roach x bream**	**Brown trout**	**Pike**	**Eels**	**Bream**
Lower lake								
Gill nets (all)	0.001	0.298	0.316	0.009	0.021	0.018	0.002	0.001
Fykes	0.012	0.006	0.003	0	0	0.003	0.017	0
Upper lake								
Gill nets (all)	0.001	0.138	0.327	0.015	0.01	0.003	0.0005	0.008
Fykes	0	0.005	0.012	0	0	0.005	0.047	0.0004

CFB Fish Stock Assessment

CFB Autumn and Winter Surveys

A total of six fish species were identified during surveys conducted on Lough Corrib by the CFB research team in autumn and winter 2008. Four different habitat types were surveyed on these occasions. These were: 1) within dense *Lagarosiphon* beds, 2) at the edge of dense *Lagarosiphon* beds, 3) within tall *Potamogeton* stands, and 4) within and above low-growing Charophyte vegetation.

Autumn Sampling

There was a clear dominance of coarse fish species in the nets surveyed (Table 10). The dominant species captured was perch (Figure 46A & B and Figure 47A). The second most abundant species recorded on this netting occasion was roach (Figure 47B).

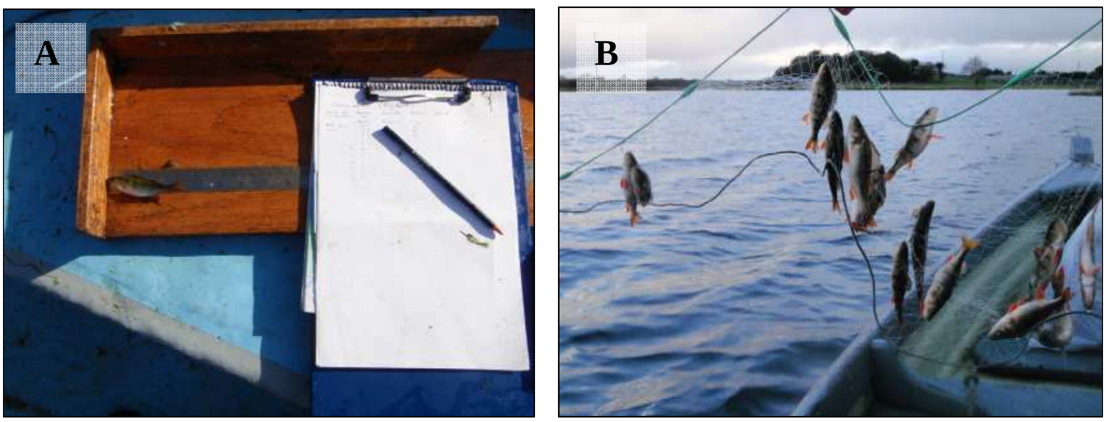


Figure 46: A) Juvenile perch being measured for fork length during the autumn survey; B) section of gill net with perch at Mogans Bay in autumn 2008.

Despite the status of Lough Corrib as an internationally important salmonid angling location, brown trout was only represented by a single individual within the samples (Table 10).

Table 10: List of fish species recorded (including numbers captured) during a fish stock survey in a range of habitat types in Lough Corrib in autumn 2008.

Species	Common name	Method	In *Lagarosiphon*	Edge of *Lagarosiphon*	*Chara* Bed	*Potamogeton* stands	Total
Perca fluviatilis	Perch	Gill net	414	240	81	564	1299
Rutilus rutilus	Roach	Gill net	60	39	3	4	106
Esox lucius	Pike	Gill net	7	3	4	3	17
Salmo trutta	Trout	Gill net	0	0	0	1	1
Scardinius erythrophthalmus	Rudd	Gill net	0	3	0	0	3
Anguilla anguilla	Eel	Dutch fykes	0	0	0	1	1
						Total	1427

Perch caught in the autumn survey made up 91% of the total catch (Table 10).

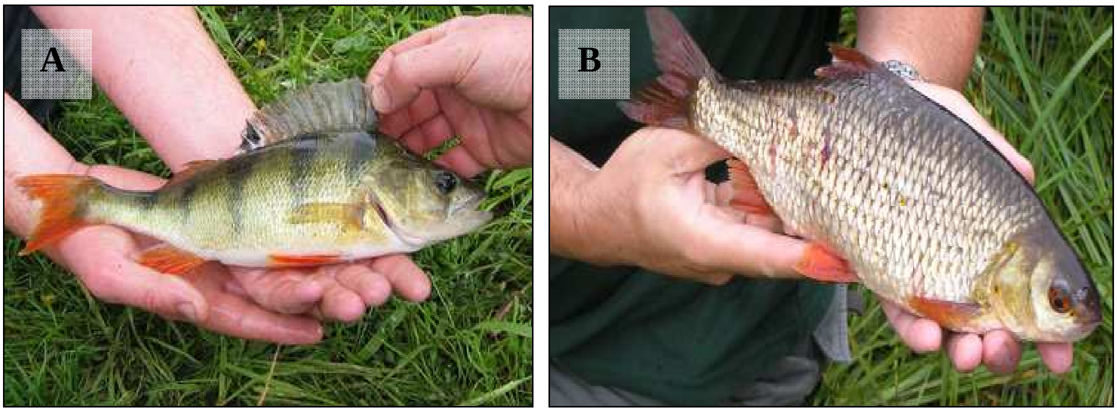


Figure 47: A) Perch and B) Roach from CFB surveys.

The tall and dense *Lagarosiphon* vegetation present at the survey sites provided a myriad of suitable habitat niches for the large numbers of small perch and roach present (Figure 48). This habitat also supported the greatest number of predatory pike.

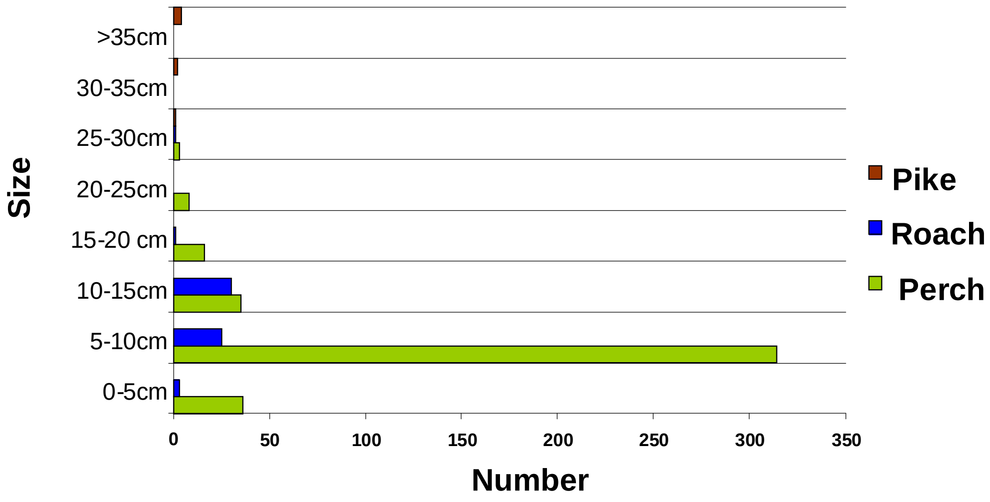


Figure 48: Length frequencies of fish captured during netting operations within *Lagarosiphon* beds in autumn 2008.

The perch recorded within the *Lagarosiphon* stands were predominantly juvenile fish (Figure 48), probably spawned on these weed beds in April 2008. The roach were, likewise, young fish, and spanned two size categories. The largest roach captured was 29 cm in fork length. The pike present in this tall vegetation were relatively young fish, although they would still be capable of cropping large numbers of small perch and roach. The pike caught in the survey measured from 24 to 89 cm, with the average size estimated at 36 cm.

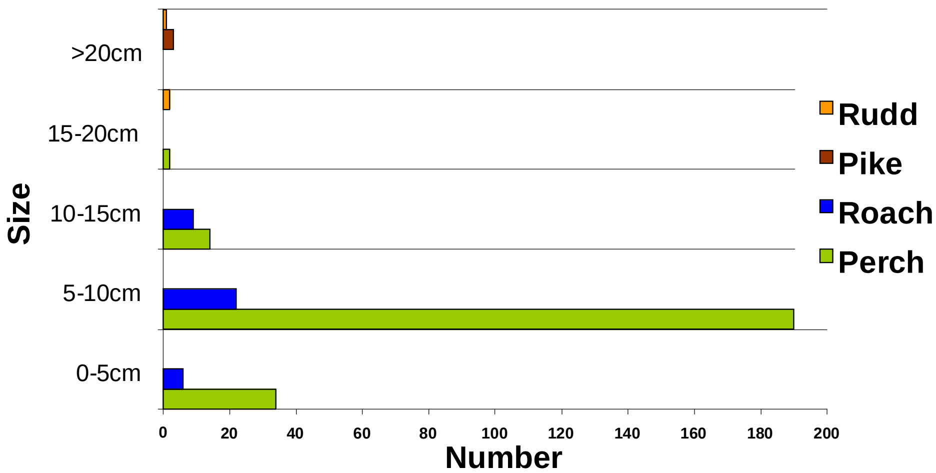


Figure 49: Length frequencies of fish species caught at the edge of the *Lagarosiphon* beds in autumn 2008.

No trout (*Salmo trutta*) or eels (*Anguilla anguilla)* were recorded in the *Lagarosiphon* beds or at the edge of these tall vegetation stands (Figure 48 and Figure 49). The roach captured in open water at the edge of the *Lagarosiphon* stands were primarily juvenile fish and only a small number of older specimens were present (Figure 49). In addition, three large rudd, measuring between 16 and 21 cm, were caught in this relatively open-water habitat. The smallest perch recorded during the autumn survey (mean 5.7 cm) were captured adjacent to the tall *Lagarosiphon* stands.

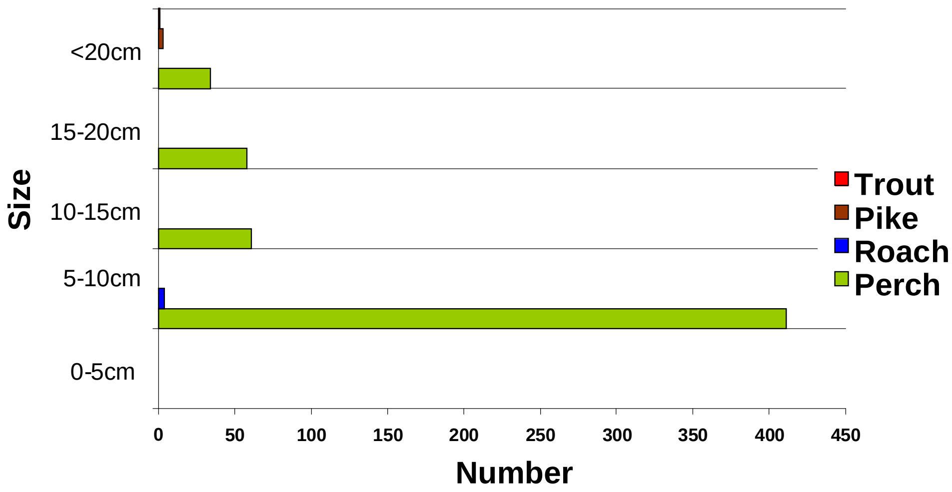


Figure 50: Length frequencies of fish species caught within tall-growing *Potamogeton* stands in autumn 2008.

The tall *Potamogeton* stands presented a comparable habitat to that provided by *Lagarosiphon*, although the weed mass in the latter was considerably denser. As with the *Lagarosiphon*, the majority of perch in the *Potamogeton* stands were juvenile, measuring between 5 and 10 cm in fork length. It was noteworthy, however, that a number of different perch cohorts were represented in the *Potamogeton* stands (Figure 50). This was the only habitat where brown trout were recorded. In this instance, only one trout, measuring 21 cm fork length, was captured. Relatively few juvenile roach were present within the tall *Potamogeton* stands.

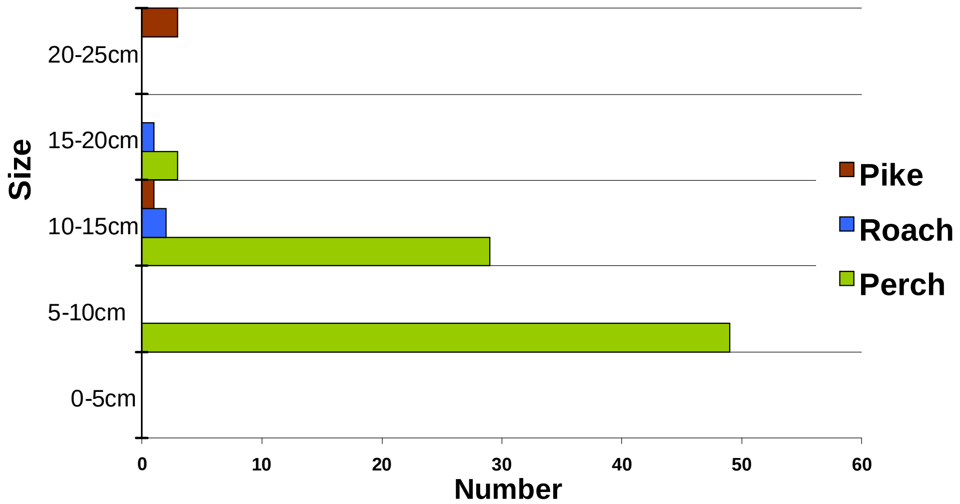


Figure 51: Length frequencies of fish species caught at Charophyte beds in autumn 2008.

The relatively open habitat above the Charophyte beds held fewer fish by comparison with the other vegetation habitats (Table 10 and Figure 51). The dominant fish species in this open water habitat was the juvenile perch. The Charophyte habitat supported a similar biomass of predatory pike to that of the open water at the edge of the tall *Lagarosiphon* and *Potamogeton* stands.The perch present at the edge of the *Lagarosiphon* stands were significantly smaller than those caught within the *Lagarosiphon* beds and smaller again than those encountered within the other two habitat types (Figure 52). There was no statistically significant variation in mean length of perch between the two native macrophyte habitat types, with mean lengths of 8.4 cm and 8.3 cm for populations within *Potamogeton* and Charophyte beds, respectively.

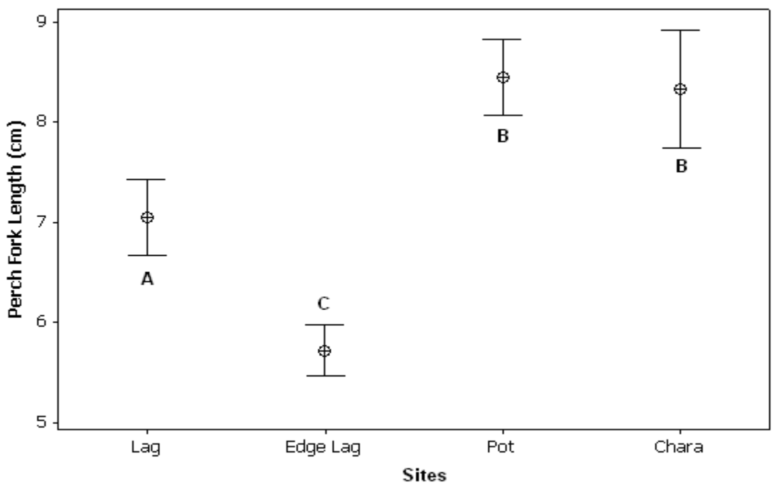


Figure 52: Interval Plot indicating variation in perch fork length (cm). ANOVA indicates a significant difference between samples (P < 0.001). TUKEY test indicates the relative significances between samples (95% confidence interval). Where samples share a common letter, they are statistically comparable.

A total of 1,427 fish were recorded in the autumn survey and approximately 90% of these were returned alive to the water. Juvenile stocks appeared to be in excellent physical condition and it is apparent from the figures that stocks of juvenile perch and roach are thriving.

Figure 53A & B illustrates the relative species abundance recorded in the four macrophyte habitats surveyed in autumn 2008. Perch clearly dominated all four of the habitat types examined. However, there was variation in the relative abundance of the other species. Thus, roach numbers were highest in, or proximal to, *Lagarosiphon* beds. Further, the predatory pike was most numerous in the *Lagarosiphon* beds, but was represented in all four habitats. The only trout captured was from within the tall *Potamogeton* stands. The low overall representation of trout in the samples recorded is indicative of a reduced population in this section of Lough Corrib.

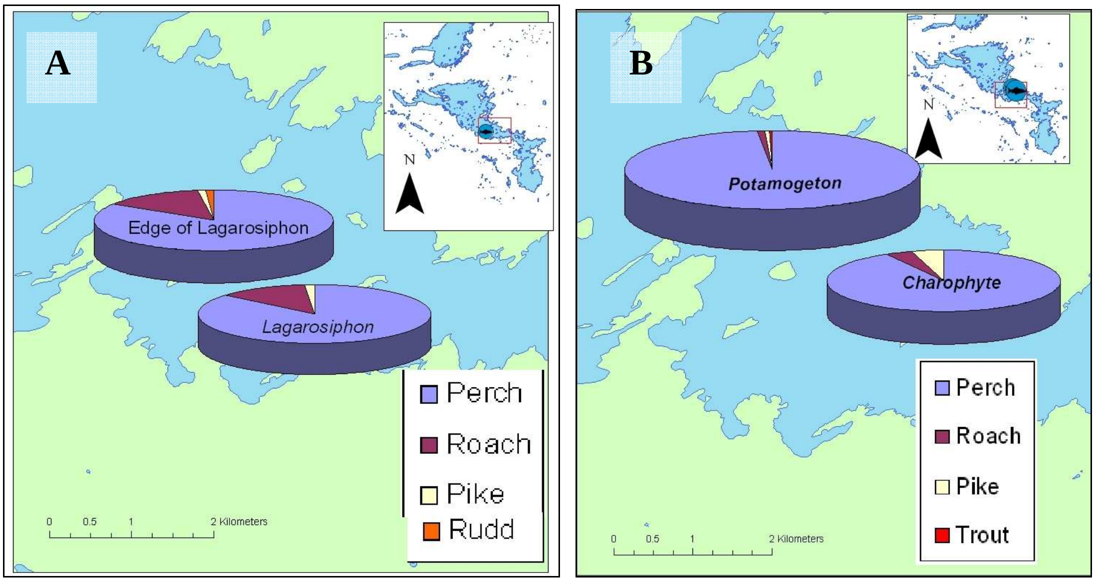


Figure 53: A) Fish species abundance within *Lagarosiphon* stands and at the edge of *Lagarosiphon* beds in Mogan's Bay in autumn 2008. B) Fish species abundance in tall *Potamogeton* stands and in/above low-growing Charophyte stands at Annaghkeen Bay in autumn 2008.

Winter Sampling

The overall numbers of fish caught during the winter netting operation were much lower than those recorded in autumn (Table 10 and Table 11). A total of 116 fish were caught on this occasion, compared to 1,427 in autumn.

Table 11: List of fish species recorded (including numbers captured) during a fish stock survey in a range of habitat types in Lough Corrib in winter 2008.

Species	Common name	Method	In *Lagarosiphon*	Edge of *Lagarosiphon*	*Chara* Bed	*Potamogeton* stands	Total
Perca fluviatilis	Perch	Gill net	0	1	5	59	65
Rutilus rutilus	Roach	Gill net	28	1	0	1	30
Esox lucius	Pike	Gill net	5	8	0	6	19
Salmo trutta	Trout	Gill net	1	0	1	0	2
Scardinius erythrophthalmus	Rudd	Gill net	0	0	0	0	0
Anguillla anguilla	Eel	Dutch fykes	0	0	0	0	0
						Total	116

Figure 54 compares temporal variation in the mean fork length of perch and roach captured at all sites during the autumn and winter sampling occasions. Fork length varied from mean values of 8.9 and 7.5 cm to 5.9 and 13.7 cm (for roach and perch, respectively) from autumn to winter. This variation represented a significant change (ANOVA, P <0.001), with an increase in length in perch, but a decrease in mean roach lengths with the onset of winter.

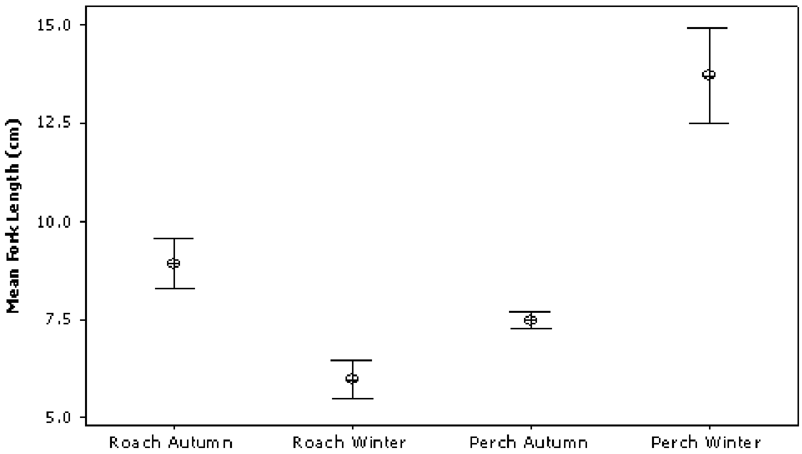


Figure 54: Temporal variation in the mean fork length (cm) for perch and roach population (± 95% confidence interval) at all sites in autumn and winter 2008 (ANOVA indicates a significant difference between samples: P< 0.001).

The roach were smaller when encountered in winter than they were when sampled in autumn (Figure 54), indicating possible size-specific habitat preferences. The majority of the roach captured in the winter were juvenile fish and measured less than 10 cm in fork length (Figure 55). Perch sampled during the winter showed a significant increase in mean length from the autumn sample, suggesting that conditions better suited them in the habitat types surveyed than it did the roach.

Again, the most abundant species was perch, with a total of 65 individuals. However, this species was best represented within the tall *Potamogeton* habitat type. By contrast, most of the roach were recorded in the tall but denser *Lagarosiphon* stands (Figure 55).

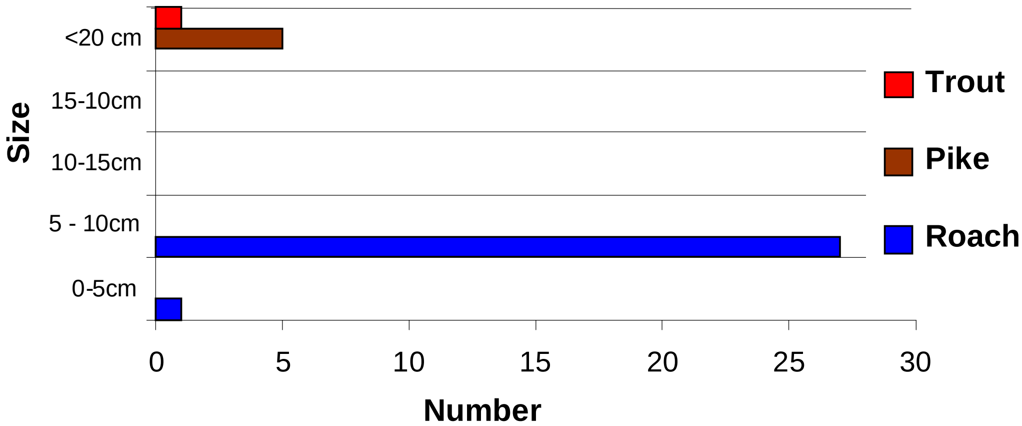


Figure 55: Length frequencies of fish species caught within *Lagarosiphon* stands in winter 2008.

The majority of the roach captured within the *Lagarosiphon* stands were juvenile fish, most less than 10 cm in fork length. A total of five pike were captured within the *Lagarosiphon* beds. These ranged between 30 and 62 cm in fork length (Figure 55). The fish were in good physical condition. In addition, one brown trout (48 cm) was captured in this tall vegetation.

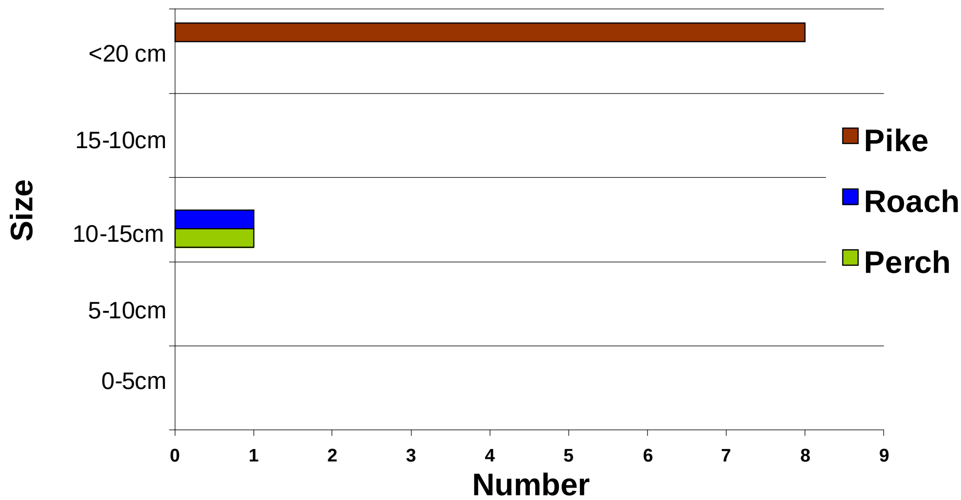


Figure 56: Length frequencies of fish species caught at the edge of *Lagarosiphon* stands in winter 2008.

Pike were relatively numerous in the open waters at the edge of the tall *Lagarosiphon* vegetation (Figure 56). These fish occupied a similar size range to those present within the weed, with fork lengths ranging from 26 to 65 cm. However, only one roach and one perch were caught in this habitat type.

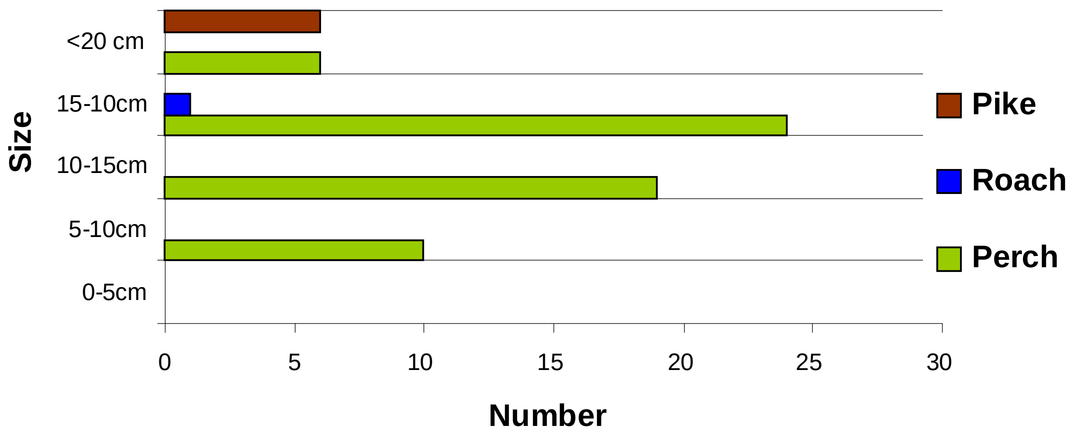


Figure 57 : Length frequencies of fish species caught within the *Potamogeton* stands in winter 2008.

Within the tall-growing *Potamogeton* stands a small population of perch, ranging in fork length from 5 to 22 cm, was recorded (Figure 57). There was a statistically significant increase in the size of perch captured during this sampling period, compared with the autumn sample (P< 0.05, Figure 54). This would suggest that the fish present during autumn found conditions within this habitat to be favorable and remained *in situ*.

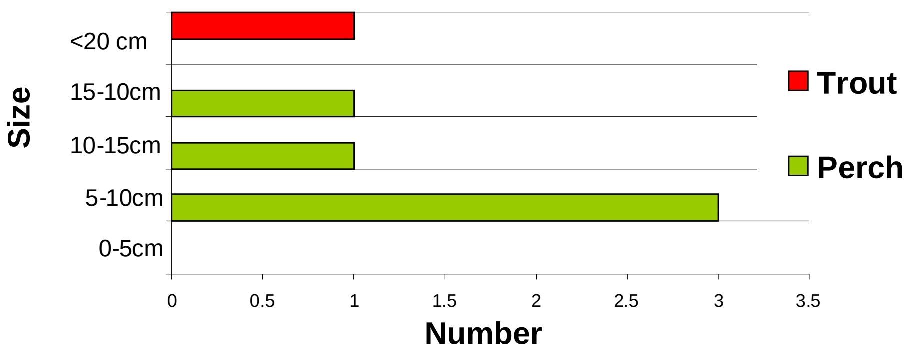


Figure 58: Length frequencies of fish species caught within the Charophyte stands in winter 2008.

Only two species of fish (perch and trout) were recovered from nets in or above the Charophyte beds (Figure 58). The mean size of the perch was smaller than those recorded within the *Potamogeton* stands (Figure 57).

When the overall representation of fish species recorded in winter (Figure 59A and B)) is compared with that present during the autumn (Figure 53 A & B)), it is apparent that the dominance of perch, particularly within, and proximal to *Lagarosiphon*, is diminished during the latter period.

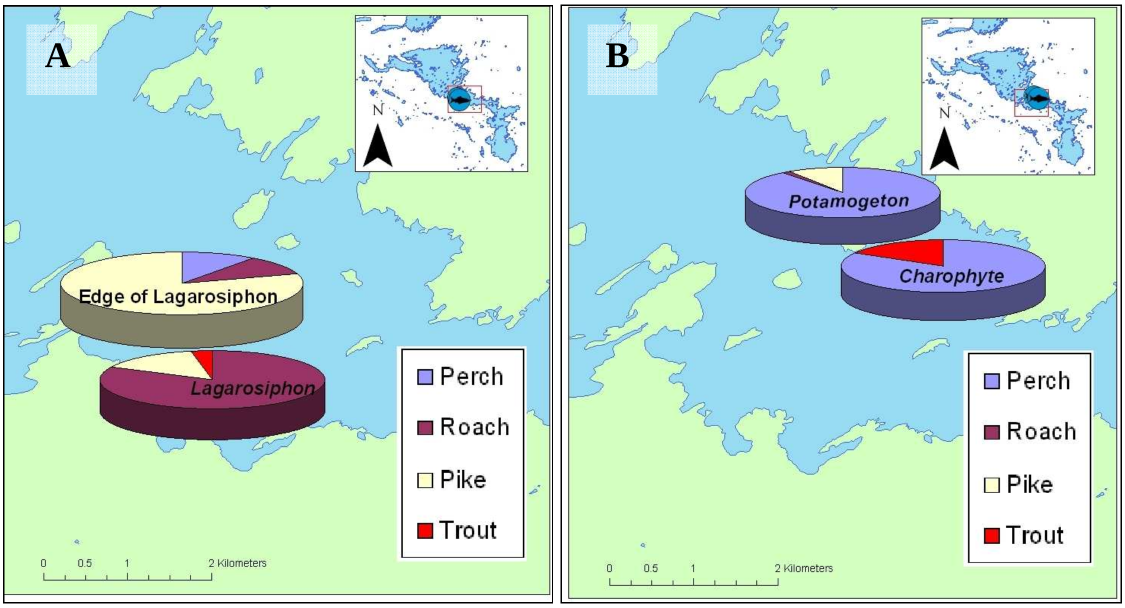


Figure 59: A) Fish species abundance within *Lagarosiphon* and at the edge of *Lagarosiphon* stands at Mogan's Bay in winter 2008. **B) Fish species abundance in tall *Potamogeton* stands and in/ above the low-growing Charophyte stands at Annaghkeen Bay in winter 2008.**

STRIVE Fish Stock Survey

The results from the fish stock surveys undertaken by QUB (C.Harrod, internal report) in upper Lough Corrib are presented in Table 12. During these surveys, the fish community in both the invasive and native habitats (as was the case with the CFB and WFD surveys) was dominated by roach and perch.

Table 12: Comparison of fish community in *Chara*- (native) and *Lagarosiphon*- (invasive) dominated areas, estimated as mean CPUE (n net^{-1} h^{-1}, total n = 830).

Gear	State	Roach	Perch	Pike	Bream	Roach x Bream	Salmon	Eel
Pelagic gillnet	Invasive	2.6	1	0.1	0	0.1	0.1	0
Benthic gillnet	Invasive	1.7	3.8	0.1	0	0.1	0	0
Fyke net	Invasive	0	0.1	0.1	0	0	0	0.28
Pelagic gillnet	Native	4.5	1.9	0.1	0.1	0.1	0	0
Benthic gillnet	Native	2.5	1.2	0.2	0.1	0,1	0	0
Fyke net	Native	0	0	0.1	0	0	0	0

Although there is considerable variation within habitat, the median abundance of fish was higher in *Chara*-dominated habitats during the first survey carried out in June 2008 (Figure 60).

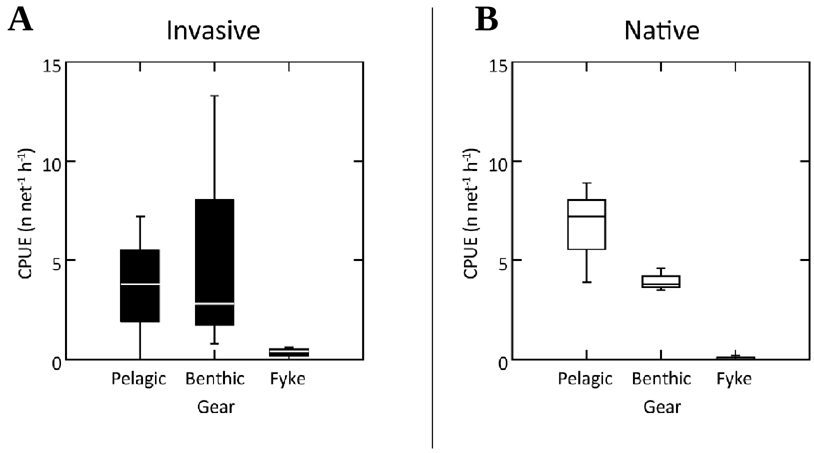


Figure 60: Box-Whisker plot comparing median catch per net hour of fish captured in A) *Lagarosiphon* and B) *Chara*- dominated habitats.

A similar comparison based on total biomass showed that median catches were greater in native habitats (Figure 61).

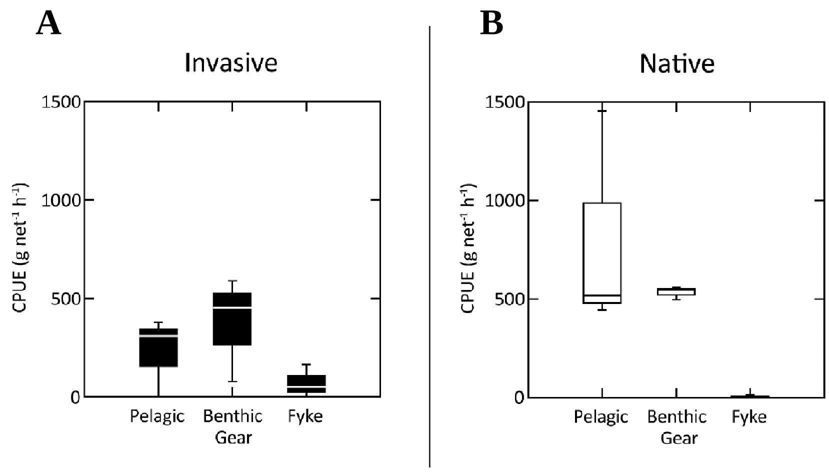


Figure 61: Box-Whisker plot comparing median biomass of fish catches in A) *Lagarosiphon*; B) *Chara*- dominated habitats.

Due to the dominance of roach and perch in survey catches, comparisons of size structure between habitats have focused on these species (Figure 62). In both species, smaller fish are associated with *Lagarosiphon*-dominated habitats, suggesting that the invasive macrophyte represents an important refuge for these fish.

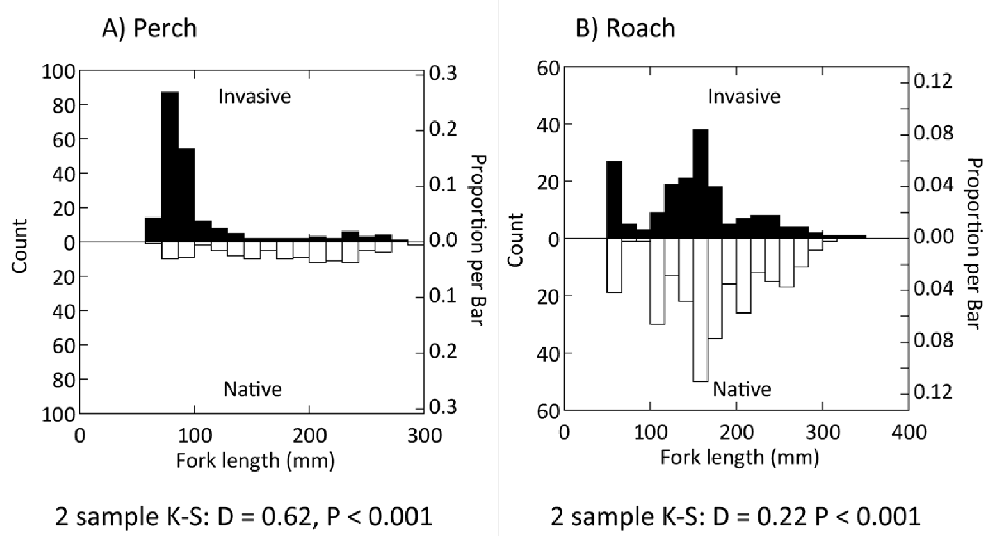


Figure 62: Length-frequency histograms comparing the size structure of A) perch and B) roach in *Lagarosiphon*- (filled bars) and *Chara*- (open bars) dominated habitats.

Comparisons of mean back-calculated length at age (Figure 63) demonstrated that perch, with a slower growth trajectory, were associated with *Lagarosiphon*, whilst the opposite was observed in roach, where faster growing individuals were captured from invasive habitats.

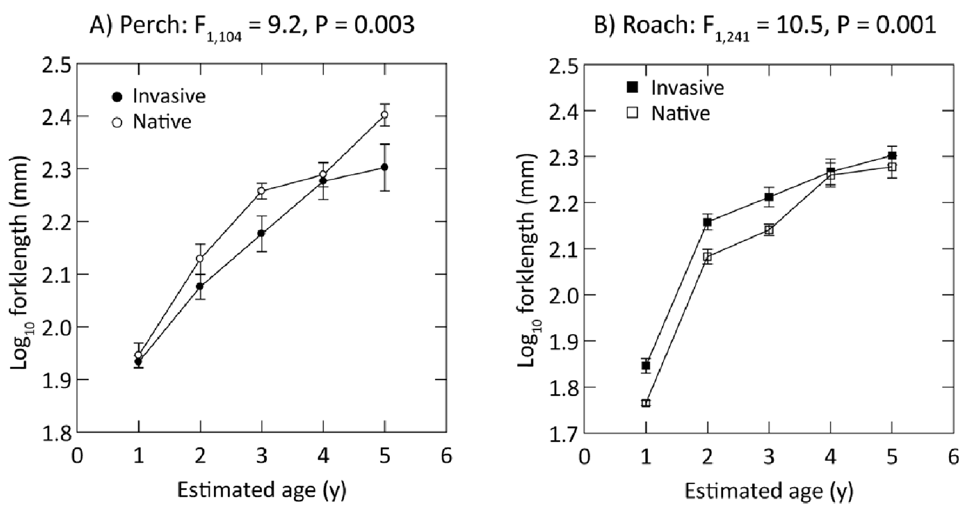


Figure 63: Comparison of mean length at age in A) and perch B) roach in *Lagarosiphon*- (filled markers) and *Chara*- (open markers) dominated habitats.

Work to date has shown that there are considerable ecological shifts associated with *Lagarosiphon*, including a decreased biomass of fish, use of the macrophyte by smaller roach and perch and changes in the growth of perch (-) and roach (+). Interestingly, stable isotope data (not shown here) provide no evidence that carbon from the large biomass of *Lagarosiphon* is entering food-web, even in the fish and macroinvertebrates associated with it.

3.4 *Lagarosiphon* Control

3.4.1 Mechanical Cutting

Ten areas in the northern sector of the upper lake were targeted for mechanical weed clearance in 2008 (Figure 64 and Figure 65). Cutting, using the OSMA weed cutting boat that was fitted with a pair of trailing knives or V-blades, commenced in July 2008 and has continued into January 2009.

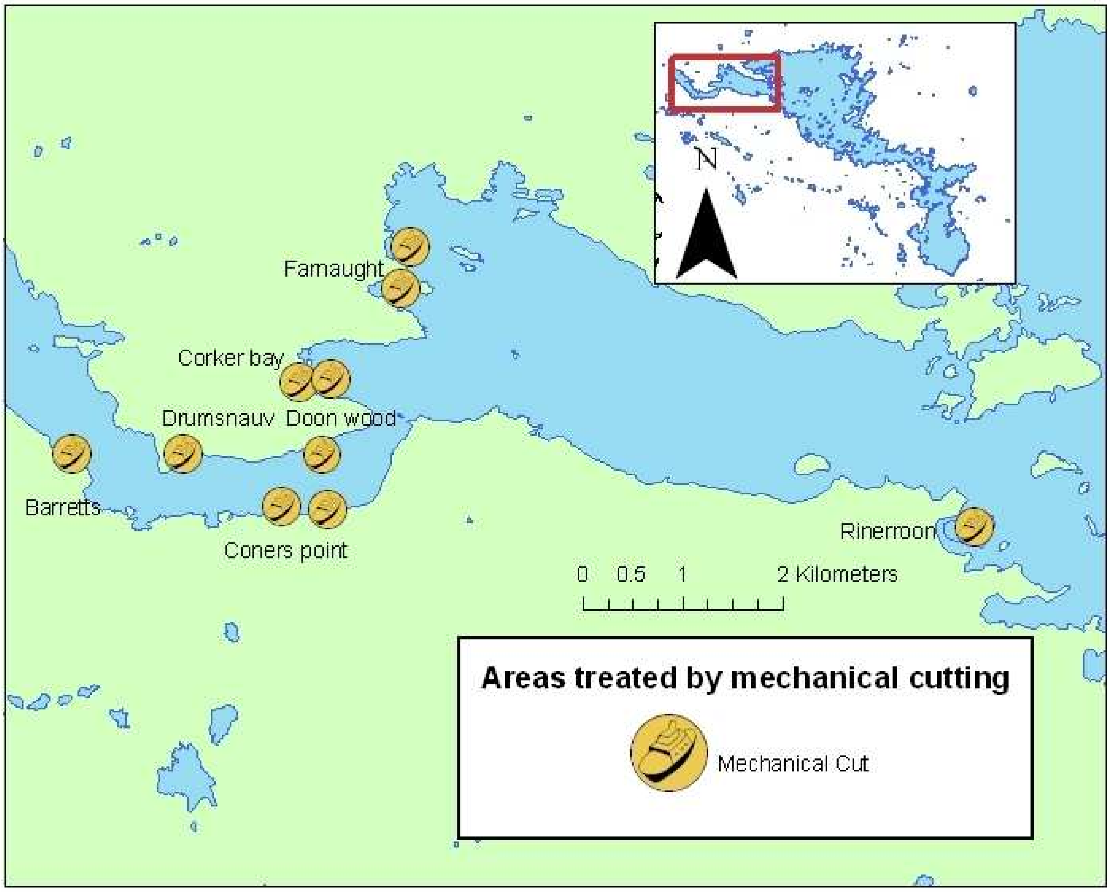


Figure 64: Map of northern sector of upper Lough Corrib showing the location of sites where *Lagarosiphon* was mechanically cut and removed in 2008.

Between July and December 2008 a total of *circa* 29.2 ha of *Lagarosiphon*-infested lake bed, at 10 separate locations (Table 13), was mechanically cut and the weed removed from site. The infestations varied considerably in size in the different bays, with some occupying less than 0.3 ha while others covered in excess of 19 ha of lake bed (Figure 65).

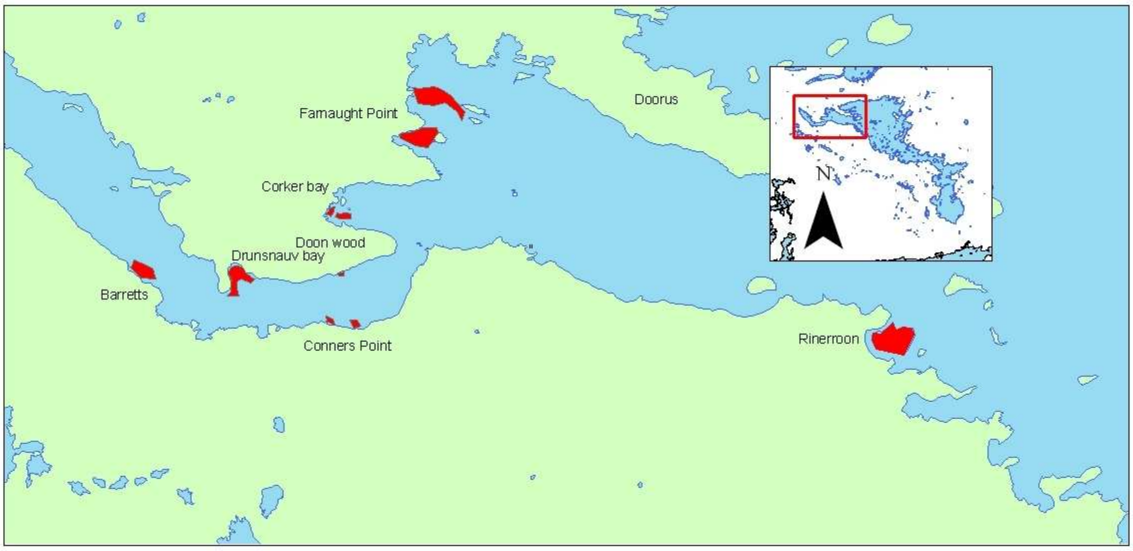


Figure 65: Map showing the specific areas where *Lagarosiphon* was cut and removed from the lake in 2008.

During this cutting and harvesting operation, *circa* 4,700 tonnes of *Lagarosiphon* has been removed from the upper lake.

Table 13: List of the bays and littoral zones where *Lagarosiphon* was mechanically cut and removed. The area of lake bed cleared of this invasive species is presented in each case.
(* *Circa* 25.5 % of the *Lagarosiphon* in the bay (totaling 19.45 ha) has been treated to date).

Site	m^2
Barrets	37,742
Drumsnauv	53,372
Conners Point west	5,827
Conners Point east	7,739
Doon Wood	2,479
Corker Bay	5,650
Corker Bay	10,279
Farnaught	71,110
Cornamona Bay	97,088
Rinerroon*	49,748

The efficacy of the weed cutting and removal operations was significantly influenced by the specific morphology of the plant at any given time (see Section 3.2.1). When *Lagarosiphon* plants are ‘collapsed’ (most commonly between May and October), it is more difficult to collect and remove the cut vegetation. This reflects the fact that the stems are less buoyant during this period and consequently, when cut at root level, they do not float to the surface. This makes it significantly more difficult for the weed harvesting boat to collect and remove the weed. Further, the risk of regrowth from cut plant fragments that lie on the lake bed is greatly increased. In a number of cases it was necessary to re-treat bays that had already been cut during the summer months (e.g. Farnaught and Drumsnauv). By contrast, when the *Lagarosiphon* plants are predominantly 'erect', highly branched and creating a surface canopy (commonly between October and March), the cut vegetation floats to the surface from where it is relatively easily collected and removed.

The impact of plant morphology and life cycle on the efficacy of *Lagarosiphon* cutting and harvesting is demonstrated in Figure 66.

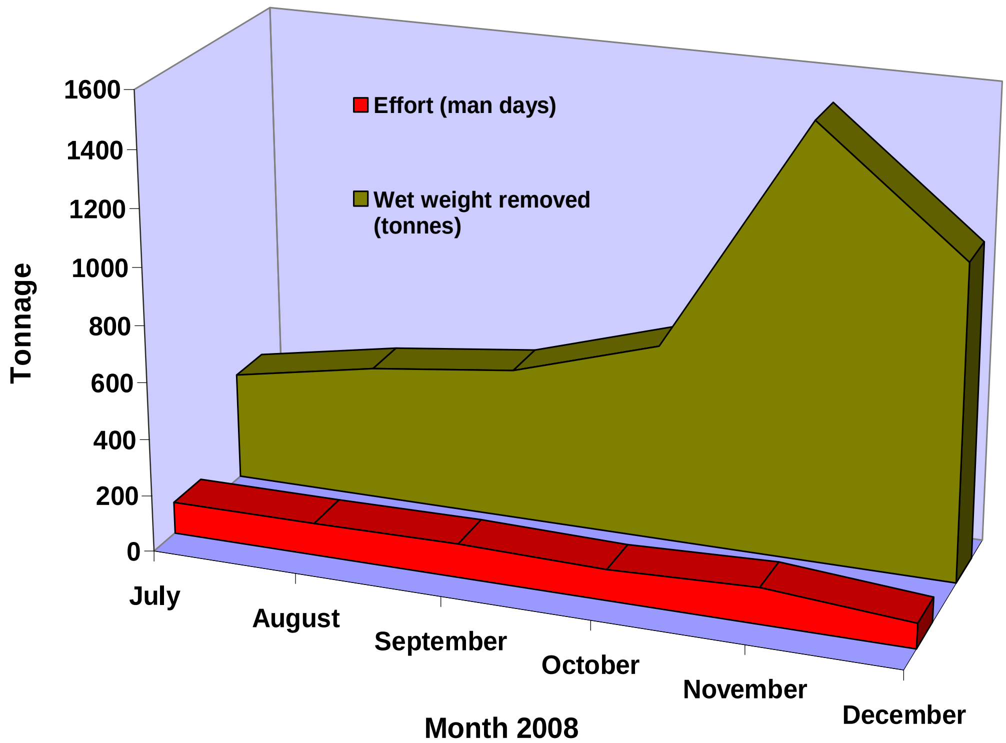


Figure 66: The wet weight (tonnes) of *Lagarosiphon* removed by cutting plotted against the effort (man days) used to remove the weed.

Between July and December the weed cutting effort, in respect of man days, varied relatively little. In the four months from July to October, an average of 450 tonnes of

Lagarosiphon was removed from the lake each month. The tonnage increased each month between July and October (Table 14), probably reflecting the increased familiarity of the staff with the cutting and harvesting operation. Using a similar effort, this figure increased to an average of 1,150 tonnes per month in November and December (Figure 66). The maximum monthly haul of weed was recorded in November when 1,521 tonnes of *Lagarosiphon* was removed (Table 14). This dramatic increase is explicable primarily as a consequence of plant morphology and the ease with which the ‘erect’ weed can be cut and collected in winter.

Table 14: Wet weight of cut *Lagarosiphon* removed from upper Lough Corrib between July and December 2008. The effort employed to cut and remove this vegetation is also presented.

Month	Tonnage	Man days
July	380	112
August	473	114
September	535	120
October	689	109
November	1521	128
December	1107	88
Total	**4707**	**671**

Weather conditions play an important role in determining the overall efficacy of the cutting and weed removal operation. This is best performed on bright, calm days when the weed is visible and the course of the boat is not disturbed by wind or turbulent water conditions. During the latter half of 2008, weather conditions were less than ideal for cutting and harvesting, although relatively few days were lost because of inclement weather.

The *Lagarosiphon* removed from the lake is normally stacked on higher ground some distance from the shore (Figure 67). The volume of the weed rapidly decreases as the weed dries out. Research is ongoing to find a beneficial use for this plant material.

Figure 67: One of the stacks of cut *Lagarosiphon* (approx. 4 m in height) that was removed from Rinerroon Bay in November 2008.

3.4.2 Biocontrol

A survey to locate natural enemies of *Lagarosiphon* in its country of origin, South Africa, was undertaken in November 2008. Several phytophagous species were recorded for the first time, with at least three showing notable promise as potential candidate agents. The results from this survey are presented in detail in Baars, J-R., Coetzee, J., Martin, G., Hill, M.P. and Caffrey, J.M. (see Appendix II).

3.4.3 Light Exclusion

The initial trial using light excluding geotextile was conducted on the south side of Devinish Island, in the middle lake, in August 2008. A relatively small stand of *Lagarosiphon* (60-70 m^2) was treated by applying 75 m^2 of biodegradable jute geotextile. The invasive weed population at this site had only recently established, although it had gained a firm foothold in the area. In an effort to halt its progress within this sector of the lake, and to assess the possibility of eliminating it altogether using light exclusion, it was decided to cover the entire stand with geotextile. Surveys to evaluate the impact that the geotextile was having on the treated site, and to monitor the physical condition of the biodegradable geotextile, were conducted towards the end of August, September and November.

Following some seven weeks *in situ*, thin filaments of *Chara glomerata* were observed growing through the narrowly porous textile material (Figure 68). With progress through the autumn, these native plant stands continued to grow and created a fragile vegetation substrate, up to 30 cm tall, on the geotextile mat. In places, notably where no *Chara* was present, significant growths of epiphytic algae were recorded (Figure 69). The geotextile showed no evidence of deterioration or decay by the end of November.

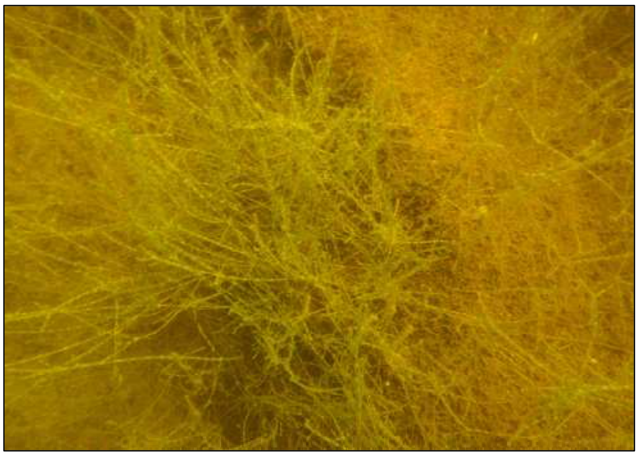


Figure 68: Charophyte plants (*C. glomerata*) growing through the jute geotextile at Devinish Island in 2008, following 7 weeks submersion.

While the geotextile was not disturbed to determine the status of the *Lagarosiphon* beneath, no evidence of any growth was recorded. Observations would suggest that the settlement of silt and the presence of *Chara* and epiphytic algal mats on the material would significantly contribute to light reduction beneath the geotextile and, consequently, expedite the eradication of the *Lagarosiphon*.

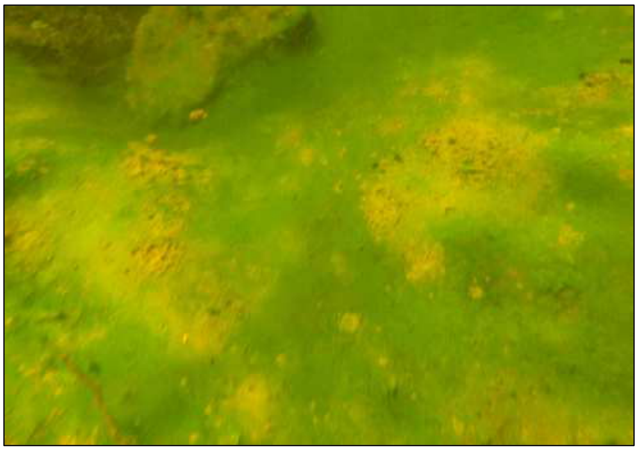


Figure 69: Algal growth on the textile material after the 7 week settlement period at Devinish Island.

A second site that was deemed to be suitable for treating with this geotextile was identified in the middle lake. This *Lagarosiphon* stand was located on the north shore of Fudges Island and measured *circa* 150 m^2. The weed at this site was covered in mid-August. Observations made some four weeks following geotextile placement showed significant algal and sediment settlement on the material. No Charophyte vegetation had, at that time, penetrated through the geotextile.

In light of a number of positive results recorded using the jute geotextile at Devinish and Fudges, it was decided to undertake a large-scale geotextile placement operation, on this occasion at Mogan's Bay, in the middle lake. A large stand of *Lagarosiphon,* measuring *circa* 70,000 m^2, was present at this site. An area of weed measuring *circa* 1,500 m^2, at the north-western end of this stand, was selected for initial treatment. The placement of the material took considerable effort (a total of 14 man days) and involved modifying one of the boats to facilitate its smooth delivery onto the water (Figure 70).

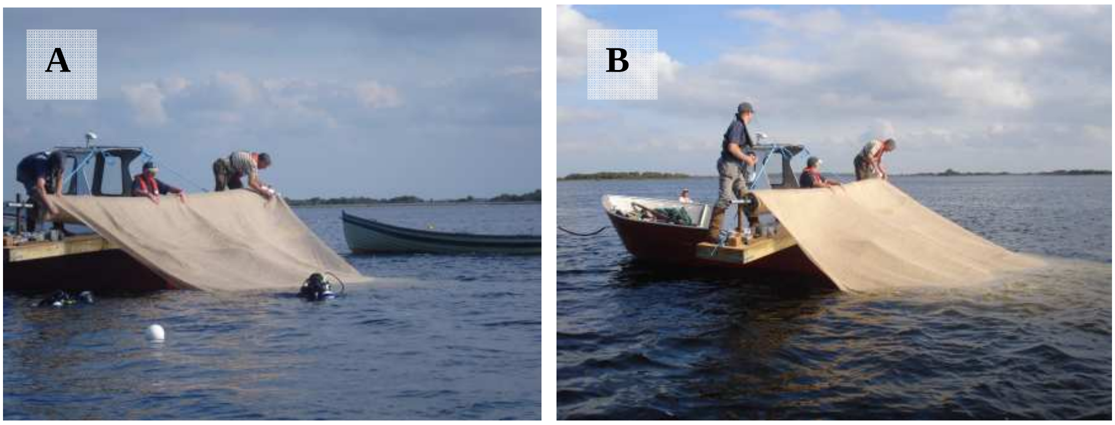


Figure 70A & B: Geotextile being placed on the water above dense *Lagarosiphon* bed*s* at Mogan's Bay in 2008.

A total area of 1,725 m^2 of *Lagarosiphon*-infested lake bed has been treated with jute geotextile in 2008 (Figure 71). Using previous estimates of 13.8 kg of *Lagarosiphon* per square meter (Caffrey and Acevedo, 2007), the weight of weed potentially eradicated by these operations could be as much as 23.8 tonnes.

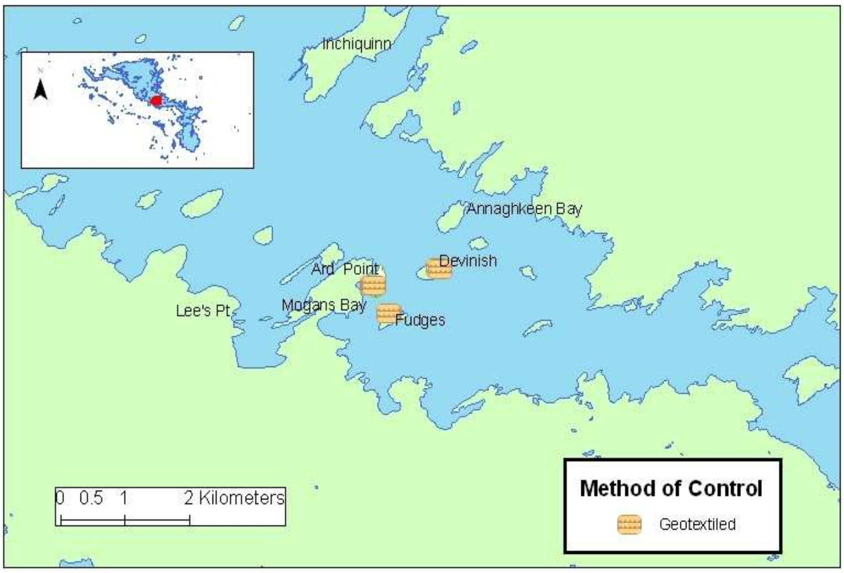


Figure 71: Locations in the middle lake where geotextile was used to exclude incident light from *Lagarosiphon* beds during 2008.

Based on the limited trials conducted to date, it is clear that relatively calm weather conditions are required to ensure efficient and accurate geotextile placement. Further, the specific morphological state of the plant, as dictated by life cycle, also has a significant influence on the efficiency of these operations. Effectiveness and ease of application is greatest when the plant canopy has been sloughed off and the majority of the plant stems are 'collapsed', as generally occurs during the summer months (see Section 3.2.1).

3.4.4 Hand Removal

Hand removal by scuba divers at sites where *Lagarosiphon* has only recently invaded and where the level of abundance is low can be an effective long-term strategy for its eradication (Clayton *et al.*, 2003). This method is most effective when used in conjunction with other control methods (e.g. in an area of rocky substrate that is inaccessible to the weed cutting boat or at the fringes of weed beds where geotextile has been placed). In 2008, a number of newly colonised, small and isolated populations of *Lagarosiphon* were identified in both the upper and middle lake during survey work (Figure 72). Hand removal was the chosen method at a number of these sites. In the upper lake, divers carefully removed *circa* five isolated strands of *Lagarosiphon* at each of the two small sites in Ashford Bay, an area from which no *Lagarosiphon* had been reported before 2008. Isolated *Lagarosiphon* strands were also removed from a site off Cannaver Island's northern shoreline in the upper lake, where only a small plant population was present. Further, a small number of isolated strands were removed from the area surrounding the bridge that connects Inishdoorus Island to the main shore. This particular removal operation was a strategic attempt to reduce the risk of *Lagarosiphon* being transported by those angling boats that regularly use this route to access the northern end of the upper lake.

Snorkelers were deployed at Vinlush, east of Doorus Peninsula on the upper lake, to remove the small invasive weed stand that was identified at this site. It was deemed to be a priority to remove this small population in order to reduce the risk of the weed spreading to the Carrick shore.

In the middle lake, hand removal was employed to eliminate isolated *Lagarosiphon* stands (>50 plants) that were located adjacent to the area covered by the geotextile at Devenish Island. Lastly, hand removal was again used in Annaghkeen Bay in an effort to limit the southerly *Lagarosiphon* migration. Here, small populations were discovered in close proximity to the main boat channel. Again, this was a strategic undertaking designed to reduce the risk of having the weed transported to the lower lake by boat traffic. At this site >10 isolated plants were discovered and subsequently removed during an extensive survey of the area.

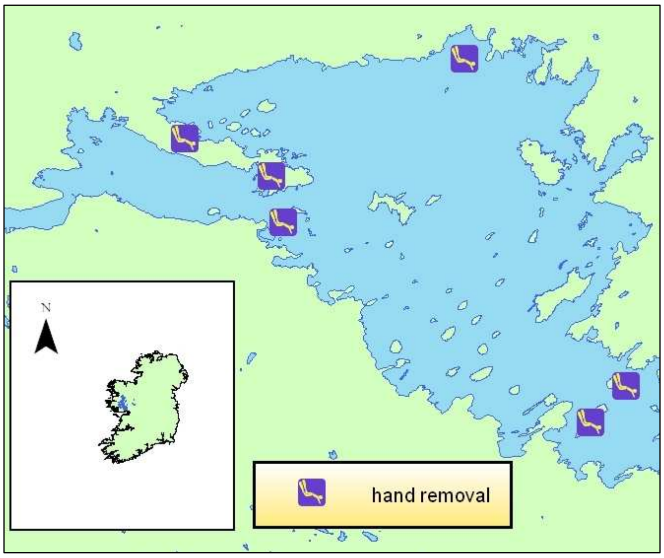


Figure 72: Sites in Lough Corrib where hand removal by divers was used to control *Lagarosiphon* in 2008.

In all cases, the maximum amount of root material was extracted from the substrate and all of the weed material collected was placed in sealed bags and removed from the lake. These areas will be resurveyed in 2009 to ensure that all of the *Lagarosiphon* has been successfully removed.

3.4.5 Chemical Control

In the latter part of 2008, the herbicide dichlobenil was used to treat two *Lagarosiphon*-infested locations on Lough Corrib (Figure 73). It was first applied to a densely-infested small harbour area at Rinerroon Bay (Figure 74) in mid-November. The second site treated was located at Farnaught in the northern sector of the upper lake. The weed in this bay had been mechanically cut in October 2008 but there was a *Lagarosiphon*-dominated area protected by rocks and boulders

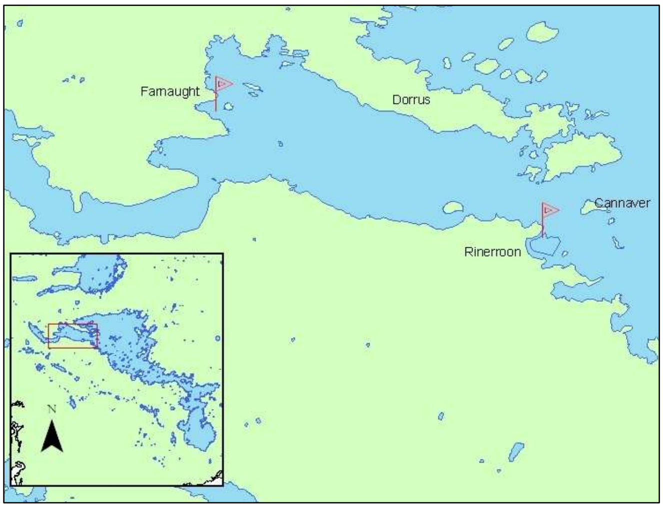


Figure 73: Location (marked by flags) of the two sites in upper Lough Corrib treated with the herbicide dichlobenil in 2008.

that was inaccessible to the weed cutting boat. Dichlobenil was applied to this area, which measured *circa* 200 x 300 m, in late November 2008.

A preliminary examination of the harbour in Rinerroon revealed a 60% die back of the treated vegetation. The remainder of the *Lagarosiphon* exhibited a loss of vitality (Figure 74).

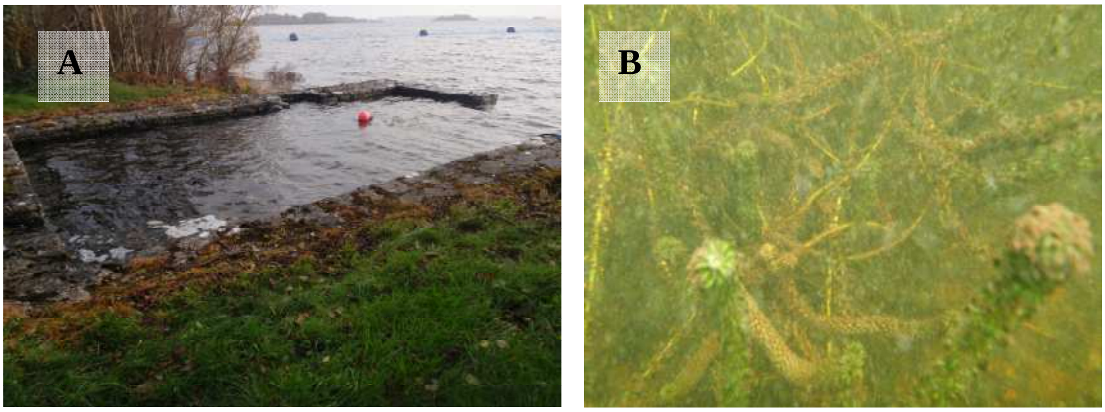


Figure 74: A) Harbour at Rinerroon; B) *Lagarosiphon* within the harbour 4 weeks after treatment with herbicide.

Likewise, at Farnaught, the *Lagarosiphon* was in the process of collapsing and appeared unhealthy when examined in December 2008. Divers will fully assess the effectiveness of the chemical treatment at both sites in late February 2009

4 Discussion

Over 120,000 non-native species of plants, animals and microbes have invaded the United States, United Kingdom, Australia, South Africa, India, and Brazil, and many have caused major economic losses in agriculture and forestry, as well as negatively impacting ecological integrity (Pimentel *et al*., 2001). For example, of the 27,515 plant species identified in the UK, only 1,515 are considered to be native (Crawley *et al*., 1996). Precise economic costs associated with some of the most ecologically damaging alien species are not always available. With species invasions that are responsible for extinctions, it is impossible to assign monetary values. However, where monetary value can be assigned, it is estimated that non-native species invasions, globally, are causing more than US$ 1.4 trillion annually in damages. This expenditure amounts to approximately 5% of the annual global economy (Pimentel *et al*., 2001). Within this expenditure, a not insignificant amount is assigned to the control of aquatic invasive weeds. For example, in the US, a total of US$ 100 million is invested annually in the control of alien aquatic weed species (OTA, 1993).

The number of non-native freshwater species recorded in Irish watercourses has increased significantly in the late 1900s (Caffrey, 1994; Caffrey, 2001; O'Neill and Stokes, 2004; Wade *et al*., 1997). Northern Ireland and the Republic of Ireland have international obligations to address invasive species issues, principally the Convention on Biological Diversity, International Plant Protection Convention, Bern Convention and the Habitats Directive.

Studies of species invasions have determined that, the sooner action is taken to address any threat, the greater the chance of success and the less costly it will be, both in terms of biodiversity and other resources (Defra, 2007). A crucial part of eradication is a contingency plan, which determines the action to be taken when an invasive species has been recorded. This approach is based, crucially, on regular surveillance for invasive non-native species and the fast application of tried and proven methods of control. In this way, control can be implemented quickly to maximise the effectiveness of early eradication efforts.

Lough Corrib constitutes an extremely important ecological and conservation site. Currently present in the system are a number of non-native species (e.g. Zebra mussel (*Dreissena polymorpha),* Canadian pondweed *(Elodea canadensis)* and Curly leaved waterweed *(Lagarosiphon major*)). *Lagarosiphon* has not yet been discovered in any other large natural aquatic system in Ireland. It is crucial, therefore, that the weed is, first and foremost, retained in Lough Corrib and that every conceivable effort is made to ensure that it cannot escape to infest other natural aquatic habitats in the country. It is also impingent upon us to work tirelessly to develop a suite of suitable control methods that can be used to bring the invader under control, and possibly even eradicate it, in Lough Corrib.

It is clear from the results recorded in Lough Corrib during 2008 that *Lagarosiphon* is continuing to spread and that there is no sign of a decrease in the rate of this population expansion. Not only has there been a considerable increase in the number of new sightings but this has been accompanied by a dramatic expansion in the ground coverage and biomass of this highly invasive weed at existing sites. By the end of 2008, a total of 113 *Lagarosiphon*-infested sites had been recorded in the upper and middle lake. Considering that, in 2007, some 64 infested sites had been documented (Caffrey and Acevedo, 2007), this represents a 55.4% increase in the number of new locations identified in a single year. It should be noted that this figure probably represents an underestimation as less resource was placed on identifying new sites for this invasive weed in 2008, reflecting the priority given to physical weed removal operations.

The spread of the *Lagarosiphon* population has been recorded throughout the upper and middle lake. However, of more concern is the rapid increase in the number of individual populations present in the middle lake and the insidious encroachment of this highly invasive weed towards the shallow lower lake. In 2007, 11 new sightings for *Lagarosiphon* were recorded in this shallower middle lake area. These were more or less confined to the upper sector of the middle lake. In 2008, however, 17 new sites were recorded. Interestingly, and worryingly, a number of these new sightings are farther south in the lake than this plant was ever previously recorded. At present, the most southerly location with a healthy, although small population (*circa* 6 m^2) is at Kilbeg pier (GPS reference IM 23823, ITM 42355), 3.8 km south of the most southerly recording from 2007.

Although *Lagarosiphon* is yet to be recorded in the lower lake, surveys of the area indicate that the habitat is suitable for the establishment and growth of this invasive plant. It is considered, therefore, that, without continued and rigorous surveillance, followed where necessary by the implementation of tried and tested control measures, it will only be a matter of time before *Lagarosiphon* gains a foothold in this shallow and expansive watercourse.

The exclusion of the native aquatic flora and the loss of habitats associated with the establishment and expansion of *Lagarosiphon* was acutely apparent from the macrophyte surveys undertaken in 2008. A total of 25 macrophyte species were identified from the 47 transects surveyed during this period. It is noteworthy, however, that the non-native *Lagarosiphon major* was present in 26 of these transects.

At many of the sites examined, a monoculture of *Lagarosiphon* was present (Figure 75). Few, if any, indigenous macrophyte species were able to survive beneath the dense, light-excluding canopy produced by this vegetation. The habitat created by these expansive, tall-growing alien plants is quite different to that produced by most native macrophytes, and particularly the lush and highly productive, low-growing *Chara* meadows for which Lough Corrib is renowned. *Lagarosiphon* shares some common features with a number of the tall natives, such a *Myriophyllum spicatum*, *Potamogeton lucens* and *P. perfoliatus*, although none of these indigenous species grow as densely or produce a fraction of the biomass that *Lagarosiphon* is capable of producing.

Figure 75: Monoculture of *Lagarosiphon* that is typical of many infested sites in Lough Corrib.

As the *Lagarosiphon* habitat type is such a consistent monoculture (Figure 75), which broadly differs from anything that may have been present in the lake prior to its arrival, it is likely to attract appreciably different biotic communities. Results from biotic surveys conducted in Lough Corrib in 2008 revealed considerable differences in the macroinvertebrate fauna between the native Charophyte vegetation and the introduced invasive *Lagarosiphon*. Significant differences in macroinvertebrate abundances were generally recorded, with higher values normally associated with the exotic *Lagarosiphon* (see Appendix I). This obviously reflects the architecture of the plant and the greater availability of suitable habitats for the macroinvertebrate species.

During the recent macroinvertebrate survey, large numbers of Zebra mussel (*Dreissena polymorpha*) were recorded attached to the tall *Lagarosiphon* plants. It is suggested that *Lagarosiphon* may be creating habitat conditions that favour the early invasion and spread of this other highly invasive species in Lough Corrib. The level of settlement of

Zebra mussel on *Lagarosiphon* plants will be closely monitored in 2009 and subsequent years.

Consistently, there were higher numbers of macroinvertebrate taxa contributing to the overall abundances on the native plant habitat compared to the exotic plant habitat. This indicates that there are only a few taxa on the exotic stands that make up most of the macroinvertebrate abundance. Lower species diversities may make the macroinvertebrate community less resilient to ecological change and, therefore, arguably more vulnerable. Furthermore, this indicates that these communities are less diverse and, although other trophic levels, such as fish, are shown to be opportunistic in their feeding strategy (Kennedy and Fitzmaurice, 1971; Kelly-Quinn and Bracken, 1990; Amundsen *et al*., 2001; Ormerod *et al.*, 2004), they will be dependent on a smaller complex of macorinvertebrates within the *Lagarosiphon* stands. This could prove significant if the expansion of *Lagarosiphon* and the exclusion of indigenous species continues. The structural complexity of the macrophyte habitat has also been shown to influence the feeding patterns of fish (Dibble *et al*., 1996; Warfe and Barmuta, 2006) and may result in higher levels of predation. The consequences of this are that the changes in the richness, abundance, composition and biomass of the macroinvertebrate community are likely to result in a knock-on affect on the trophic web structure of littoral ecosystems in Lough Corrib. This reflects the very different habitat types that *Lagarosiphon* (occupying practically the full water column) and Charophyte species (occupying relatively shallow vegetation mats, rarely more than 0.8 m deep) present for macroinvertebrates and / or fish (see Appendix I).

Results from fish stock assessments conducted in the upper and middle lake indicated that a healthy stock of coarse fish, dominated by small perch and roach, was present in most of the habitat types and bays investigated. The numbers of brown trout recorded were small, probably reflecting the small mesh sizes used during sampling. The CFB survey in the middle lake indicated that the tall macrophyte habitat type, whether provided by *Lagarosiphon* or by *Potamogeton* species, is important for juvenile fish populations. These plant stands provide a ready epiphytic algal and macroinvertebrate food source for the young fish, as well as providing concealment from predatory fishes and birds. However, results from survey work conducted in upper lake showed that, in this relatively deeper sector of the watercourse, coarse fish were most abundant in the Charophyte vegetation (C. Harrod, internal report). This variation in fish stocks and fish community structure between lake areas highlights the potential changes that can be expected as *Lagarosiphon* monocultures expand and create a new and varied habitat type for resident fishes.

The large juvenile fish population recorded within the *Lagarosiphon* beds in the middle lake is consistent with the areas being utilized as fish nursery grounds. As the habitat provided by *Lagarosiphon* is far more expansive (in terms of lake area and water column depth occupied), denser and more physically complex than that provide by any native plant species, it probably provides more favorable conditions in and on which coarse fishes can spawn, hatch and survive through their most vulnerable first winter. Observations while diving in April and May 2008 revealed extensive carpets of perch spawn draped over large areas of *Lagarosiphon*. During the summer months, clouds of perch, and to a lesser extent, roach fry were observed swimming within the *Lagarosiphon* stands. These exceeded anything that had been observed in the lake in previous years (K. Molloy, pers. comm.). Netting in autumn and winter 2008 revealed that large numbers of both species were also present in the *Potamogeton* stands, indicating a good survival from fry to fingerling stage.

It is important to note that there is no indication that the *Lagarosiphon* is being integrated directly into the food web of either the resident fish or the macroinvertebrates. Preliminary food web analysis undertaken by the STRIVE group from QUB in Lough Corrib has demonstrated considerable ecological shifts associated with *Lagarosiphon*. Despite the obvious association between the *Lagarosiphon* habitat and juvenile coarse fish, stable isotope analysis has provided no evidence that carbon from the large biomass of *Lagarosiphon* is entering the diets of fish or macroinvertebrates (C. Harrod, internal report).

During fish sampling operations that were undertaken in November, a noticeable die back of the tall *Potamogeton* species' and *M. spicatum* plant stands was observed. Although this is a natural, seasonal phenomenon, it can significantly impact juvenile fish, forcing them to seek alternative feeding sources and sanctuary. At this time of year, *Lagarosiphon* is entering its most vigorous growth phase. During the winter period, this invasive species produces lush, expansive and tall vegetation stands that must ideally suit the requirements of many fish species and cohorts within the lake. It is, therefore, conjectured that the expansion of *Lagarosiphon* populations in Lough Corrib will enhance the overwintering survival of at least some of the resident coarse fish species currently resident in the lake.

The implications of this improved overwintering survival of coarse fish for the management of the lake as a prestigious brown trout and salmon fishery are significant. There will obviously be increased competition for available food and space. Furthermore, the coarse fish will directly interfere with anglers by rising for flies and taking trolled baits. Traditionally, Lough Corrib has been promoted worldwide as a prestigious wild salmon and brown trout fishery. It continues to attract large numbers of tourist and domestic salmonid anglers (particularly during the mayfly season). The resulting benefit of this angling resource to the local and national economy is significant. The potential impact that the expansion of *Lagarosiphon* populations could have on the conservation status of the brown trout and on the associated economic revenue is considerable. Continued management and control of *Lagarosiphon* is of crucial importance in maintaining balanced and ecologically healthy fish stocks within Lough Corrib.

An in depth knowledge of the complexities of the life cycle strategies exhibited by *Lagarosiphon* populations, under Irish conditions, is essential if we are to successfully control its establishment, growth and spread. Understanding the biological traits of nuisance species should make it possible to manipulate vulnerable stages of their growth cycle in order to control populations. The seasonal change to the morphology of *Lagarosiphon* is a dramatic trait of this species. This variation in morphology causes significant alternation to the habitat conditions in an affected area. Further, the morphological condition of the plant exerts a significant influence on the efficacy of the weed control measures in operation at this time.

From the research undertaken in 2008, it is clear that the efficiency of the *Lagarosiphon* removal operations was substantially increased when the weed was cut during its 'erect' stage. The dense, floating canopy produced by the plant during this (winter) phase of its annual cycle makes it easier for the boat operators to determine the location and extent of the offending weed population. This minimises the use of divers, although they are still required to accurately demarcate the positions of the younger, more low-growing plants at the outer periphery of the stands. The presence of buoyant, tall-growing and highly branched plants further enhances the cutting and harvesting efficiency. When the *Lagarosiphon* is 'collapsed' (normally May to October) the stems are substantially less buoyant and, commonly, do not float to the surface when cut. This seriously restricts the efficiency of the harvesting operation and leaves a large volume of cut plant material on the lake bed to recolonise and establish new weed populations.

While in the 'erect' phase of its life cycle, the application of the light exclusion technique, using geotextile, is made significantly more difficult. When the geotextile material is placed over tall, erect stands of *Lagarosiphon,* a large number of heavy weights are required to bring the material (and the trapped weed) to the lake bed. Even then, the volume of weed contained beneath the geotextile makes it difficult for divers to properly seal the edges. Where this is not done correctly, incident light will penetrate and some level of photosynthesis will continue. In its 'collapsed' phase, it is far easier to precisely place the geotextile and to secure it properly to the lake bed. While the plant is in this growth phase, substantially fewer resources are required to successfully complete the operation.

It is clear, therefore, that the morphological state of the plant at any time in the year will significantly influence the management and control measures to be operated. In general, intensive *Lagarosiphon* cutting and harvesting campaigns should be limited to the period between October and April, when the majority of the stems are buoyant and branching. The bulk of the light exclusion work, using geotextile, will be conducted when the weed is 'collapsed' and more receptive to this control method. This is not to say that no cutting will take place during the summer months, as this method of weed control patently must continue when weather conditions permit. Likewise, there will be areas where it will be possible, and necessary, to place geotextile during the winter months. It is simply a matter of staff and resource allocation aimed at maximizing the control of *Lagarosiphon* in the lake.

The potential effectiveness of the cutting operations currently being conducted on Lough Corrib, and their capacity to provide long-term control of the treated *Lagarosiphon* populations, was determined experimentally in 2008. This experiment was designed to assess the viability of plants that were cut with different levels of severity. Using plants whose stems were cut within 1 cm of the root crown (which replicated the cut applied by the V-blades currently used in Lough Corrib) and those cut to within 10 cm of the crown, it was possible to demonstrate that, where a deep cut is applied, the remaining plant will not regrow and will eventually die off. Where a length of green stem tissue (*circa* 10 cm or more) remains following the cut, the plant is able to photosynthesise and rapidly produces elongated stems and branches. The results from this experiment demonstrate the benefits that should accrue from the deep cutting methods currently being applied in Lough Corrib.

In order to investigate the potential of naturally produced *Lagarosiphon* fragments to successfully establish and grow in the lake, the growth patterns displayed by a number of different fragment types were studied in experimental aquaria. The fragment types used were a) from the stem crown, b) from the mid-stem section and c) from the mid-stem section but with a developed aerial or adventitious root. All fragment types rapidly settled to the substratum in the aquaria, successfully rooted into this soft substrate and produced healthy branched stems. However, the plant fragments with existing aerial roots were less successful in rooting into the sediment and showed a reduced growth rate among their newly produced branches.

These results suggest that detached *Lagarosiphon* fragments with aerial roots, normally produced when the plants are in the latter stages of their ‘erect’ phase (mainly around late winter and early spring, may be less successful in establishing new populations than fragments without roots. From a management perspective this is an important finding and suggests that cutting should optimally be timed to coincide with this ‘erect’ phase of the plant’s life cycle. The reduction in the comparative ‘fitness’ of fragments potentially released at this stage (i.e. erect and with aerial roots) may indicate a possible weak phase in the plant's life cycle.

Aquatic macrophytes often exhibit a preference for vegetative reproduction over sexual reproduction. This may be related to the difficulty in raising the flowers above the water for aerial fertilization (e.g. Arber, 1920). In the case of *Lagarosiphon*, populations outside the native range (southern Africa) have only female plants and, so, no sexual reproductive stage occurs (Cook, 1987). Vegetative reproduction in macrophytes occurs primarily *via* stem fragmentation (e.g. Barrat-Segretain, 1995), but some species use the whole plant (e.g. *Eichhornia crassipes* - Penfound and Earle, 1948), shoot fragments (e.g. *Ceratophyllum demersum, Elodea canadensis and Myriophyllum spicatum* - Barrat-Segretain, 1996) and specialized organs such as tubers (e.g. *Potamogeton pectinatus* – Van Wijk, 1989), runners (e.g. *Luronium natans* - Arber, 1920), rhizomes (e.g. *Nymphaea alba* - Smith *et al.*, 1989) and the club-shaped shoot system apices or turions (e.g. *Myriophyllum verticillatum* - Aiken and Waltz, 1979).

Based on field observations during recent years, it is suggested that the majority of natural population dispersal among *Lagarosiphon* populations occurs during the winter/spring months when the stems are erect. At this stage the stems are buoyant and, being close to the water surface, are regularly subjected to winter and spring storms that will break and release healthy stem fragments. Under the influence of wind action or natural flow, these fragments float from the confined bays into the lake proper and can be carried for long distances before they sink. If the fragments sinks in an area that is suitable for growth (relatively sheltered, between 2 and 5 m deep and with a muddy substrate), then there is a strong possibility that a new population of this highly invasive species will establish there.

The general viability of *Lagarosiphon* fragments, as determined by the fragmentation experiments, reinforces concerns about the potential for spread of this aggressive invasive weed by mechanically cut or naturally dehisced fragments within the lake. It is, therefore, crucial that management activities strategically prioritise areas where the potential to create fragments is greater (e.g. at harbours and in boating or navigation channels). It is clear, however, that this is not the only dispersal mechanism available to this robust and highly adaptive species. Biotic and abiotic factors can also contribute to fragmentation. Such factors can include boat passage, bird movement, storm action, natural water flow within the lake, among others.

While fragmentation represents a significant and successful vegetative reproduction and dispersal mechanism for *Lagarosiphon*, this adaptable species has another asexual reproduction strategy available to it. The collapse of the previously erect *Lagarosiphon* stems in summer produces extensive mats of stems, many with existing aerial or adventitious roots, on the lake floor. These mats can extend for several meters away from the parent plant base. In the time following collapse, the additional energy provided by the parental plant enables these stems to rapidly produce lateral buds. In addition, the aerial roots from these stems penetrate the lake substratum and provide the plant with independent energy resources allowing for the production of new vertical stems and additional subterranean roots. This collapse and lateral regrowth, producing fully independent plants distal from the parental plant, has been termed here as 'self layering'. From *in situ* observations, this local population expansion strategy confers *Lagarosiphon* with a significant competitive advantage over indigenous plants. The collapsed material excludes light from any surviving understory species while maintaining an energy link to the parental plant, and thus providing access to resources for rapid growth.

One of the problems with this ongoing *Lagarosiphon* research and control programme has been the lack of adequate, long-term funding. This has meant that the programme was executed on a piece-meal basis and by a number of different scientific personnel. In 2008, however, funding through the Life+ Programme, jointly sponsored by the EC and NPWS, has been granted for research on *Lagarosiphon* in Lough Corrib and on a wider range of invasive species in the Grand Canal and Barrow Navigation network. This grant aid is most welcome and will provide a level of funding for this important work on invasive species from May 2009 to early 2013. An important feature of this funding is the continuity that it will give to contracted scientific staff to enable them conduct longer term studies into aspects of the life cycle and control of this aggressive, non-native and alien species.

5 Further Research

Lagarosiphon major has represented a serious ecological and social problem in Lough Corrib since it was first reported in 2005. Results from research undertaken in recent years have clearly demonstrated that the invasive weed is spreading rapidly within the lake and will, if its progress is not halted, ultimately dominate all suitable habitats in the upper, middle and lower lake. This domination will be at the expense of native and, in some cases, protected species and habitats.

Research findings to date have shed light on some aspects of the complex ecology of this invasive species. More detailed information relating to the life cycle strategies, the adventive traits and the factors that favour its growth in Lough Corrib are required if effective and targeted control mechanisms and procedures are to be developed. The research conducted to date has also helped to refine existing weed control methods, although a great more needs to be done in order to bring about a timely resolution to the expanding *Lagarosiphon* problem in Lough Corrib.

Research will be ongoing with *Lagarosiphon* until such time as effective control or containment procedures are developed. This research will be conducted under the following main headings.

Distribution and Status

No *Lagarosiphon* has yet been recorded in the large and relatively shallow lower lake. This is reflected in the continued dominance of indigenous biotic communities and unobstructed recreational exploitation in this water body. This unimpacted status promotes a high level of ecological integrity in the lower lake and is central to the maintenance and survival of a number of protected species and habitats. In the coming seasons, the status of macrophyte communities in this lower lake will be closely monitored and a particular focus of attention will be paid to areas that appear to be suitable for *Lagarosiphon* establishment. At the first sign of this invasive species in the lower lake, an intensive eradication campaign will be mounted and a rigorous subsequent monitoring programme will be set in place.

The status and spread of *Lagarosiphon* in the upper and middle lake will be rigorously monitored and control programmes will be implemented to deal with new infestations. The extent of the spread of the weed at existing sites will be closely monitored and efforts to determine the factors that most influence this spread, whether biotic or abiotic, will be mounted.

Lagarosiphon Control Strategies

While the mechanical cutting and harvesting programme as it is currently operated in Lough Corrib is relatively effective in removing large volumes of weed from key areas in the lake, it is also labour intensive and, at times, less efficient than it could be. Between May and October, when the plant has shed its canopy vegetation and its stems have lost their buoyancy, it is difficult to harvest the cut weed. This allows the cut stems to root and establish new populations. It is, therefore, proposed to explore the prospects of developing a new harvesting boat that will be able to gather cut plant material that does not immediately float to the surface. In the interim, cutting and harvesting programmes will be intensified during times of the season when the *Lagarosiphon* is easily located and when the stems are buoyant, mainly between October and April.

While trials using the biodegradable geotextile are still at an early stage, the preliminary results are showing considerable promise. It is, therefore, proposed to expand this control programme to include more and larger *Lagarosiphon*-infested sites. Much of this work will be focused on the middle lake to reduce the opportunity for the plant to spread into the lower lake. This work will be strategically timed around the summer period when the plant has shed its canopy and the stems are less buoyant. Further modifications will be made to the boat that is currently used to place the geotextile in order to increase the area that can be covered in a given time period. Further research will consider the long-term implications of the geotextile applications, including quantifying the ecological benefits to different trophic groups and the potential Charophyte bed rehabilitation.

The application of chemical control to *Lagarosiphon* in areas that are not suitable for mechanical control or light exclusion will be discussed with NPWS in 2009. A list of sites that are deemed to be suitable for herbicide treatment will be compiled and submitted for consideration.

Desk studies are currently underway to explore the possibility of adopting a biocontrol approach to the problem of *Lagarosiphon* in Lough Corrib. Several phytophagous species were recorded for the first time during a recent field investigation in South Africa, with at least three species showing notable promise as potential candidate agents. Work on the potential for biocontrol on *Lagarosiphon* in Lough Corrib will be conducted in collaboration with UCD and the University of Grahamstown in South Africa.

A constant search for new and innovative weed control methods will be maintained through desk studies and collaboration with scientists and weed managers, both nationally and internationally.

Biological Research

A comprehensive study into all aspects of the morphological changes associated with the life cycle of *Lagarosiphon* under Irish conditions will be investigated in 2009 and subsequent years. High precision data-loggers will be deployed at established *Lagarosiphon* beds in the north and middle lake to determine how changes over time in respect of key water physical and chemical parameters influence morphological changes and rate of change in the *Lagarosiphon* populations. This information will aid in the determination of those factors that influence growth, morphological changes and vegetative performance. Complimentary information on other trophic groups, including macroinvertebrates and fish, will also be quantitatively measured in order to determine the impact that *Lagarosiphon*, at its various life stages, has on these communities and on the quality of the habitat. In addition, this research will be contextualised by examining in detail the environmental impacts that heavy infestations with *Lagarosiphon* have on water quality and habitat conditions.

Detailed research under laboratory conditions will explore the complex links that obviously exist between the different morphological stages, the varied fragment types and overall reproductive strategies. This data will directly inform future management and control practices.

There are bays in the upper lake where conditions appear to be ideally suited to *Lagarosiphon* establishment and growth. However, even though these bays are adjacent to infested areas and, it is assumed, must be exposed to viable plant fragment settlement, no established *Lagarosiphon* colonies have yet been recorded. In order to determine if specific substrate conditions can inhibit *Lagarosiphon* settlement and growth, purpose-built plant enclosures containing a range of fragment types will be deployed in a number of these bays. The results from these experiments will provide a basis for further sediment analysis, where features such as nutrient status, trace element content and physical substrate characteristics will be studied

Further research into the quantitative impact that *Lagarosiphon* in Lough Corrib has on native communities will be undertaken. Those communities to receive most focus will include macrophytes, macroinvertebrates and fish. Research will endeavour to determine if the habitat or aquatic conditions produced by *Lagarosiphon* favour one species or community over another. For example, initial data recorded in 2008 suggests that juvenile perch and roach are likely to overwinter far more successfully than normal because of the presence of *Lagarosiphon*. This, among other aspects, will be studied in order to allow informed comment about potential future dynamic changes among fish populations and communities in Lough Corrib. Special focus will be given to the level of Zebra mussel settlement on *Lagarosiphon* plants in 2009 and subsequent years.

Stable isotope analysis of predator, prey and producer species will be conducted in order to fully assess the impact that the presence of *Lagarosiphon* on communities and food webs within the lake. This work will be conducted in collaboration with Queen's University, Belfast.

The course and rate of natural recolonisation by indigenous species and communities following *Lagarosiphon* control will be examined in detail. For example, it is hoped to compare ecological integrity associated with the range of different control approaches.

Special focus will be paid to all aspects, including biological, temporal and spatial, of the recolonisation of sites where geotextile material has been used to control *Lagarosiphon*.

6 Management Recommendations

Based on investigations conducted in Lough Corrib during 2008, and in previous years, more detailed information is currently available on the complex life cycle of *Lagarosiphon major*. This information, in combination with results from ongoing trials using a variety of weed control methods and strategies, has helped to identify potential weaknesses in the plant's life cycle that can be specifically targeted for control. In 2009 and subsequent years, a more strategic approach to control will be adopted in Lough Corrib and lessons learned from ongoing research will inform management practices.

A number of key management recommendations have emerged as a consequence of ongoing research efforts in Lough Corrib. These should serve to inform future weed control practices and improve the effectiveness and overall efficacy of these operations.

- Mechanical cutting and harvesting operations should continue to focus on *Lagarosiphon*-infested sites in the upper lake and move progressively southward, in the general direction of water flow. This strategic approach will minimise the risk of *Lagarosiphon* populations becoming re-established from viable fragments brought into treated areas by natural water currents.

- The control methods selected for different sites and for different times of the season should, where appropriate, pay reference to the morphological state of the plant. Thus, while mechanical cutting and harvesting will continue year-round, activities will be intensified during the 'erect', canopy-forming growth phase of the plant, from October to April. At this stage the stems are buoyant and, when cut, float to the surface, from where they are easily and effectively harvested.

- Consideration will be given to developing a weed harvesting boat that is capable of collecting cut vegetation that does not automatically float to the water surface. Such a craft would need to be capable of collecting cut plant material to a maximum depth of 5 meters.

- Geotextile placing operations will be targeted around the 'collapsed' phase of the plant, when the canopy vegetation is absent and the majority of the stems have lost buoyancy. At this stage in the growth cycle, it is easier to cover the designated weed bed and to properly attach the material to the substrate.

- Strategically, the primary focus for geotextile placement will be the middle lake, thereby restricting the spread of *Lagarosiphon* to the lower lake.

- Where weed control using mechanical or environmental methods are impractical, for example because of shallow water or the presence of obstructive rocks and boulders, selective herbicide applications will be considered.

- Surveillance monitoring of non-impacted sites, particularly in the lower lake but also in middle and upper lake, must continue for the duration of the project. Mitigation measures must be in place to deal with new infestations before they become too well established to effectively handle.

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APPENDIX I

Changes to the invertebrate fauna of littoral habitats induced by the alien invasive species *Lagarosiphon major* (Hydrocharitaceae).

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Executive summary:

Submerged and floating aquatic macrophytes are an integral component of littoral ecosystems, and directly and indirectly affect the composition of other biotic components. Although many plant species are fed on by phytophagous invertebrate species directly, macrophytes are generally considered to provide a substrate for colonisation and indirectly affect trophic web structure. The species richness, relative abundance, community structure and biomass of invertebrates were used to assess the changes that occur when plant communities shift from a native plant community to a monotypic invasive plant. Changes in the vertical complexity of submerged macrophytes were induced by a shift from a predominant Charophyte spp. plant bed to a vertically diverse plant stand of *L. major* (in up to 4m of water depth). We investigate the hypothesis that the vertical changes in plant structure affect the distribution of invertebrates in species richness, abundance, and biomass. Results indicate that species richness was similar, but invertebrate communities were distinctly different in native and exotic plant habitats. No consistent pattern in biomass was found, but the most notable differences occurred in the vertical distribution of certain invertebrate taxa, like *Bithynia tentaculata* (and other gastropods) and Chironomidae. This study indicates how a dominant invasive macrophyte can change littoral ecosystems resulting in further trophic web changes.

Key words: invertebrate communities, submerged macrophytes, vertical distribution, structural complexity, invasive species, littoral habitat, gastropods.

Introduction

Submerged and floating aquatic macrophytes are an integral component of littoral habitats. Vegetated littoral habitats are markedly different to un-vegetated habitats particularly in their composition of other biotic components. Although many plant species are fed on by phytophagous invertebrate species directly (McGaha, 1952), macrophytes are generally considered to provide a substrate for colonisation and indirectly affect trophic web structure (Hargeby *et al.*, 1994). Variability in the plant species compositions and growth forms presents an infinite combination of habitats. Plants in general promote invertebrate colonisation (Theel *et al.*, 2008), and the complexity of plant communities is shown in many studies to promote the diversity of invertebrates (Brown *et al.*, 1988**;** Humphries, 1996; Scheffer, 1998; Olson *et al.*, 1999; Wright *et al.*, 2002; McAbendroth *et al.*, 2005; Savage *et al.*, 2005; Theel *et al.*, 2008) as well as their morphology (Humphries, 1996; Cheruvelil *et al.*, 2000; Cheruvelil *et al.*, 2002). These macrophyte species provide a heterogeneous habitat that may affect the availability of epiphytic algae (Cattaneo *et al.*, 1998; Tessier *et al.*, 2004), change predator-prey interactions (Scheffer, 1998; McCarthy and Fisher, 2000), and alter the richness and abundance of other biotic components like invertebrates (Theel *et al.*, 2008; Warfe and Barmuta 2006), fish (Killgore et al., 1993; Dibble *et al.*, 1996; Harrel et al., 2001; Warfe and Barmuta 2004) and birds (Krull, 1970; van den Berg *et al.*, 1997). Changes to macrophyte habitat structure will as a result potentially affect the invertebrate community composition. This change in composition may be as a result of natural spatial and temporal changes (van den Berg et al. 1997, James *et al.*, 1998), but also result from the introduction of invasive species (Schmitz and Simberloff, 1997; Theel *et al*, 2008). The abundance and density of macroinvertebrates has been shown to differ greatly over time and between macrophyte species (Olson *et al.* 1999). Contrary to expectation, with the introduction of an invasive species that presents a complex heterogeneous plant habitat, the invertebrate fauna may increase in diversity, abundance and biomass.

Invasive species are a worldwide threat to the biodiversity and functioning of our ecosystems (Manchester and Bullock, 2000; Mooney and Cleland, 2001; Pimentel, 2002; Hulme, 2006) and the agricultural and economic health of our society (Ranjan, 2008; Waage and Mumford, 2008). Invasive species are considered the second most important threat to our biodiversity following habitat destruction (UNEP, 1992), and in the assessment of protected habitats in Ireland one of the key threats was the invasion of alien plants and animals (NPWS report, 2008). In obligation to the Convention on Biological Diversity Ireland is required to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species (UNEP, 1992), and is a focus of the EC Water Framework Directive (2000/60/EC) and the Ireland National and Global Strategy for Plant Conservation. The mechanisms by which exotic species change our native habitats is diverse, although the most common being through competitive interactions with our native species (Stokes *et al*., 2004). In both terrestrial and aquatic ecosystems plant invasions often result in a shift from a diverse species complex to a monotypic plant community. However, some studies indicate that in some circumstances, particulary complex macrophyte habitats, that invertebrate communities within invasive species are similar to native plant habitats (Theel *et al*., 2008). However, if plant habitat complexity and heterogeneity affect diversity then the change in aquatic habitats that were relatively simple plant habitat types, may be expected to be quite substantial.

In this study the invertebrate species richness, relative abundance, community structure and biomass was used to assess the differences in the invertebrates collected on the invasive *L. major* and native Charophyte spp. in Lough Corrib, County Galway.

Methods and Materials

Invertebrate communities

The architecture of Charophyte and *L. major* (Figure 1a) are very different and required specifically modified sampling nets to ensure comparisons could be made between plant types. A modified box sampler was constructed (0.5 x 0.5 x 0.5m) covered in mesh on all sides except for the base which was made up of a sliding plate (Figure 1b). The box was placed over Charophyte stands, the edges around the box cut and the plate was pushed underneath the plant sample cutting the plants off above the sediment layer. The entire sample was then transferred to tubs and placed in bags for processing. As most of the sites were at a depth of about 3m the samples had to be taken by divers. The *L. major* samples were collected using a modified net which sampled the plants within an area on the lake bottom of 0.5 x 0.5 x 0.5m and the entire water column (up to the water surface).

To determine the position of the invertebrate communities and thus providing a better comparison to the Charophyte samples, the net with the *Lagarosiphon* samples were sectioned off every 0.8m (Figure 1c). The entire net was brought on board boats and sectioned off into the four sections and placed in bags for processing. Plant samples were hand washed over sieves (500µm mesh) to remove the macroinvertebrates (Figure 1d), and the remaining plant material was air dried in a glasshouse for a period of time and dried in an oven for 72 to 120 hours (depending on the size of the sample) to a constant weight and weighted to record the dry weight (DW g). The invertebrate samples were preserved in 70% IMS and sorted under lights in the laboratory. On occasion samples with large numbers of individuals were sub-sampled, including taxa like Chironomidae, *Crangonyx pseudogracilis*, and *Radox balthica*. Where possible taxa were identified to the lowest taxonomic level, notable exceptions include Chironomidae, Leptoceridae and Oligochaeta.

To obtain the biomass equivalent, all the taxa removed and identified were maintained separately and dried to a constant weight in an oven for 24 to 72 hours at 60°C (Wollheim and Lovvorn, 1996; James *et al.*, 1998), and weighted using a fine scale balance (accuracy of 0.0001g). The molluscs were dried and weighed in their shells (Andersson *et al.*, 1994). Dried specimens were then supplied to Queens University for Isotopic analyses (Strive Project).

Monitored Quadrats

In order to assess the growth rate of *L. major* infestations and assess the competitive interaction with native Charophyte spp., quadrats were marked and monitored, and continue to be monitored for at least 1 year. Quadrats (0.5 x 0.5 m) were established to represent three conditions. These were 1. Charophyte stand seeded with *L. major* shoots (Figure 2a & b), 2. Charophyte spp. stand with no modifications (100% cover) (Figure 2c), and 3. *L. major* stand with no modifications (100% cover) (Figure 2d). Quadrats were marked using a bright cord (visible under water) with a plant marker and snap cap providing buoyancy. The lengths of the cord for the markers were adjusted depending on the plant species to make them clearly visible even when plants grew over the season. Quadrats (5 replicates) were also established at one site (Rinneroon Bay) in an area where

L. major had been cleared using a 'v-blade' which was dragged along the substrate. This was done in order to assess the potential regrowth of *L. major* fragments and compare this to seeded quadrats within the same bay. At two sites 2 data loggers (Tinytag) were placed at circa 0.6m above the substrate within Charophyte and *L. major* stands. Temperatures were recorded every hour, and data loggers were retrieved for downloading the data after three and half months, and replaced with new data loggers.

Data analyses

Samples were compared between bays using ANOVA (STATISTICA 7.1; Statsoft, 2005). Communities were compared using NMDS plots and ANOSIM analysis was conducted to assess the significant differences between groups assigned a priori. TWINSPAN analysis was used with pseudospecies assigned using presence absence data (CAP 4.1). Regression analysis was used to compare relationships using STATISTICA 7.1. Relative abundance rank order plots were analysed for significant differences (see Magurran, 2004).

Figure 1: *L. major* plants occupying the entire water column (a), Box sampler constructed to sample the Charophyte spp. (b), net used to sample the *L. major* plants to include the entire plant and sectioned off in 0.8m sections (c), Plant samples collected were washed carefully above sieves to remove the invertebrates (d).

Figure 2: *L. major* shoots (about 9) bound together and weighted (a), bound shoots placed within healthy Charophyte spp. stands and quadrate marked (0.5 x 0.5m)(b), with control Charophyte spp. (c) and *L. major* stands (d – inset: marker system used) in close proximity monitored.

Results

Invertebrate taxa

A total of 100,069 individuals were sorted and identified from the samples collected from the three bays in June (2008). A total of 51 taxa were recorded and many of the invertebrate groups typically found in littoral habitats were represented (Table 1). Three groups represented most of the abundances, including non-biting midges Chironomidae (Diptera), crustaceans including *Crangonyx pseudogracilis* and *Gammarus deubeni* (Gammaridae) and several snails (Mollusca), particularly *Bithynia tentaculata* (Bithyniidae) and *Radix balthica* (Lymnaeidae). Several species occurred in small numbers and may only represent short-term associations with the plants, like the stonefly *Siphonoperla torrentium* (Chloroperlidae) which was probably using the plant to emerge.

Taxon Richness

To compare species richness between plant species the samples of *L. major* throughout the water column were combined to represent the overall taxa recorded per 0.25m^2 lake bottom. The differences in taxon richness varied between bays from no significant difference in taxa richness between Charophyte and *L. major* samples in Bob's Island and Rinneroon Bay, to significantly fewer taxa recorded on Charophyte spp. in Kitteens Bay (Figure 3).

Invertebrate community

However, when the similarity between communities recorded on the different plant species was analysed clear differences between species were noted (Figure 4). With the exception of some overlap in the *L. major* samples collected in Bob's and Rinneroon Bay, samples from different bays were notably different (Figure 4). This indicates that there is significant difference in the communities found on the different plant species and there are differences between bays. This may be expected as a result of differences in the bays in amongst others the depth profile, substrate composition, current and temperature.

Table 1: List of taxa collected on Charophyte spp. (C) and *Lagarosiphon major* (L) in three bays surveyed in Lough Corrib in June 2008.

			Bob's Island		**Rinneroon Bay**		**Kitteens Bay**	
Order	**Family**	**Genus/Species**	**C**	**L**	**C**	**L**	**C**	**L**
Plecoptera	Chloroperlidae	*Siphlonoperla torrentium (*Pictet.)	0	13	0	2	0	0
Ephemeroptera	Caenidae	*Caenis horaria*	11	4	0	27	39	24
		Caenis luctuosa (Burmeister)	4	0	0	0	0	0
	Baetidae	*Cloeon simile* Eaton	0	2	1	2	0	1
Trichoptera	Polycentropodidae	*Holocentropis dubius* (Rambur)	2	5	0	1	0	3
		indet.	6	35	86	11	138	47
	Phryganeidae	indet.	8	1	2	0	4	1
	Lepidostomatidae	*Lasiocephala basalis* (Kolenati)	10	2	6	9	5	0
	Leptoceridae	indet.	13	4	18	41	60	414
	Limnephilidae	indet.	5	6	1	7	2	7
	Ecnomidae	*Ecnomus tenellus* (Rambur)	0	0	0	1	0	0
Coleoptera	Chrysomelidae	indet. (Larvae)	73	2	0	3	3	19
		indet. (Adult)	7	0	0	0	0	0
	Dytiscidae	*Dytiscus spp.* (Larvae)	0	0	0	44	0	155
		Strictotarus duodecimpustulatus	1	0	1	0	0	0
	Haliplidae	*Haliplus spp.* (Larvae)	2	4	1	3	14	4
		Haliplus spp. (Adult)	1	0	0	2	0	0
	Helophoridae	*Heleoporus spp.*	0	2	1	4	1	0
	Elmidae	*Limnius volckmari* (Panz.)	10	0	0	0	0	0
		Oulimnius tuberculatus Mull	17	0	0	0	0	0
		Elmis aenea (Mull.)	0	1	0	0	0	0
	Gyrinidae	indet.	0	0	0	1	0	6
Diptera	Chironomidae	indet.	332	3914	1210	41045	2042	11516
Hemiptera	Corixidae	indet.	0	63	0	145	4	11
	Velidae	*Velia caprai* Tamanini	0	0	0	1	0	0
Odonata	Zygoptera	indet.	7	424	0	62	129	215
Lepidoptera	Crambidae	*Acentria spp.*	0	6	0	94	3	20

			Bob's Island		**Rinneroon Bay**		**Kitteens Bay**	
Order	**Family**	**Genus/Species**	**C**	**L**	**C**	**L**	**C**	**L**

Crustacea	Asselidae	*Asselus aquaticus* (L.)	151	47	10	110	291	69
	Gammaridae	*Crangonyx pseudogracilis*	146	1440	1125	7990	1471	811
		Gammarus duebeni (Lillj.)	463	1996	2	137	3	3
Oligochaeta	Oligochaeta	indet.	6	0	298	8	5	0
Tricladida		indet.	0	0	1	2	0	2
Acari	Hydracarina	indet.	2	1	1	126	2	60
Hirudenea	Erpobdellidae	*Helobdella stagnalis* (L.)	11	0	3	5	11	4
		Erpobdella octoculata L.	19	1	4	6	44	15
		Piscicola geometra (L.)	0	0	0	0	1	0
	Glossiphoniidae	*Glossiphonia complanata* (L.)	2	46	1	18	0	0
		Glossiphonia heterodita (L.)	1	0	0	12	0	3
Mollusca	Bithyniidae	*Bithynia tentaculata*	1089	3338	100	2124	1409	549
	Lymnaeidae	*Radix balthica* (Muller)	0	130	107	7517	682	1501
		Lymnaea stagnalis (Linn.)	2	1	0	0	0	0
		Stagnicola palustris (Muller)	0	0	0	1	0	0
		Lymnaea sp.	5	3	0	1	0	0
	Valvatidae	*Valvata piscinalis*	0	0	0	0	5	2
		Valvata macrostoma	193	69	0	6	4	1
		Valvata cristata	209	25	5	10	96	7
	Planorbidae	*Planorbis vortex*	325	203	5	41	0	0
		Planorbis carinatus	10	17	5	57	0	0
		Planorbis fontinalis	0	5	0	0	0	0
	Physidae	*Physa fontinalis (Linn.)*	0	0	0	1	0	0
	Hydrobiidae	*Potamopyrgus antipodarum*	1	0	0	0	0	0
Bivalvia	Pisidiidae	*Pisidium* spp.	128	14	4	10	53	25
	Dreissenidae	*Dreissena polymorpha (Pallas)*	8	37	0	147	21	51
Vertebrata		*Gasterosteus aculeatus*	4	0	0	0	4	0

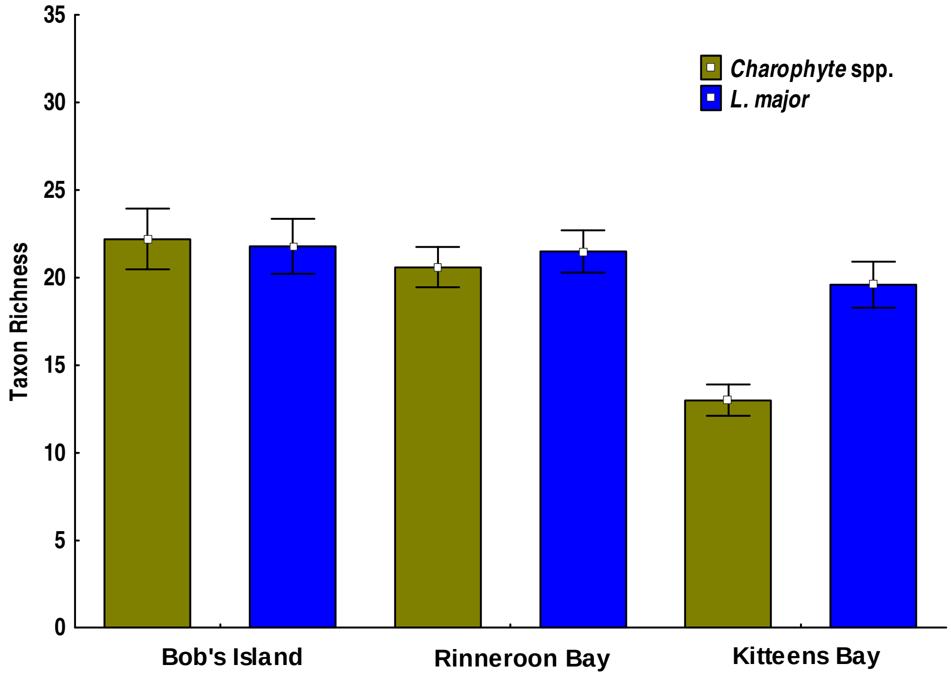

Figure 3: Comparison of the taxon richness of the invertebrate fauna collected on Charophyte spp. and *L. major* in three bays of Lough Corrib in June 2008.

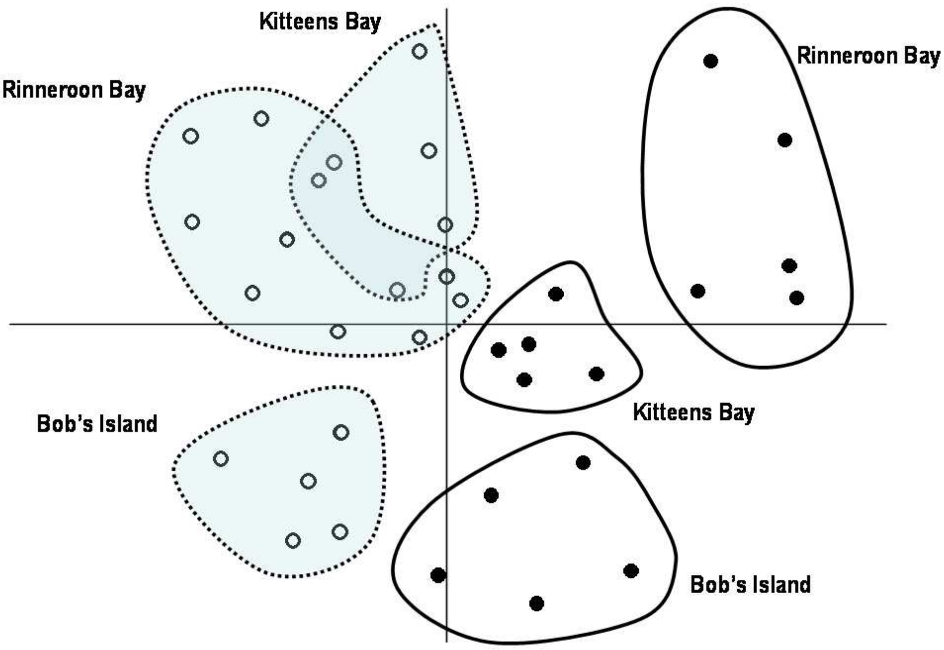

Figure 4: MDS plot of the invertebrate communities collected on Charophyte spp. (closed circles) and *L. major* (open circles) in three bays in Lough Corrib collected in June 2008.

Invertebrate abundance

Significant differences in the invertebrate abundances were recorded between Charophyte spp. and *L. major* samples in all the bays (Figure 5). The largest differences were recorded in Kitteens bay. In order to determine if there is a particular association of the invertebrates to *L. major* the abundances were corrected for plant volume sampled. Consistently, Charophytes spp. samples were small due to the plant architecture in the bays. When abundances were corrected for volume there were still some significant differences in abundances (Kitteens Bay), but were similar in Bob's Island (Figure 6). This indicates that the density of invertebrates on the two plants species are similar per unit volume in some bays (Bob's Island), but generally higher on *L. major* in others (Rinneroon and Kitteens Bay).

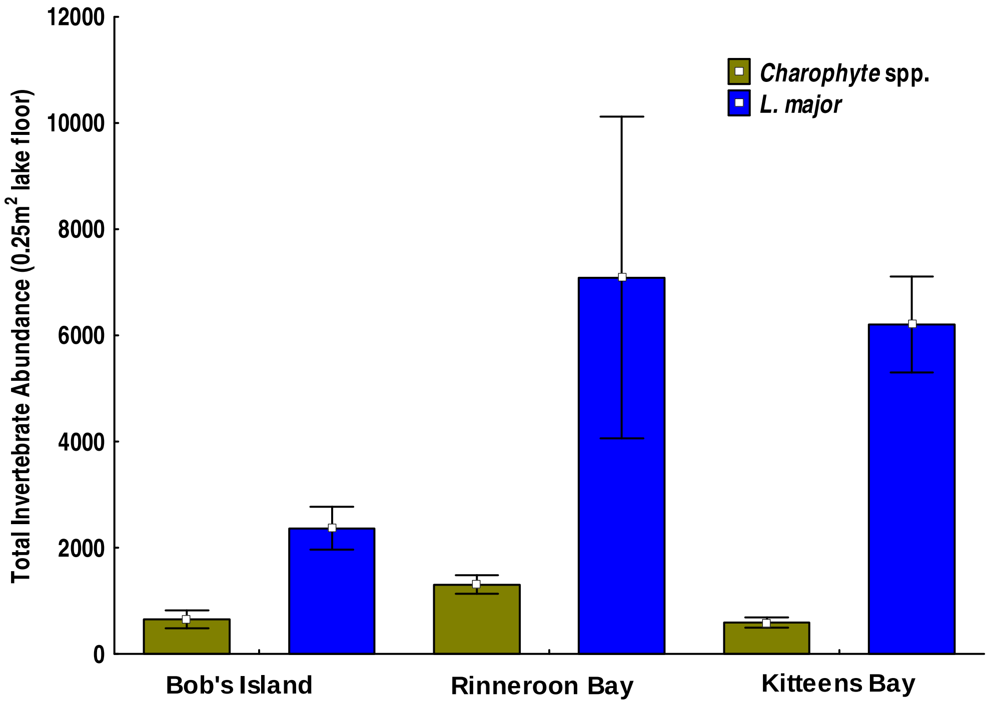

Figure 5: Total invertebrate abundance (per $0.25m^2$ of lake floor) collected on Charophyte spp. and *L. major* in three bays of Lough Corrib.

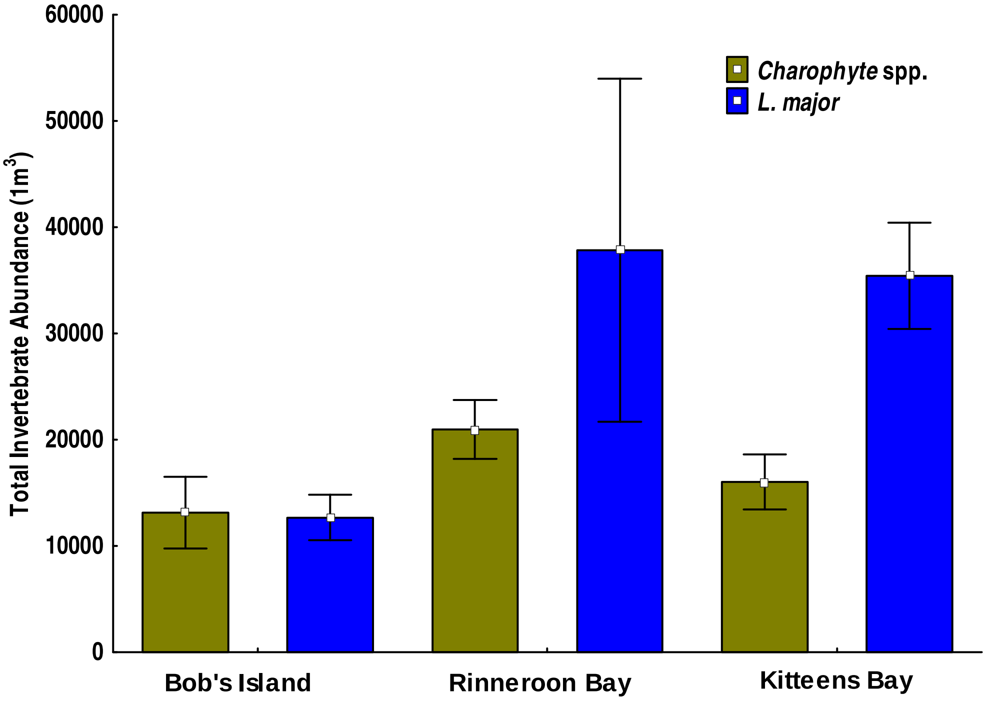

Figure 6: Total invertebrate abundance per $1m^3$ of plant material of Charophyte spp. and *L. major* in three bays of Lough Corrib.

When the taxa abundances are assessed in relation to the entire invertebrate abundances (relative abundance and accumulative relative abundances) some interesting patterns are noted. There is a notable consistent difference in the number of taxa that contribute to the significant portion (80%) of the overall invertebrate abundance between the two plants surveyed (Figure 7). In Bob's island 8 and 3 species, Rinneroon Bay 4 and 2 species, Kitteens Bay 5 and 3 contribute to <90% of the overall abundances on Charophyte spp. and *L. major* plants respectively (Figure 7). There is a clear spread of species that contribute to the overall abundance on Charophyte spp. indicating that there are only a few taxa that make up the majority of the invertebrate abundances on *L. major*, representing a relatively more uneven community structure on the exotic plant.

Invertebrate distribution in L. major *stands*

The invertebrate samples were maintained in the various depth categories (A- 2.4 to 3.2m; B- 1.6 to 2.4m; C- 0.8 to 1.6m; D- 0 to 0.8m) to assess the differences in the invertebrate communities found at the various depths throughout the water column. A cluster analysis indicates that there is a significant overlap in the communities between the depths (A to D), but again indicates that the communities found in the different bays were significantly different (Figure 8). The differences between the depths within each of the bays are not significant using ANOSIM ($p>0.05$). There are however notable differences in the distribution of individual taxa, which show affinities to the plant material close to the surface of the water (A and B to a depth of 1.6m). This is particularly the case for Chironomidae and the crustacean *Crangonyx pseudogracilis* (Figure 9a & b). The distribution of molluscs vary between species, with both *Bithynia tentaculata* and *R. balthica* occurring throughout the water column with larger numbers occurring at the base of stands and near the water surface (Figure 9c & d). *B. tentaculata* and *R. balthica* seem to increase with increasing biomass of Charophyte spp. ($r^2 = 0.89$, $n= 15$, $p<0.05$, and $r^2 = 0.74$, $n= 15$, $p<0.05$), but this relationship is not significant on *L. major* ($r^2 = 0.01$, $n = 41$, $p>0.05$, $r^2 = 0.01$, $n = 41$, $p>0.05$). The results in general show that the distribution of the taxa is largely altered on *L. major*.

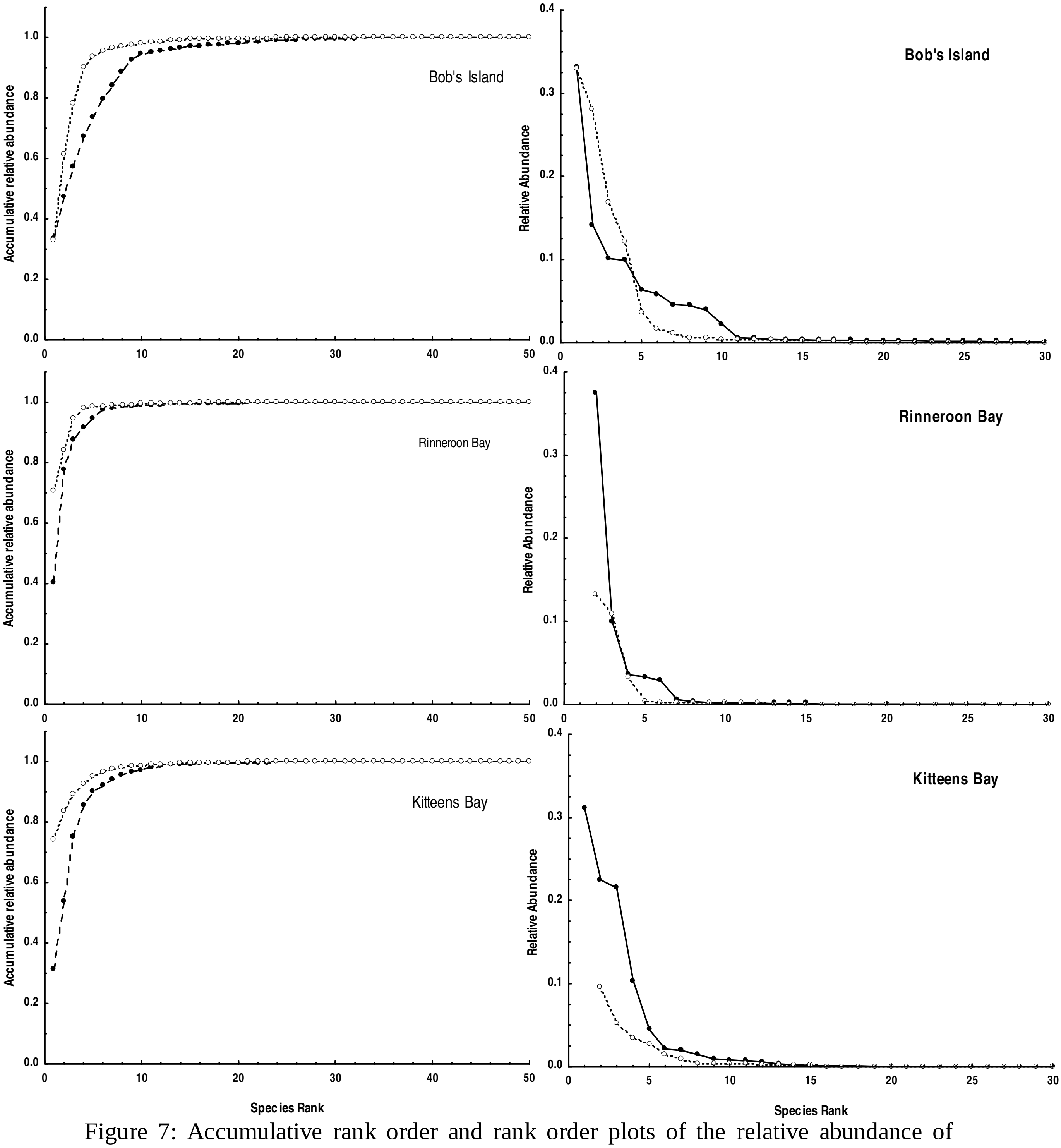

Figure 7: Accumulative rank order and rank order plots of the relative abundance of invertebrate taxa collected on Charophyte spp. (closed circle) and *L. major* (open circle) in three bays of Lough Corrib in June 2008.

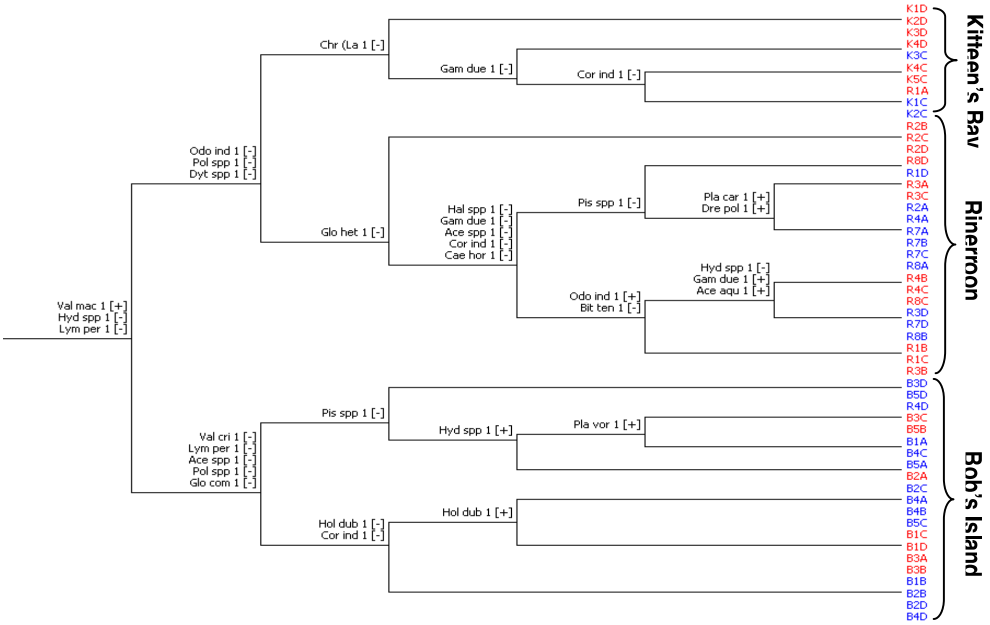

Figure 8: TWINSPAN analysis (presence/absence) of the invertebrate communities collected from four different depth categories (A- 2.4 to 3.2m; B- 1.6 to 2.4m; C- 0.8 to 1.6m; D- 0 to 0.8m) of *L. major* in three bays in Lough Corrib in June 2008.

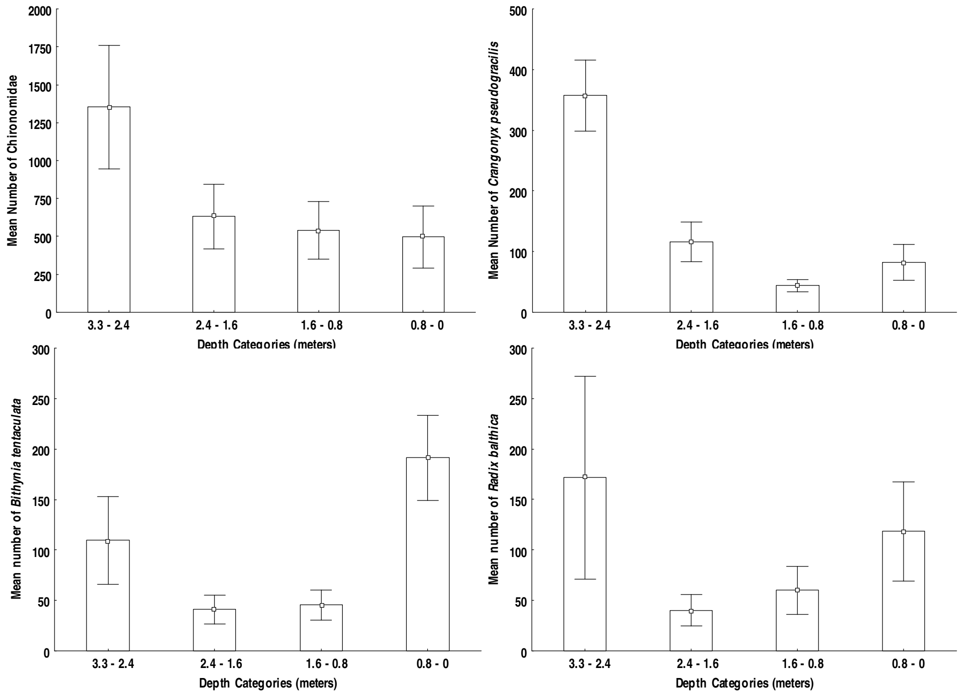

Figure 9: The mean number of individuals of Chironomidae (a), *Crangonyx psuedogracilis* (b), *Bithynia tentaculata* (), and *Radix balthica* (d) collected on *L. major*

from the various depth categories throughout the water column (water surface about 3.2m).

This may be as a result of a number of factors, amongst others, architecture of the plant, increased amount of food supply (like periphyton) and reduced predation pressure.

Invertebrate biomass

When the invertebrate numbers are converted to biomass (DW g) there is no consistent pattern in the difference between the plant species and bays sampled (Figure 10). In some bays there is a higher biomass on *L. major* (Bob's Island and Kitteens Bay) and in Rinerroon Bay there was a higher biomass on Charophyte spp. (Figure 10). When the biomass was corrected for plant volume the biomass was similar on the two plant species at two of the bays but there was still a significantly higher biomass on the Charophyte spp. in Rinerroon Bay (Figure 11). This indicates that if similar amounts of plant material are compared that there is a similar or higher invertebrate biomass on Charophyte spp. compared to *L. major*.

The majority of the invertebrate biomass is attributed to the high numbers of gastropods, with a high percentage biomass of the overall invertebrate weights made up of a single species *Bithynia tentaculata* (Figure 12). The mean contribution of this species varied between 64 and 95%. When the weights were removed from the data and corrected for volume the patterns in the difference between the two plants were again variable, ranging from higher biomass on Charophyte spp. in Bob's Island and lower in Kitteens Bay (Figure 13).

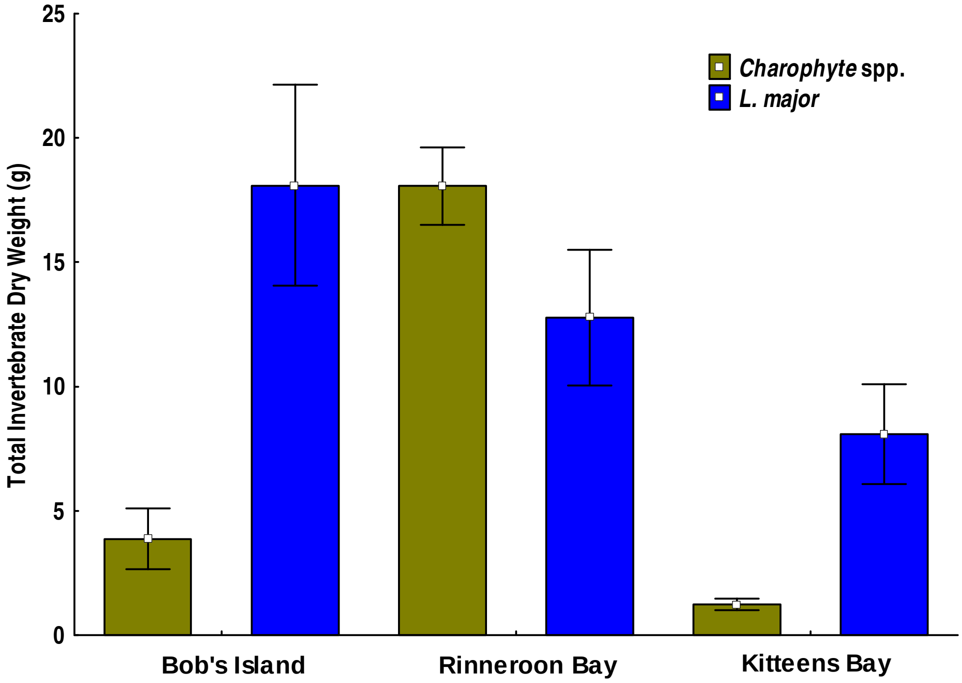

Figure 10: Total invertebrate biomass (g DW) collected on Charophyte spp. and *Lagarosiphon major* in three bays in Lough Corrib (per 0.25m^2 lake bottom).

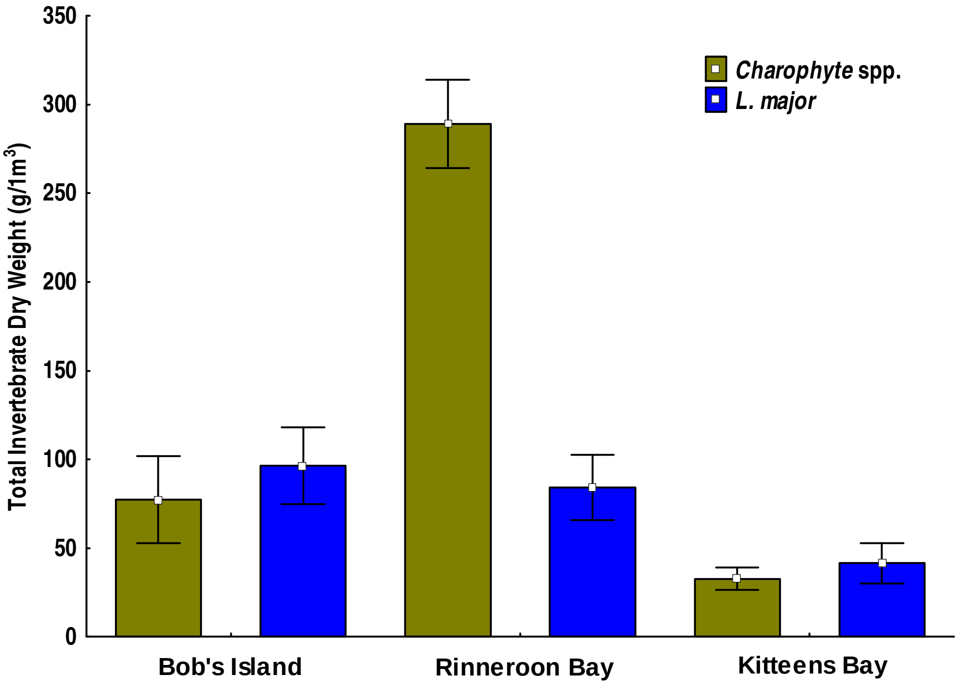

Figure 11: Total invertebrate biomass (g DW) per unit volume (1m^3) of Charophyte spp.

and *Lagarosiphon major* collected in three bays in Lough Corrib.

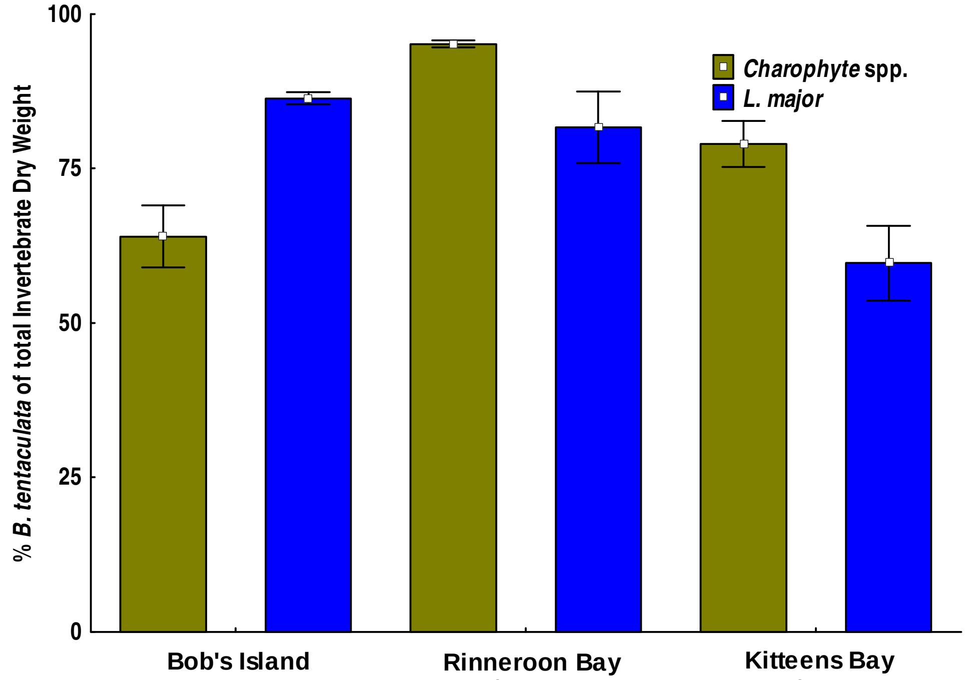

Figure 12: The percentage biomass of *Bithynia tentaculata* of the total invertebrate DW per unit volume ($1m^3$) of Charophyte spp. and *Lagarosiphon major* collected in three bays in Lough Corrib.

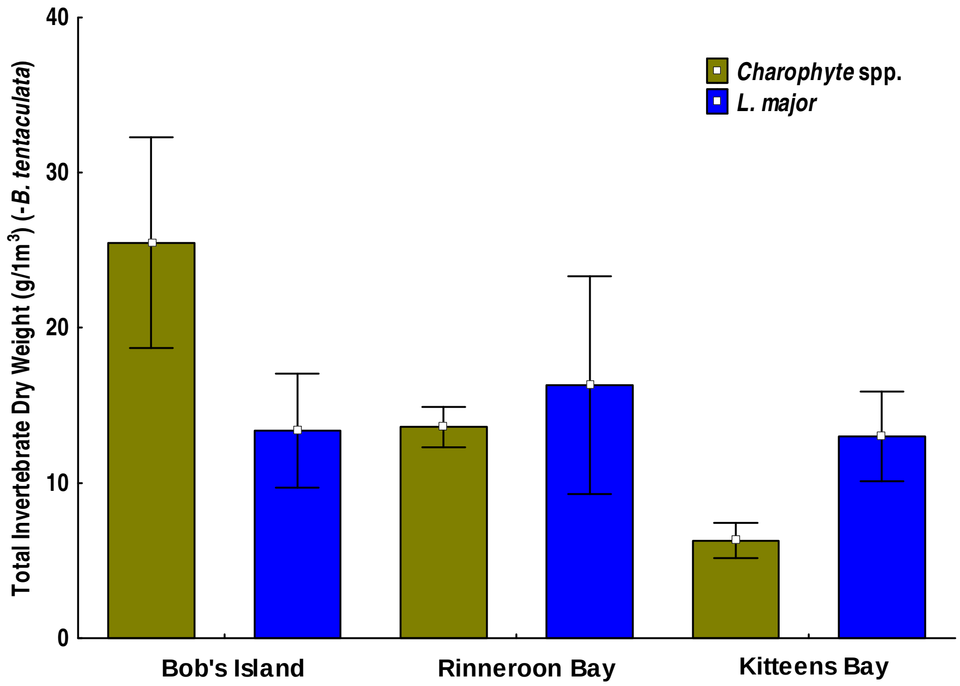

Figure 13: Invertebrate biomass (g DW) per unit volume ($1m^3$) of Charophyte spp. and *Lagarosiphon major* collected in three bays in Lough Corrib with *Bithynia tentaculata* removed.

Macrophyte growth and biomass

There were significant differences between the biomass (DW g) of Charophyte spp. and *L. major* samples taken at each of the bays (Figures 14 to 16). In each bay the mean biomass of *L. major* was significantly higher, with the exception of August samples where the biomass was similar for both species in Kitteens Bay (Figure 16). As would have been expected the biomass of Charophyte spp. in most bays peaked in August and decreased slightly in October. The *L. major* plants clearly show that the vertical structure and overall biomass per sample varied between bays and between sampling dates (Figures 14 to 16). Plants show a marked change in the growth structure over this 5 month period (clearly visible in Bob's Island and Rinneroon Bay), with a surface dominance in plant biomass in June followed by a collapse of the plant recorded in August (where long strands were seen along the bottom substrate) and a re-growth to the surface as indicated by the October samples. This cycle of plant growth is notably different in the bays (particularly in Kitteens Bay), which probably result from differences in factors amongst others like currents, depth profiles, and temperatures.

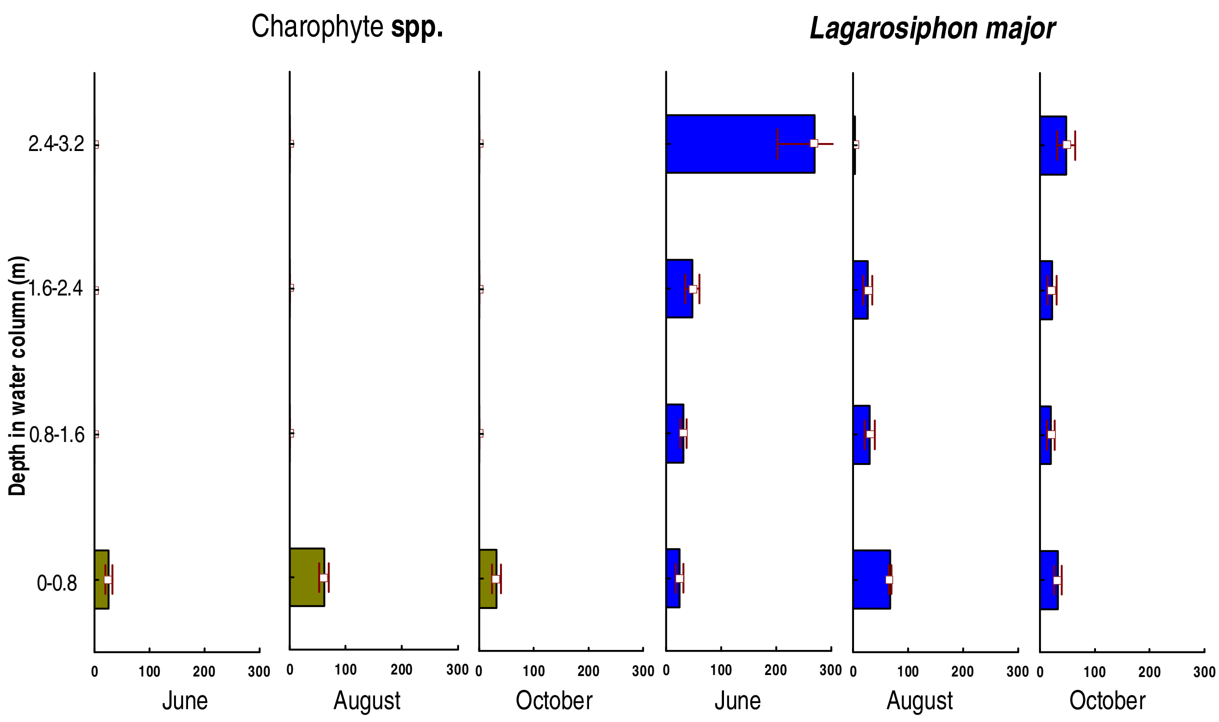

Figure 14: Plant biomass (g Dry Weight) of Charophyte spp. and *L. major* at various depth categories collected in Bob's Island in June, August and October 2008.

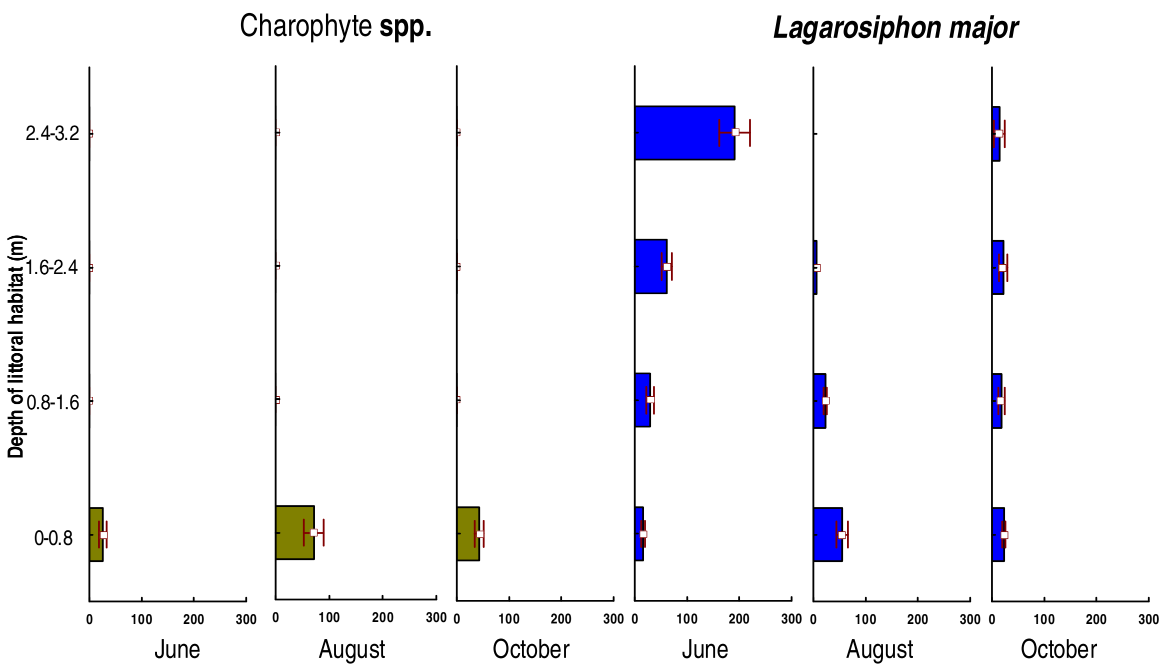

Figure 15: Plant biomass (g Dry Weight) of Charophyte spp. and *L. major* at various depth categories collected in Rinneroon Bay in June, August and October 2008.

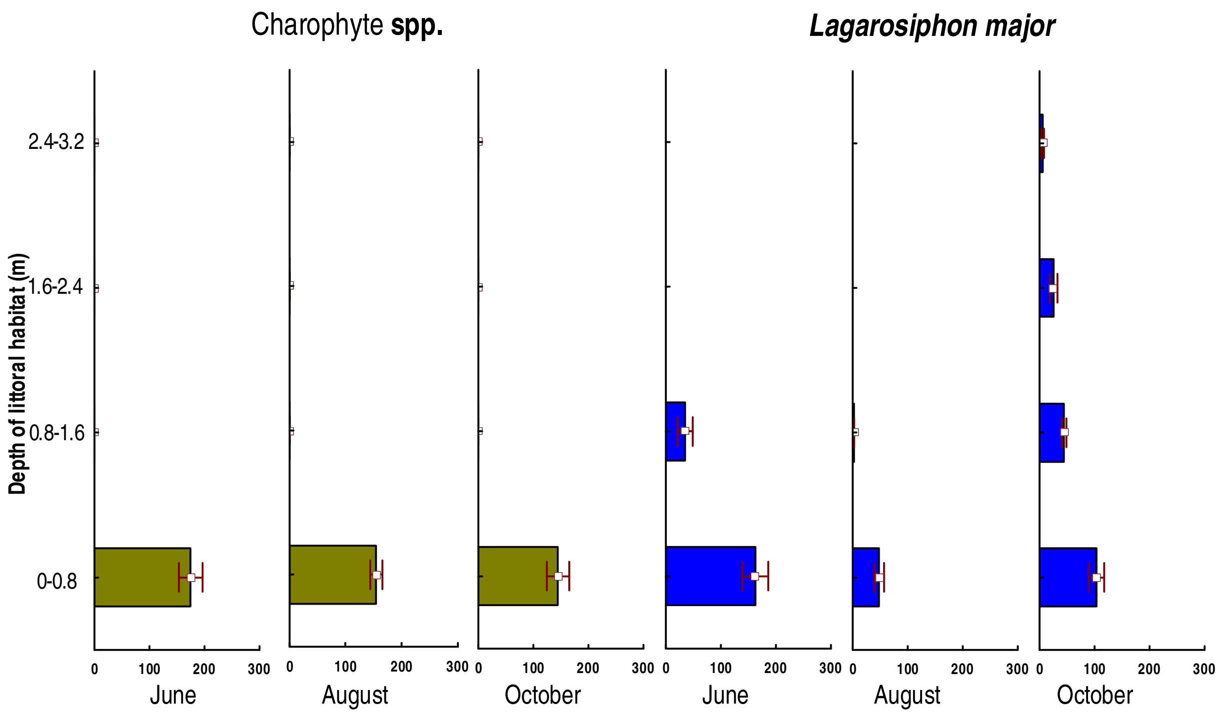

Figure 16: Plant biomass (g Dry Weight) of Charophyte spp. and *L. major* at various depth categories collected in Kitteens Bay in June, August and October 2008.

Monitored Quadrats

Plots were established in May 2008 in four bays in Lough Corrib, but one bay was disrupted during mechanical control operations. The results show that the height of Charophyte spp. increased during the growth season at all of the bays (between May and August) (Figure 17). The quadrats seeded with *L. major* shoots established well and grew rapidly during the same period. It is noteworthy that the growth rates of seeded quadrats of *L. major* in the three bays were appreciably different. This was more evident in the percentage cover attained by seeded quadrats in each bay by August, with 23.0 (±3.0), 16.8 (±1.9), 8.0 (±1.2) in Bob's Island, Rinneroon Bay and Curraraevagh Bay respectively. Changes were recorded in the heights of *L. major* again reflecting the changes in the plant structure during the year within the water column in areas with 100% cover.

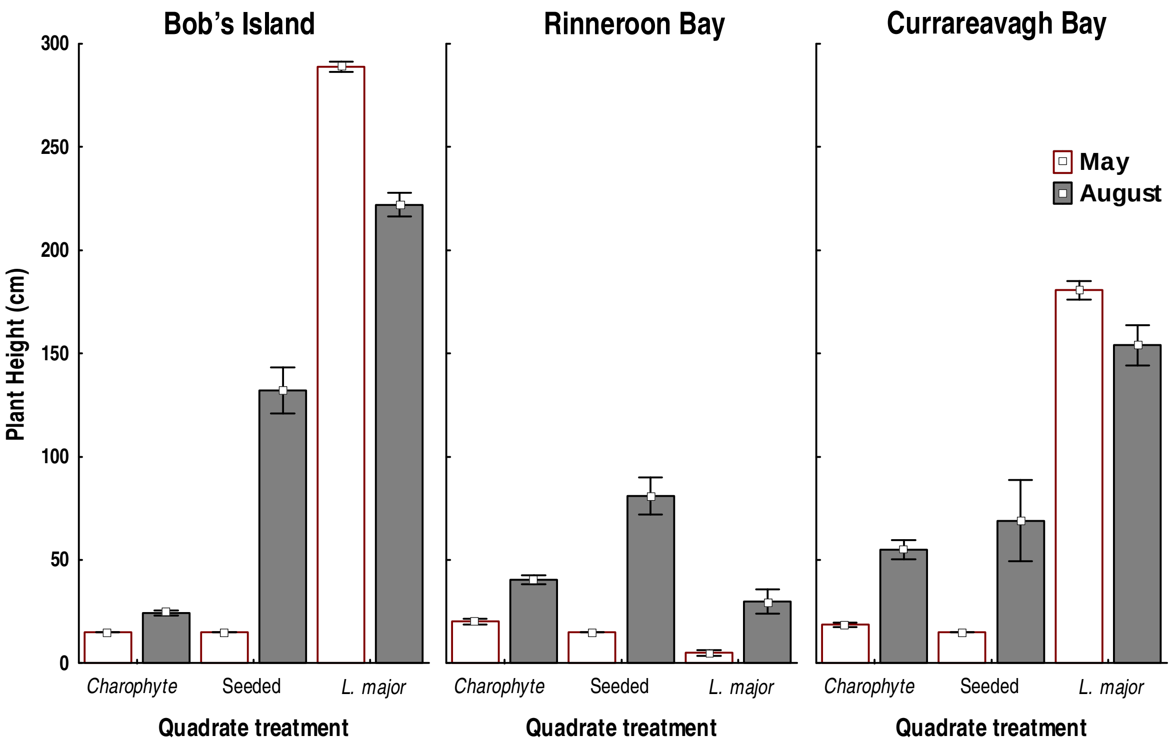

Figure 17: Mean plant heights (±SE) of quadrats (0.25m^2) monitored at three bays in Lough Corrib, with three treatments, including Charophyte spp. (100% cover), Seeded quadrats with *Lagarosiphon* shoots (cover increased from 2 in May to 25% in August), *L. major* (100%), except Rinerroon where *L. major* represents a mechanically controlled area (>1% cover in May).

The temperatures within the Charophyte spp. and *L. major* were not different within each bay. Temperatures between bays however did vary with temperatures largely 0.5 to 1 degrees higher in Currarevagh Bay compared to Bob's Island (Figure 18). The differences in temperature are probably enough to result in different growth rates of plants at each of the bays, but seem to be contrary to expectation that plants in higher temperatures grow faster during summer. This suggests that *L. major* grows better in cooler temperatures as is evident during the winter months in Lough Corrib, when the plants flourish.

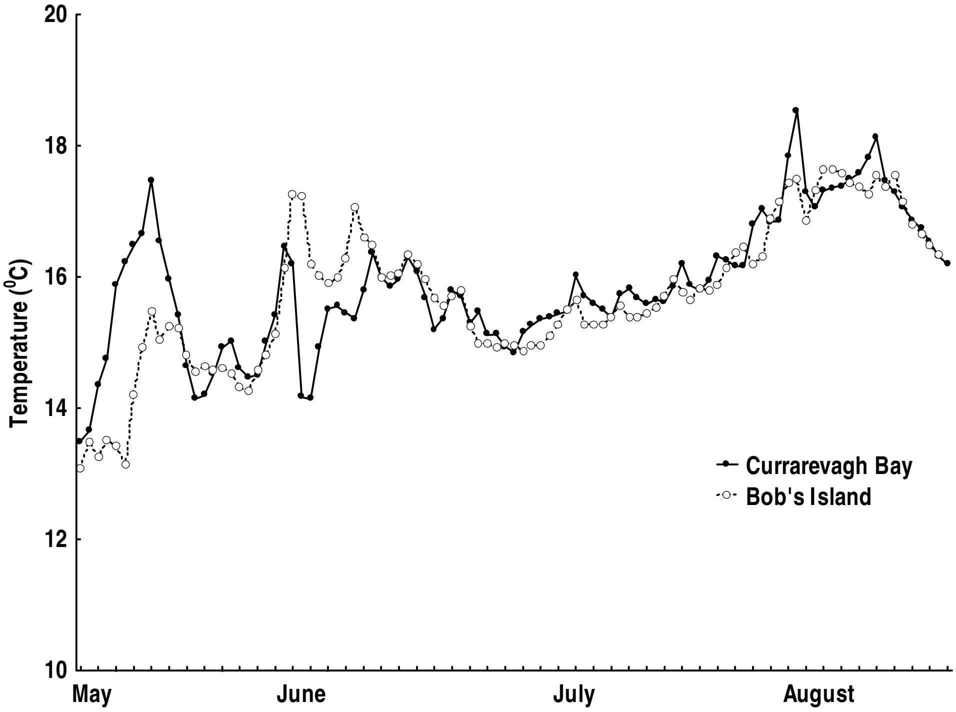

Figure 18: Mean daily temperature recorded within *L. major* stands (circa 0.6m above the lake substrate) at an hourly interval in two bays in Lough Corrib, Bob's Island and Currarevagh Bay.

Discussion

The results from a single period in the summer show that there are notable differences in the invertebrate fauna between the native Charophyte spp. and the introduced invasive species *L. major*. The patterns are not consistent between different bays, and depending on the measure (richness, abundance and biomass) the native plant habitat show higher values in some cases and lower in others compared to the exotic plant habitat. The species richness was similar on the two plant habitats, but the community composition was distinctly different and consistently so between bays. This has also been found with the invasion of other submersed species such as *Hydrilla verticillata* (Theel *et al*., 2008), where differences were found in some of the measures and not others. Furthermore, the invertebrate communities in Lough Corrib were noticeably different in the different bays on the same type of plant habitat with the greatest similarity between *L. major* plants in two of the bays. These spatial differences can be expected as many physical factors affect the distribution of invertebrates in littoral habitats (Champion and Tanner 2000).

There was a clear pattern in the overall abundance of invertebrates, with a higher number consistently recorded on *L. major*. However, it is noteworthy that this represents the actual condition in the various bays, and *L. major* is consistently different in plant architecture in comparison to the Charophyte spp. The individual values were therefore corrected for plant volume/DW and the differences between the plant types were reduced, and in at least one bay both plant types had similar abundance levels. Despite this, when the relative abundances of each taxa is compared the community structure is considerably different. Consistently, there were a higher number of taxa contributing to the overall abundances on the native plant habitat compared to the exotic plant habitat. This indicates that there are only a few taxa on the exotic stands that make up most of the invertebrate abundances. Lower species diversities may make the invertebrate community less resilient to ecological change and therefore arguably more vulnerable. Furthermore, this indicates that these communities are less diverse and although other trophic levels such as fish are shown to be opportunistic in their feeding strategy (Kennedy and Fitzmaurice, 1971; Kelly-Quinn and Bracken, 1990; Amundsen *et al*., 2001; Ormerod *et al*., 2004) they will be dependent on a smaller complex of invertebrates within the *L. major* stands. The structural complexity of the macrophyte habitat has also been shown to influence the feeding patterns of fish (Dibble *et al*., 1996; Warfe and Barmuta, 2006), and may result in higher levels of predation. The consequences of these changes indicate that the changes in the richness, abundance, composition and biomass of the invertebrate community are likely to result in a knock-on affect on the trophic web structure of littoral ecosystems in Lough Corrib. This is particularly so because the change in plant habitat with the introduction of *L. major* which occupies almost the entire water column (3-4m) is very different to the carpet like plant habitat of Charophyte spp. (0.2 to 0.8m).

When the biomass of the invertebrates are considered there is no consistent pattern between bays but there were always differences between plant habitat types (native vs exotic) within each of the bays. However, when plant volume sampled was accounted for, the biomass per unit volume of plant was similar on the native and exotic plant habitat within the different bays. It is clear in this study, as has been recorded in other aquatic systems (Talbot and Ward, 1990), that the gastropods make up a large portion of the overall biomass. This is in part as a result of the inclusion of the shell of gastropods (Andersson *et al.*, 1994). When one of the most abundant species was removed from the weights, i.e. *Bithynia tentaculata* the biomass results showed differences in the plant habitats in some bays and not in others.

The results of this study representing one part of the growth season indicates that plant structure has a direct influence on several aspects of the invertebrate composition, as has been shown in many other studies (Brown *et al.*, 1988**;** Scheffer, 1998; Olson *et al*., 1999; McAbendroth *et al*., 2005; Theel *et al*., 2008). The plant biomass results indicate, and field observations confirm that *L. major* goes through a distinct growth pattern during the year and that the rate of these growth pattern changes are dependent on the local conditions within each bay. Despite the changes in plant architecture of *L. major* in the different months, the stands still occupied a comparatively larger part of the water column than the Charophyte spp. habitat. This is of significant consequence when the distribution patterns of individual invertebrate taxa are analysed, as certain species seem to have an association with the lower parts of the plant, such as Leptoceridae, and others with the upper canopy, such as *Crangonyx pseudogracilis*. It is likely that natural seasonal differences in the life history of each taxa will result in a change in invertebrate abundance and distribution through the *L. major* stands, but the changes in the growth forms will further affect the invertebrate composition in abundance and distribution. The lack of consistency in plant habitat has been shown to be affect invertebrate communities (Hargeby, 1990), and may result in erratic changes in the invertebrate communities and certain species may not be able to persist. These seasonal changes capturing the growth changes of the plant will be assessed when samples collected in August and October in 2008 and further samples scheduled to be collected in 2009 are processed.

Acknowledgements

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APPENDIX II

Survey of the *Lagarosiphon* species in South Africa for candidate biocontrol agents

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Executive summary

The alien invasive weed, *Lagarosiphon major* (Hydrocharitaceae) is a submersed aquatic macrophyte which poses a significant threat to water bodies in Ireland, Britain and mainland Europe. Relatively recent substantial infestations prove difficult to control using traditional control methods and biological control needs to be considered as an alternative, risk free, sustainable control option for the future. As one of the first stages of initiating a biocontrol programme a survey for natural enemies is required in the country of origin to assess the availability of promising candidate agents. *Lagarosiphon* species are native to the African continent and a short-term survey was conducted in South Africa to assess the presence of suitable candidate agents and initiate collaborative efforts with an appropriate institution. Several phytophagous species were recorded for the first time, with at least three showing notable promise as candidate agents that warrant further consideration. Amongst these a leaf-mining fly, prob. *Hydrellia* sp. (Ephydridae) causes significant leaf damage and occurred over a wide distribution despite high levels of parasitism by braconid wasps. Another fly was recorded mining the stem of *L. major* but specimens are as yet unidentified. A small weevil, cf. *Bagous* sp. (Curculionidae) was recorded at two sites and seems to mine the shoot tips stunting the growth of the main stem. Several leaf feeding lepidopteran species were recorded with relative frequency, but are expected to feed on a wide range of plant species and as a result are unsuitable as candidate agents when other species show better promise. Similar complexes of natural enemies have been found on related plant species on other continents and some have previously been released as biocontrol agents in the USA on *Hydrilla verticillata*. Lessons from well established biocontrol programmes provide valuable insights into the potential of the species recorded on *L. major* in South Africa as biocontrol candidates for Europe.

Introduction

Oxygen weed, *Lagarosiphon major* (Ridl.) Moss ex Wager (Hydrocharitaceae) is a submersed invasive macrophyte found in several countries in western Europe (Symoens and Triest, 1983; Preston *et al*., 2002; Reynolds, 2002; Stokes *et al*., 2004; van Valkenburg and Pot, 2007) and New Zealand (McGregor and Gourlay, 2002). Despite first being recorded in Ireland in 1966 (Symoens and Triest, 1983), it has only become noticeably invasive in the past few decades and discovered in Lough Corrib in 2005 (Gavin *et al*., 2007; Caffrey *et al*. 2007). Where the infestations of the weed occur the entire constructed water bodies is often occupied and monocultures also dominate large bays in natural lakes, such as Lough Corrib (in excess of 10 000m^2). These significant infestations, although conventional control methods are somewhat effective, require the consideration of alternative methods of control like biological control if we are to achieve a sustainable solution in the future. This is becoming more important since many herbicides are being de-registered and the application of chemicals in waterways is considered inappropriate (see Shaw, 2007; Water Framework Directive, EU, 2000).

Invasive, free-floating and emergent aquatic weeds are amongst the weed species in Europe considered good targets for classical biological control (Sheppard *et al*., 2005). Biological control by definition is the use of living organisms to control pest species, and is an attractive weed control method as it is a strategy that restores the natural balance by releasing natural enemies previously associated with the weed in its country of origin into the introduced range. Natural enemies or biocontrol agents may include a single or a suite of organisms (largely insects, see Julien and Griffiths, 1998) damaging different plant parts or may include pathogens, like a fungus. The approach has been employed for more than a century and has resulted in some of the most spectacular simple solutions to complex ecological problems (MacFadyen, 1998). A number of the world’s worst invasive species, which include aquatic plants have been successfully controlled in other parts of the world using integrated management programmes that were dependant on biological control (Charudattan, 2001; Hill, 2003; McConnachie *et al*., 2004).

The control of submersed plants presents a particular challenge as most biocontrol programmes have focused on terrestrial and free-floating aquatic plant invaders, with little attention given to submersed plant species in the past. One recent exception is *Hydrilla verticillata* (L.f.) Royle, where two curculionid beetles *Bagous affinis* and *Bagous hydrillae* and two ephydrid flies *Hydrellia pakistanae* and *Hydrellia balciunasi* were released as biocontrol agents in the USA (Balciunas and Burrows, 1996; Gordowitz *et al*., 1997; Julien and Griffiths, 1998). Many submersed weeds do present a significant threat to aquatic and riparian habitats (Charudattan, 2001) and certainly warrant further attention. Many species in the family Hydrocharitaceae, like *Egeria densa* Planchon, *Elodea canadensis* Michx, *Elodea nutallii* (Planchon), *Hydrilla verticillata* are all significant weeds in Europe (Preston *et al*., 2002; DAISIE, www.europe-aliens.org). Biological control investigations have been initiated on these and other submersed weeds, like *Cabomba caroliniana* Gray, with some surveys in the countries of origin revealing promising candidate agents (Schooler *et al*., 2006; Cabrera Walsh *et al*., 2007; Schooler *et al*., 2007). Prospects for the biocontrol of *L. major* had been considered for New Zealand, but a biological control programme has not been initiated there as other species were considered to be of higher priority (McGregor and Gourlay, 2002). However, according to Sheppard *et al*. (2005) species like *L. major* may become suitable target species for biological control if surveys of natural enemies in the country of origin are completed. Indeed, a short-term survey was completed in South Africa at two sites (Schutz, 2007), but no notably promising agents had been discovered.

The genus *Lagarosiphon* is native to sub Saharan Africa and nine species are described with variable distribution ranges throughout the continent including Madagascar (Wager, 1928; Symoens and Triest, 1983). In southern Africa *Lagarosiphon muscoides* Ridley and *L. major* are the most common species encountered, with most of the records of *L. major* occurring south of Zambia (from the Cape Province to Zimbabwe). Both *L. major* and *L. muscoides* are considered as noxious weeds in South Africa (Obermeyer, 1964 & 1966), and often proliferate in man made dams (Anonymous, 1980a & b). As a result of the extensive natural distribution range in southern Africa and rather localised surveys previously completed (Schutz, 2007) the aim of this study was to survey for natural enemies on *Lagarosiphon* species over a wider geographic range, with particular focus on

L. major. The survey would include sites from some of the most southerly records in Eastern Cape Province (~750m a.s.l.) to high altitude sites (1400 to 2000m a.s.l.) in Mpumalanga Province in South Africa.

Methods and Materials

A field survey was undertaken in November 2008 (12-23rd) by the authors as a collaborative project. Distribution records from SANBI (Fig. 1) and published literature (Symoens and Triest, 1983) were used to target localities where *L. major* had been recorded, and priority was given to sites with recent records where possible (some locality records date back to the 1890s). In suitable climatic areas further impoundments were surveyed, and additional site records held by Rhodes University were also visited. At each site plants were assessed for damage, which was collected for dissection and rearing. Different types of damage were assessed under microscopes and material was kept cool for rearing out the adult stages of the specimens collected. Specimens were sent to relevant experts for identification. The plant material collected at each site was sent to Dr Rene Glen and Lesley Henderson (PPRI) for confirmation and tentatively identified in the field using Cook (2004). At each site hydrochemical parameters were recorded with a hand held meter in order to characterise the water, including Temperature (°C), pH, Conductivity (µS/s), Total Dissolved Solids (ppm), Sodium Chloride (NaCl, ppm), and Dissolved Oxygen (mg/l & % saturation). A water sample was collected at each site using a sterile specimen tube and fixed using HCl. Samples were sent for nutrient analysis.

Results

The survey was conducted from the 12th to the 23rd November 2008, and coincides with the spring period a few weeks after the rainfalls usually start in the eastern regions of South Africa. In excess of 65 sites were assessed although 34 sites were surveyed in some detail (Figure 1). The macrophyte stand encountered showed signs of vigorous growth, and both *L. major* and *L. muscoides* were regularly encountered (Plate 1a & b).

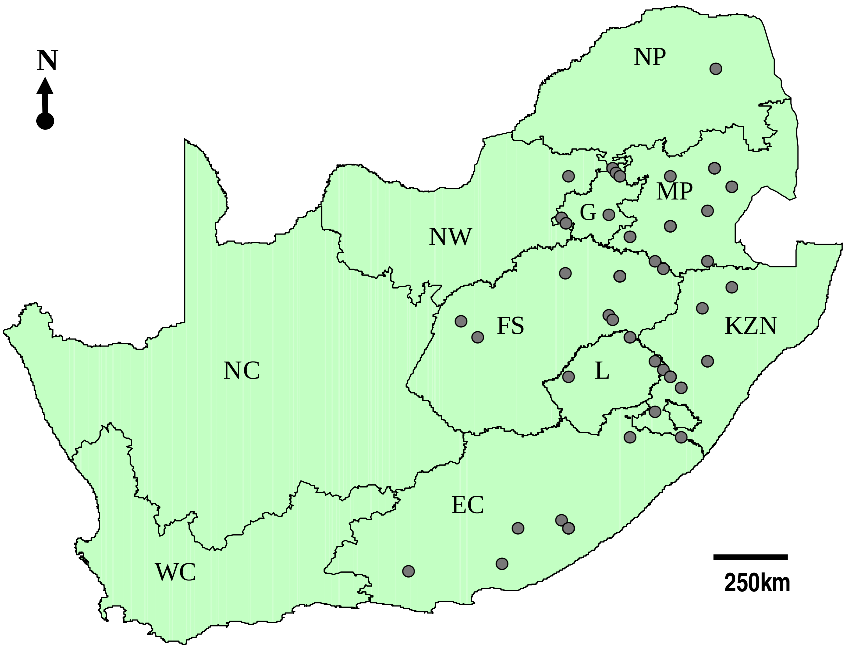

Figure 1: Distribution records of *L. major* in South Africa held by South African National Biodiversity Institute (SANBI). GT – Gauteng, MP – Mpumalanga, NP – Northern, NW – Northwest, KZN – Kwa-Zulu Natal, EC – Eastern Cape, WC – Western Cape, NC – Northern Cape, FS - Free State, L – Lesotho.

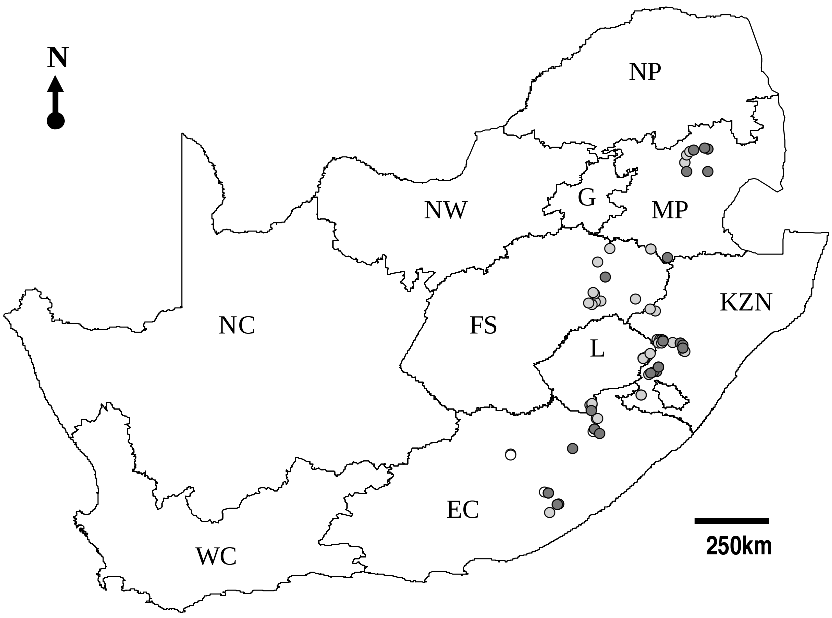

Figure 2: Distribution of sites sampled in South Africa. Sites where *L. major* (dark grey circles), *L. muscoides* (light grey circles) and no *Lagarosiphon* was recorded (open circles) during the survey. GT – Gauteng, MP – Mpumalanga, NP – Northern, NW – Northwest, KZN – Kwa-Zulu Natal, EC – Eastern Cape, WC – Western Cape, NC – Northern Cape, FS - Free State, L – Lesotho.

At most sites male and female reproductive structures were visible (Plate 2a & b). With the recent rains many dams were coloured from runoff but plants were by and large visible on the surface of the water particularly *L. major*.

Plants were usually accessible from the bank occurring in less than 1.5m depths, with some ponds only having a depth of circa 0.5m. As a result most parts of the plants were accessible while wading into the water and rhizomes and roots were usually inspected for feeding damage and abnormalities ascribable to natural enemy damage (proportionately less time was spent searching amongst the rhizomes and roots of plants and the results may underestimate the presence of root feeding organisms).

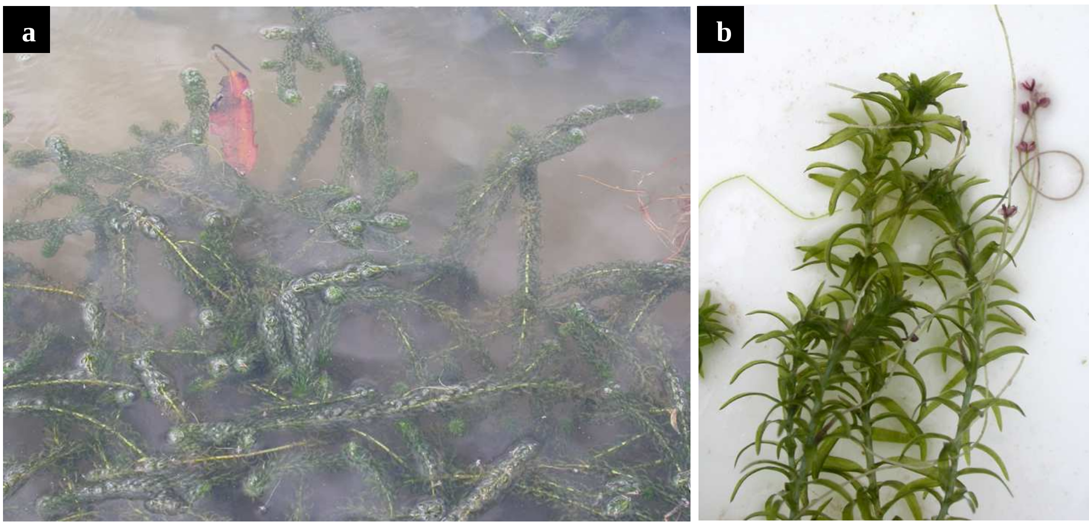

Plate 1: General morphology of the two main species, *Lagarosiphon major* (a) and *L. muscoides* (b) surveyed in South Africa.

Sites surveyed included mostly man made dams (Plate 3a) and reservoirs, what appeared to be natural lakes and also some rivers (Plate 3b) and streams. Stands of *L. major* ranged from small clumps amongst beds of *L. muscoides* along the edges of dams to large beds occupying the entire water column of small dams. Where *L. major* was recorded in rivers the stands were generally much smaller, with the exception of a slow flowing large river, Mooi River (near Rosetta, Kwa-ZuluNatal) where large stands occurred on the river banks stretching for at least a few hundred meters (occupying up to ~25% of the channel width).

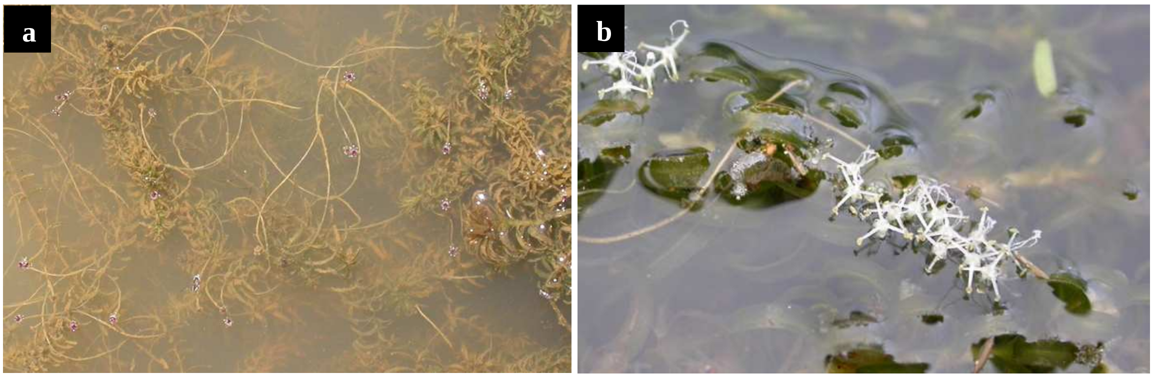

Plate 2: Female (a) and male (b, circa 1.0mm) reproductive structures of *L. major* recorded at most sites surveyed in South Africa. Male structures floating on the water surface are attracted to the depressions formed by the female flower which facilitates pollination.

Plate 3: Sites surveyed in South Africa including man made dams (a) (Dam on Sani Pass Road), and slow flowing rivers (b) (Mooi River in Kwa-Zulu Natal).

Water chemistry

The water chemistry characteristics serve to characterise the sites and compare sites where the two *Lagarosiphon* species were recorded (Table 1). The habitats varied considerably where the two species were recorded, from rivers to reservoirs to shallow natural and man-made ponds. The values recorded for each of these parameters reflect this diversity of habitats, but there are characteristics worth noting. Temperature is a variable parameter that fluctuates daily (in a 24 hour cycle) and sites were visited at different times of the day and could therefore not be directly compared. However, water temperatures were considerably warmer (maximum of 29.1) than that recorded during summer in Ireland (although winter temperatures in these areas are very cold). Most of the sites had high conductivity levels, and were all basic with pH levels well over 8.00. Many of the sites visited were also maintained as a salmonid fishery and the dissolved oxygen levels somewhat reflect clean water conditions, although in highly vegetated small ponds the oxygen reached super saturation levels of over 160%. In general sites had relatively low TDS values, with the notable exception of sites with high levels of pollution evident arising from the catchment.

Table 1: Depth, temperature and water chemistry characteristics of sites surveyed for *L. major* and *L. muscoides* in South Africa.

Parameter	***L. major***	***n***	***L. muscoides***	***n***
Depth (m)	0.85 ± 0.05	22	0.89 ± 0.05	14
Temperature (°C)	21.8 ± 0.8	21	22.3 ± 0.7	10
pH	8.21 ± 0.24	21	8.83 ± 0.37	11
Conductivity (µS/s)	337.2 ± 87.0	21	252.7 ± 38.0	11
NaCl (ppm)	105.9 ± 26.0	21	79.9 ± 10.8	11
TDS (ppm)	157.2 ± 45.6	21	112.7 ± 17.3	11
DO (%)	102.4 ± 8.5	21	118.6 ± 10.9	11
DO (mg/l)	8.96 ± 0.70	21	10.58 ± 0.91	11

Values quoted as mean ± Standard Errors

Phytophagous natural enemies

Many aquatic invertebrates were found amongst the plant material but the focus of the survey was on likely phytophagous organisms feeding on the *Lagarosiphon* species. Several organisms were encountered that were mostly insect groups. In the absence of confirmed identities six types of damage were noted and are dealt with separately below. Specimens sent for identification are lodged at the National Collection of Insects (ARC – PPRI) in Pretoria.

Leaf-mining fly

The larvae of this species mines the leaves, and pupates within the leaf tissue from which the adult emerges. The larva feeds internally on the leaf chlorenchyma leaving the upper and lower epidermal layers intact (Plate 4bgreatly reducing the photosynthetic area. The larva moves between leaves and may feed on up to 15 leaves before pupating (Plate 4a). Eggs may be laid on shoot tips and larvae seem to affect the shoot tips and the stem elongates leaving the damage obvious further down the stem. The pre-pupa and pupa are noticeable within the leaf (Plate 4c & d), and may be quite hard to find sheltered by nearby leaves. Similar leaf mining species were noticed on *L. muscoides* and *L. major*, although these plants may support different species as the larva on *L. muscoides* (from Rooikrans Dam) were noticeably smaller than those collected elsewhere on *L. major* (their size may have been affected by resource availability). The fly larvae and pupae were noticeable at most of the sites surveyed. Although adults were reared from the material during the survey it was unclear how and where they laid eggs on the plant. Adults flies (Plate 4e) were kept alive for several days during transit with a supply of sugar water. The fly has been tentatively identified as an ephydrid fly, prob. *Hydrellia* sp. (Diptera: Ephydridae) (by Dr. M. W. Mansell through Biosystematics Division (BD) PPRI, to be confirmed by Dr Wayne Mattais, Smithsonian Institute, dipteran specialist). Similar fly larvae were also collected from *L. muscoides*, and await identification.

A braconid parasitoid was common at almost every site, many of the fly pupae collected in the field were parasitized (clearly darker than healthy pupae). Adult parasitoids were observed in the field searching and probing what appeared to be pre-pupae. The adults held a bubble of air between the wings and abdomen and walked over the plant material with reasonable speed while searching for larva or pupa. Specimens reared from one site have been identified as an *Ademon* sp. (Dr Gerhard Prinsloo, BD-PPRI; he said that about ten species are known from this genus from the USA, Europe, Africa and the orient and that the recorded hosts were ephydrid flies).

Plate 4: Leaf mining fly (prob. Ephydridae: Diptera) on *L. major*: typical leaf damage (a), fly larva feeding within the leaf tissue (b), fly larva pupating within the leaf (c), pupa close to emergence (eye spots visible) (d), Ephydrid adult fly, cf. *Hydrellia* sp. reared from pupa collected from the field (e).

Stem-mining fly

At a single site, larvae were noted burrowing down the stem of *L. major* stems (Plate 5a) (Lydenberg, Mpumalanga). A small number of affected stems were found at the site (Plate 5c), and only parasitoids were reared from the specimens collected. The larvae appeared larger than the leaf-mining flies, and burrows seemed to be in the outer layers of the stem (Plate 5b). Damage to the stem did not seem to stunt the growth of the main stem, but only a few specimens were collected and stems may support more than one larva at higher fly densities.

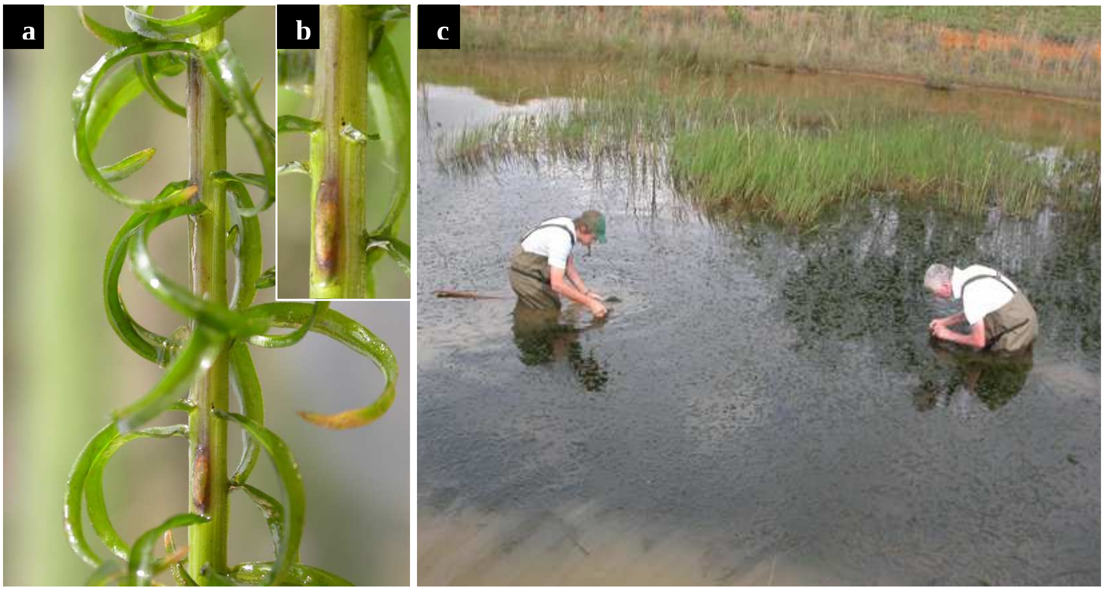

Plate 5: Stem-mining fly collected on *L. major* in a single site in South Africa. Stem with mining damage and fly pupa under a thin epidermal layer (a), close up of the pupa and tunnel in the main stem (b), fish hatchery in Lydenburg where the fly was collected (c).

Leaf-feeding lepidopteran

Damage attributed to leaf-feeding lepidopteran larvae was readily encountered at different sites. The leaves were cropped up to near the base and left stems leafless in areas along the length (Plate 6a). Feeding damage at times was noted to damage the stem and older feeding sites on stems were evident in places but rarely severed the stem entirely. Although identifications are not complete it is suspected at least two species were noted. These may include prob. *Synclita obliteralis* (Plate 6b & c) and prob. *Parapoynx* species (Plate 6e) (Lepidoptera: Crambidae, Nymphulinae) (family and subfamily confirmed by Vivienne M. Uys, BD – PPRI).

Plate 6: Leaf feeding Lepidoptera collected on *L. major* and *L. muscoides* in South Africa. Characteristic leaf feeding damage to shoots (a), leaf feeding larva of *Synclita* spp. (b), damage and larval case of *Synclita* sp. (c), adult moth of prob. *Synclita obliteralis* (d), larval case and damage of *Parapoynx* spp. (e).

Leaf and shoot feeding weevils

Two curculionid beetles were encountered at separate sites during the survey. They were quite distinct in size, with the smaller of the two collected at two of the sites (Plate 7a) (Roadside dam near Stutterheim and Kubusi Lake, EC) and the larger weevil at only one site (Plate 7c) (roadside pond, EC). Both were only encountered in the Eastern Cape, and subsequent collection trips conducted by the Rhodes University team at Kabusi proved unsuccessful in recovering any additional specimens. From maintaining the weevils during the collection trip it appeared that only the smaller weevil fed readily on the material. At the sites were the weevils were found the shoot tips of the plants were noted to be damaged (Plate 7b). The crowns of the main stems in many instances were damaged to such an extent that side shoots were produced (Plate 7d). It is expected that the larvae of the weevils burrow into the main stem, as eggs were found amongst the whorl of leaves at the shoot tip when weevils were maintained during the field trip. Adults fed on the leaves, and feeding damage was noticeable as elongated holes along the length of the leaf.

Six adults of the larger weevil were all collected at one site. The adults were hand collected off shoots close to the surface of the water. Adults were maintained on shoot tips and were relatively agile on the leaves of *Lagarosiphon*, suggesting an association between the weevil and the plant. However, observations on the plant material on which the weevils were kept suggest that the weevils were not feeding. During the field trip several adults died, and the last of the adults died in culture in the laboratory. Specimens were sent for identification and were confirmed to be a *Bagous* sp. (Coleoptera: Curculionidae, Bagoini) (Riaan Stals, BD-PPRI).

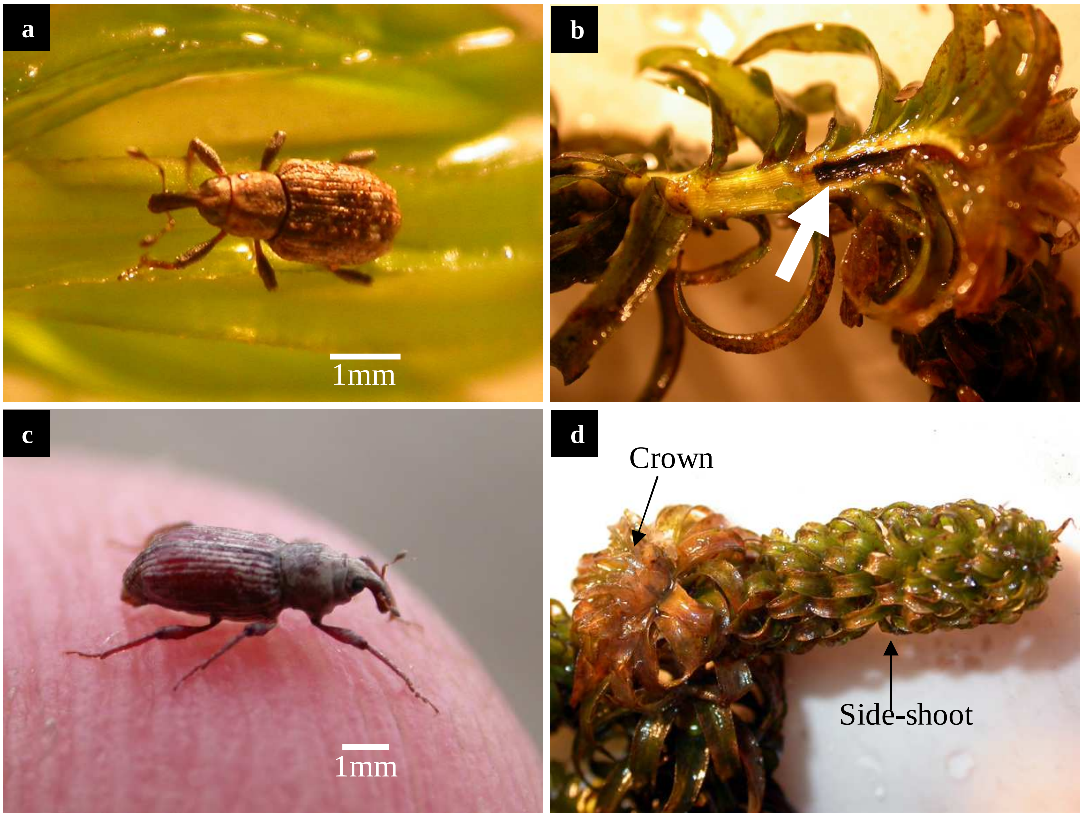

Plate 7: Crown and stem-mining weevils collected on *L. major* in South Africa. Smaller of the two adult weevils, *Bagous* sp. A (a), crown damage probably due to larval feeding damage (b), larger of the two adult weevils, *Bagous* sp. B (c), side-shoot stimulated by crown damage on the main stem (d).

Discussion

The survey resulted in the discovery of numerous species that fed and caused significant damage to *L. major* in the country of origin. It is the first large scale concerted survey conducted on this target weed in South Africa. As in many other submerged invasive plant species, like *Egeria densa*, *Hydrilla verticillata* and *Cabomba caroliniana* dedicated surveys in the country of origin have revealed a complex of phytophagous natural enemies (Balciunas and Center, 1981; Cabrera Walsh *et al.*, 2007; Schooler *et al.*, 2007). The most promising of these on this survey include the leaf-mining ephydrid fly prob. *Hydrellia* sp. (Diptera: Ephydridae). It was found to occur throughout the geographic range surveyed during the field trip and the characteristic damage to leaves was also noted occurring on many of the pressed specimens in the National Herbarium in

Pretoria (South Africa). *Hydrellia* flies seem to have a direct association with plant species in the family Hydrocharitaceae in different continents (evidence of co-evolution) and have been released and are considered as biocontrol candidates of several submersed species. Two *Hydrellia* species have been released on *Hydrilla verticillata* in USA (Balciunas and Burrows, 1996; Gordowitz *et al.*, 1997; Julien and Griffiths, 1998) and one of which is considered to cause significant damage to infestations in the field and in outdoor tanks (Doyle *et al.*, 2002; Doyle *et al.*, 2007; Owens *et al.*, 2007). In addition, impact surveys in South America show that a *Hydrellia* sp. on *Egeria densa* has a significant impact on the leaves (Cabrera Walsh *et al.*, 2007). The most encouraging aspect of this is that other biocontrol programmes exist on similar submerged plants and that the types of agents that seem to be performing well have now been discovered on *L. major* in South Africa. Furthermore, the specimens collected during the field trip are being reared at Rhodes University to initiate host specificity and impact studies and a parasitoid-free culture has already been achieved. Much time will be gained from the existence of similar programmes around the world as tried and tested techniques are already developed to rear and test similar flies in laboratory conditions (Balciunas and Center, 1981; Buckingham, 1988; Buckingham *et al.*, 1989; Buckingham *et al.*, 1991, Center, 1992; Grodowitz *et al.*, 1993; Grodowitz *et al.*, 1994; Balciunas and Burrows, 1996; Grodowitz *et al.*, 1997; Van *et al.*, 1998). The biocontrol programme in the USA has been implemented since the 1990's and provides reassuring evidence that agents like *Hydrellia pakistanae* and *Hydrellia balciunasi* are likely to be host specific and pose no significant threat to native plants. However, the host specificity of every candidate must be determined before the risks of a potential release in Europe can be assessed (see Bigler *et al.*, 2005; Shaw, 2007). It is noteworthy that there are no related species that are native to Europe within the Hydrocharitaceae, which improves the likelihood that candidate agents will be specific and pose no non-target risks of attack.

The complex of natural enemies found on *L. major* is notably similar to that discovered on *Hydrilla verticillata* on the Asian and Australian continent. This included the leaf-mining flies and two weevils, all of which were released as biocontrol agents in USA (Balciunas and Burrows, 1996; Gordowitz *et al.*, 1993; Gordowitz *et al.*, 1994; Gordowitz *et al.*, 1997; Julien and Griffiths, 1998). Small beetle species have been particularly successful as biocontrol agents and have resulted in the control of some of the world's worst aquatic and terrestrial weeds. These include the control of water hyacinth, *Eichhornia crassipes* (Mart.) Solms-Laubach (Center *et al*., 1999; Cilliers and Hill, 1999), *Myriophylum aquaticum* (Cilliers, 1999), water lettuce *Pistia stratiotes* L. and salvinia *Salvinia molesta* D.S. Mitchell (Hill, 2003). A small weevil, *Stenopelmus rufinasus* Gyllenhal has provided the most spectacular control of *Azolla filliculoides* Lamarck in South Africa where it was released as a biocontrol agent (McConnachie *et al.*, 2004) and controls this floating weed in Ireland where it arrived inadvertently (Baars and Caffrey, in prep.). It is encouraging therefore that two *Bagous* species were collected during the field survey, and observations on at least one of the species suggested that the damage induced was significant enough to stunt the growth of the main stem of *L. major*. There is some concern however in getting a confirmation of the species as the taxonomy of the Afrotropical Bagoinae is in a poor state of development. Only four species are described from South Africa, and recent revisions from Australia, Japan, India and western Palaearctic reveal the presence of numerous species and as-yet more undescribed species (Riaan Stals pers. comm.). With so few species described from South Africa it is likely that these collected from *L. major* may be undescribed species. This is a genus with few species known from South Africa. None of the few species known from South Africa appear to be of economic importance and the urgency of the review of this genus is low with no current research being undertaken.

Many aquatic plants in Ireland have been noted to be fed on by lepidopteran larvae. The leaf feeding moth, *Parapoynx stratiotata* (L.) has been recorded in southern parts of the UK (NHM, UK) and Ireland (Karsholt & van Nieukerken in Fauna Europaea), with known hosts including *Ceratophyllum* spp. (Ceratophyllaceae), *Elodea* spp. (Hydrocharitaceae), *Nuphar* spp. (Nymphaeaceae) and *Potemogeton* spp. (Potamogetonaceae). Similar host records suggest that lepidopteran species in the subfamily Nymphulinae have a wide host range and as a result are of no use from a biological control perspective.

The use of classical biological control has a history of very safe and successful programmes throughout the world, and its implementation in Ireland needs to be considered for our growing number of invasive weeds. Aquatic invasive plants present a particular threat to our native habitats and the use of mechanical and chemical control methods do not present a long term solution. Indeed, recurrent costs to control alien invasive species using anything other than biological control are unsustainable and expensive. Not all alien invasive species are suitable for biological control, but many are considered suitable (Sheppard *et al*., 2005) and with the discovery of a few promising natural enemies in this study *L. major* should also be considered as a suitable target species. In addition to the discovery of candidate agents, *L. major* has no closely related native plant species in Europe which reduces the host specificity testing procedure and potentially the likelihood of non-target impacts if agents are considered safe for release. There are some very significant factors that will potentially slow down or obstruct the biological control of plant species in Ireland and Europe, despite a long history of biological control of arthropod pests. These include the public misconception of the use of biological control, lack of a coherent legislative framework for the release of biocontrol agents, lack of ownership by a single national authority to provide permission for release, and the availability of long-term funding to provide continuity to research programmes. While we try to resolve some of these appreciable constraints it is encouraging that a purpose built quarantine facility will be in place at UCD and that procedures are in place to import natural enemies from countries outside the EU for research purposes. The importation of some of these candidate agents on *L. major* will be initiated when the quarantine facility is built and approved.

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