Central Fisheries Board
An Príomh-Bhord Iascaigh

Status and Management of *Lagarosiphon major* in Lough Corrib 2007

Joe Caffrey, Ph.D,
Silvana Acevedo, Ph.D

December 2007

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Lough Corrib is the second largest lake in Ireland. It 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. The lake is a nationally important angling resource and a major tourist angling destination. The recent arrival of the highly invasive submerged plant species, *Lagarosiphon major*, in the lake has the potential to compromise the environmental, social and economic value of this unique natural resource.

Lagarosiphon major is native to southern Africa and was introduced to Ireland by the horticulture industry as an oxygenating plant for use in artificial watercourses. The plant is currently present in garden ponds, aquatic features on golf course and in artificial lakes at many locations throughout the country. It was first recorded in a natural aquatic habitat in Ireland in 2005 when its presence was confirmed in a large sheltered bay on upper Lough Corrib. By this time, the plant had established a surface vegetation canopy that covered 12 ha of water. The present study undertook to provide information on the current status of *Lagarosiphon* in the lake, to assess the impact it is having on native biotic communities, to investigate the life cycle characteristics of the plant and to explore methods that might be used to eradicate or effectively control the plant. The project commenced in June 2007 and was jointly funded by National Parks and Wildlife Service (NPWS), Office of Public Works (OPW) and Western River Basin District (WRBD).

Results from the study to detail the distribution of *Lagarosiphon* in Lough Corrib revealed that the invasive species is well established and spreading at an exponential rate in the upper and middle lakes. The plant was recorded from 64 sites in 2007, compared with 24 in 2006 and 9 in 2005. Weather conditions for surveying were poor during the summer of 2007 and it is probable that all sites where the plant had established were not identified. In total, some 2,058 sites throughout the lake were examined by the survey team. In Rinerroon Bay, where the founder population was recorded, *Lagarosiphon* has expanded its range by 7.4 ha and its standing crop by approximately 1,000 tonnes in the

two years since 2005. No specimens of the invasive plant were recorded from the lower lake, although a significant survey effort using grapnels, glass-bottomed viewing tubes and scuba divers was made to search for the plant. The survey results suggest that the habitat in this expansive and shallow waterbody is suitable for *Lagarosiphon* establishment and growth.

Lagarosiphon is well adapted to environmental conditions in Lough Corrib and has a number of competitive traits that provide it with an advantage over native plants. The tall, dense vegetation produced by the plant accumulates deep deposits of organic mud at the base of the stand. This provides the plant with sufficient nutrient for growth, even in relatively oligotrophic water. The plant has a wide depth tolerance and, in Lough Corrib, was recorded growing at depths of between 0.12 and 6.5 m. One of the plant's greatest competitive features is its ability to produce a dense surface canopy. This effectively blocks sunlight from penetrating to native plants present in the understorey beneath the canopy.

A survey was conducted in the upper lake to determine the effect that mature stands of *Lagarosiphon* had on native species and communities. In most bays where *Lagarosiphon* had not yet colonised or where only low-density stands were present, charophytes (mainly *Chara hispida* v. *rudis* and *C. glomerata*) dominated the submerged flora and generally occupied extensive, continuous and low-growing meadows. A number of tall growing native species, including *Myriophyllum spicatum*, *Elodea canadensis* and a number of broad-leaved *Potamogeton* species, were also prevalent and commonly formed mixed species assemblages. Where *Lagarosiphon* was well established within an area, practically no native species could survive beneath the canopy. The low-growing charophytes were the first to disappear, followed by the taller species. The macroinvertebrate survey revealed significant differences in the species composition and abundance within stands of native and invasive species. This probably reflected the growth form of the plant species rather than the speciation. More obvious was the increase in the abundance of macroinvertebrate species and groups, notably Chironomidae and *Crangonyx pseudogracilis*, in bays where dense macrophyte stands are present (e.g. Rinerroon Bay). No specific macroinvertebrate associations with *Lagarosiphon*, when compared with the other native plant species examined, were recorded. The results from a preliminary fish stock survey, conducted in October, were inconclusive in respect of the impact that *Lagarosiphon* might have on the stock status within the lake. However, it is clear that the habitat structure produced by extensive forests of tall, canopy-forming vegetation will better suit cyprinid fishes, perch and pike than it will salmonid species.

Pilot control trials on *Lagarosiphon* were conducted in January 2007 and monitored until September 2007. Neither hand pulling of low-density stands by divers nor treatment with aquatic herbicide (dichlobenil) proved effective in reducing the percentage cover of *Lagarosiphon* in the trial plots. The use of light occluding black geotextile, where the tall vegetation was cut before fixing it to the lake bed, effectively controlled *Lagarosiphon* growth after eight months. However, the operation to fix the geotextile in position over the 2,500 m^2 plot was excessively onerous and, for future operations, it is recommended that a plot size no larger than 400 m^2 should be treated. The most successful result was achieved using a large V-blade trailed on an 8 m-length of chain behind a boat. The blade is designed to rip the vegetation from the lake bed by the roots rather than to cut it cleanly. Divers estimated that in excess of 95% of the *Lagarosiphon* was removed from the test plot during this operation. The percentage bottom cover present in the plot in September, eight months after the cut was applied, was *circa* 8%. Much of this regrowth resulted because fragments from adjacent uncut stands had settled and rooted in the lake bed that had been exposed by the cutting.

Because of the success achieved using the V-blade, an extended trial was conducted in Rinerroon Bay in September 2007. During this operation, contractors removed approximately 300 tonnes of *Lagarosiphon* from 4.7 ha of the bay in five days, at a cost of almost €40,000. While this was a costly operation, it served to demonstrate that significant areas of lake that contain large standing crops of *Lagarosiphon* can be cleared, with obvious advantages for conservation and lake management. On the basis of the positive results to emerge from the cutting trials, NPWS provided funding to purchase a weed cutting boat that will be dedicated to *Lagarosiphon* control on Lough Corrib. The availability of trained Fisheries Board staff to operate the boat will confer significant advantages on the overall control operation and will provide the flexibility that is required to effectively and efficiently deal with *Lagarosiphon* on this lake.

While it may not be possible to totally eradicate *Lagarosiphon* from this large expanse of water, with proper long-term funding and a coherent strategic plan, it will be possible to eradicate the invasive weed from many sites throughout the lake, to significantly reduce the level of biomass present where mature stands presently exist, to create conditions for the recolonisation of native communities, and to provide a resource that can again be used for amenity and recreation, as it was before the invasion of *Lagarosiphon*.

1. INTRODUCTION

The protection of conservation and natural heritage values in Lough Corrib, a lake of national significance in Ireland, is incompatible with the presence and expansion of the aggressive invasive aquatic plant, *Lagarosiphon major*, that is currently being witnessed on the lake. In order to effectively tackle this problem, to reverse the environmental, economic and social impacts already evidenced on the lake and its communities, and to restore Lough Corrib to its acknowledged status as a fishery of international standing and a nationally important Special Area of Conservation, it is imperative that adequate resources are immediately provided.

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 plant was present in Rinerroon Bay on upper Lough Corrib and had established a surface canopy covering 12 ha of water. This dense, surface growth precluded recreational boating or angling in the bay and clearly impacted indigenous floral and faunal communities that were resident in the area.

Preliminary research on Lough Corrib in 2005 revealed that *Lagarosiphon* had already invaded a number of other bays along the western shore of the upper lake. Knowledge of the invasive capacity and potential of this plant, and the environmental and economic havoc that it has caused over a period of 40 years in New Zealand, gave rise to serious concerns for the conservation status and overall functioning of Lough Corrib. Funding to conduct baseline trials aimed at assessing and evaluating the efficacy of a range of methods to control and/or eradicate *Lagarosiphon* in designated, *Lagarosiphon*-dominated areas of the lake was provided by the National Parks and Wildlife Service (NPWS) in October 2006. These trials were conducted in December 2006 and January 2007.

Soon after *Lagarosiphon* was confirmed to be present on Lough Corrib a '*Lagarosiphon* Task Force' was formed to assess the implications and to propose coordinated actions for the study, control and elimination of this invasive weed. The Task Force comprised personnel from the CFB, WRFB, NPWS, Galway County

Council and OPW. During 2005 and 2006 the Task Force undertook the following actions:

- Awareness leaflets and lakeside signs, press-releases and a 2007 Calendar were produced.
- Members of the Task Force (since renamed the Invasive Aquatic Species Task Force) addressed the issue on radio and television.
- The distribution of *Lagarosiphon* in Lough Corrib in 2006 was established and mapped.
- Consultations with international agencies that deal with invasive species have taken place.
- Proposals for research funding have been prepared and widely distributed.
- Policies for the control of invasive species have been included in Galway County Council Local Area Plans.
- An information website (www.alienspecies.ie) has been created.
- Pilot weed control/removal operations in Rinerroon Bay, Lough Corrib, commenced in December 2006.

In order to provide more scientific information on the status of the plant in the lake and to examine the impact it was having on indigenous biota, the Central Fisheries Board (CFB), in co-operation with the Western Regional Fisheries Board (WRFB), was commissioned to conduct a seven-month research investigation (June to December 2007). Funding was provided jointly by the NPWS, the OPW and the WRBD. The broad objectives of the investigation were to:

- Provide a detailed literature review.
- Provide an updated distribution map (in GIS) for *Lagarosiphon* in Lough Corrib.
- Indicate the relative abundance of *Lagarosiphon* at infested sites throughout the lake.
- Monitor the impact of different control methods on trial sites used in late 2006 and early 2007.
- Conduct extended *Lagarosiphon* control trials in autumn 2007. These should build on the results obtained from the previous trials conducted in the lake.

- Attempt to eradicate *Lagarosiphon* from an area of the lake that has been recently infested and where percentage cover remains low.

- Research existing, new and innovative weed control methods, including biological control.

- Study the growth pattern of *Lagarosiphon* in Lough Corrib, possibly in collaboration with Galway Mayo Institute of Technology (GMIT).

- Conduct investigations into the impact of *Lagarosiphon* growth on indigenous aquatic plant and macroinvertebrate communities.

- Provide material for use in ongoing education and public awareness campaigns.

- It is hoped to bring a leading aquatic plant management expert from New Zealand, who has considerable experience dealing with *Lagarosiphon*, to Lough Corrib in September. His views and recommendations may help inform future management plans for weed control in the lake.

2. NON-NATIVE INVASIVE SPECIES

Non-native invasive species (synonym alien species) are species that have been introduced deliberately or accidentally outside their natural range, where they have the ability to establish themselves, to invade, to out-compete indigenous species and to take over new environments (Smith and Smith, 2003). A non-native species becomes invasive when it is capable of establishing stable populations, colonising irreversibly and spreading rapidly in natural or semi-natural ecosystems (Scalera and Zaghi, 2004). When non-native species become invasive they can transform ecosystems and threaten native and conservation species (Stokes *et al*., 2006; O'Neill and Stokes, 2004).

It has been acknowledged that invasions by non-native invasive species represent one of the greatest threats to natural biodiversity worldwide, second only to direct habitat destruction (Scalera and Zaghi, 2004). They also pose a significant threat to fragile ecosystems, such as islands. Their introduction is acknowledged to be one of the major causes of species extinction in freshwater ecosystems. 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.

Invasive Species in Ireland

The number of non-native freshwater species recorded in Irish watercourses has increased significantly in the late1900s (Caffrey, 1994; Caffrey, 2001; O'Neill and Stokes, 2004; Stokes *et al*., 2004; Wade *et al*., 1997). However, not all non-native species are invasive and current problems with invasive species are caused by only a small percentage of those that have been introduced to this country (Reynolds, 2002). The presence of a truly invasive species is evidenced by a demonstrable adverse impact on native communities or habitats.

Many of the most problematic aquatic invasive species present in Ireland today were introduced in the last 20 years and some have been recorded here as recently as 2005 (e.g. *Eriocheir sinensis* (Chinese mitten crab) and *Leuciscus cephalus* (Chub)). The rate of species introductions to this country is accelerating, primarily because of increased international travel and trade.

The aquatic non-native species that are most invasive and that currently represent the greatest threat to biodiversity and commerce in Ireland include the fishes – chub and dace (*Leuciscus leuciscus*), macroinvertebrates – Zebra mussel (*Dreissena polymorpha*) and Chinese mitten crab, and plants – Curly leaved waterweed (*L. major*), Parrot's feather (*Myriophyllum aquaticum*), Water fern (*Azolla filiculoides*), Nuttall's pondweed (*Elodea nuttallii*) and New Zealand pigmyweed (*Crassula helmsii*). In the Classification of Aquatic Alien Species in Ireland, compiled under the aegis of the All-Island Invasive Species Forum, all of the above-named species are on the high impact list. This Forum is jointly funded by the NPWS and the Environment and Heritage Service (EHS). The full list is presented in Appendix I.

The majority of these species have only recently established in Ireland and, with swift, thorough and coordinated effort, on a national basis, a number of them, at least, could be eradicated. The exception to this, probably, is the Zebra mussel, which is already widespread within the country. To date, no Institution or Organization has come forward to champion the cause of invasive species control and, as a consequence, these species are continuing to expand their range within the country. Furthermore, without swift and scientifically informed intervention, new species will continue to enter and establish in watercourses throughout the country. The Chinese mitten crab and *Lagarosiphon major*, which were first verified in Ireland in 2005, and the chub, which was first reported from the River Inny in 2004, provide good examples of this.

Invasive Species and European Directives

The legislative provisions dealing with non-native species operate at a range of levels from international (e.g. Convention on Biological Diversity), European (e.g. Water Framework Directive and Habitats Directive) and national (e.g. Wildlife Amendment Act 2000). In 2001 the EU set a target to halt the loss of biodiversity by 2010 and, in

2006, it published an Action Plan entitled 'Halting the Loss of Biodiversity by 2010 - And Beyond'. One specific target of the Plan is to 'substantially reduce the impact on EU biodiversity of invasive alien species and alien genotypes' (C. Maguire, pers. comm.).

The protection of Natura 2000 sites and features, as provided for in the Habitats Directive, is among the principal drivers for addressing the issue of invasive species and conservation of biodiversity. A number of such features, in Ireland and throughout Europe, are already under direct threat from invasive species. Aquatic invasive species clearly pose a major threat to the 'maintenance and restoration at favourable conservation status' of protected species and habitats and, as such, their establishment and spread must be controlled. According to the Directive (Article 6 – 1 and 2) Member States are obliged to address the issue of invasive species in their management plans and to take appropriate steps to avoid deterioration of habitats in Special Areas of Conservation (SAC).

Alien species are included as part of the assessment of pressures and impacts that will determine ecological status for the Water Framework Directive (WFD). While invasive species are not explicitly referred to in the text of the Directive, Annex 11 of that Directive lists specific pressures to which water bodies may be subjected, including "…other specific anthropogenic impacts on the status of surface water bodies". Invasive species must be considered as potential "anthropogenic impacts" to the biological elements listed in Annex V of the Directive as they are normally introduced, either intentionally (e.g. water garden planting or fish stocking) or accidentally (e.g. hull fouling or ballast water), by man.

The WFD requires member states to achieve at least good status by 2015, aiming at maintaining high status and preventing any deterioration in existing status of waterbodies. It is widely recognized that introduced aquatic alien species have the potential to compromise the achievement of good ecological status for waterbodies and the conservation objectives for protected areas. The United Kingdom Technical Advisory Group (UKTAG) WFD group, in their draft recommendations contained in the UK Classification Scheme for Surface Waters (September 2007 – draft document) stated that "a water body will be classed as worse than high status if there is evidence that one or more (invasive) species on the high impact (red) list has become established over a significant spatial extent of that waterbody". It is important, therefore, that appropriate and rigorous management strategies are formulated to identify areas at risk and to manage problems where they currently exist.

3. *Lagarosiphon major* (Ridley) Moss

Lagarosiphon major (African curly leaved waterweed, African elodea, oxygen weed) is a member of the Family Hydrocharitaceae, which also includes other important global adventive species, such as *Elodea* and *Hydrilla*. It is native to southern Africa (Obermeyer, 1964), where its biomass can interfere with commercial navigation and water-based recreation (CEH, 2004). In Ireland *Lagarosiphon* is legally sold by garden centres, aquarists and DIY stores throughout the country. It is commonly mislabeled *Elodea crispa*. Horticulturalists and landscape gardeners use it as an oxygenating plant in artificial watercourses. As a consequence, the plant is present in garden ponds, aquatic features on golf courses and in enclosed, artificial lakes at many locations throughout the country. Work is being conducted to accurately determine the detailed distribution of the plant within the country.

Plate 1. *Lagarosiphon major* showing a) the spiral arrangement of the leaves on the stem and b) the J-shaped lower stem.

Lagarosiphon major is a perennial, submerged aquatic plant distinguished from closely related *Elodea* species by virtue of the fact that the leaves alternate spirally along the stems (Plate 1a) (Bowmer *et al*., 1995). The leaves have tapered tips, are strongly recurved downwards towards the stem and the leaf margins are minutely toothed. They typically cluster tightly towards the crown or apex of the stem. The stems are narrow (3 – 5 mm in diameter), brittle and curved towards the base (J-shaped) (Plate 1b). At the nodes, single, pale adventitious roots are produced. These trail in the water and can aid with nutrient uptake for the plant. The plants root in the hydrosoil using long, single and tough roots. The stems are sparsely branched until they approach the water surface. There they branch repeatedly to produce extremely dense mats on and below the surface. These mats can be so dense that practically no incident light can penetrate to the lake bed beneath. It is this substantial surface-reaching growth form that poses most threats for biodiversity and for recreational or commercial use in infested watercourses. Outside its native range, only female plants are known (Cook, 1982; National Botanic Gardens, 2007) and all reproduction is by fragmentation or vegetative reproduction.

Lagarosiphon achieves its maximum vegetative expression in clear, still water where it is capable of growing to a maximum depth of 6.6 m (Coffey and Wah, 1988; Global Invasive Species Database, 2007). It prefers the cooler waters of the temperate zone, with optimal temperatures in the range 18 to 23°C. The weed is tolerant of low nutrient conditions, but grows best in hard water with a good nutrient supply (Dutartre, 1986). The plant grows optimally under conditions of high light intensity. *Lagarosiphon* is sensitive to wave action and wind, preferring to grow in sheltered sites or in reed beds.

4. LOUGH CORRIB

Lough Corrib is the second largest lake in Ireland (18,240 ha). It straddles Counties Galway and Mayo (Figure 1), has a volume of *c*. 8 x 10^8 m^3, a surface area of 178 km^2 and a watershed that covers 3,139 km^2 (Cannaby, 2005; NPWS, 2001; O'Sullivan, 1996; Krause and King, 1994). The Corrib River constitutes the main outflow of water from the lake. Discharge from the Corrib River is controlled by a sluice gate in Galway City and is regulated according to the amount of recent precipitation. Discharge levels vary between 20 and 340 $m^3\ s^{-1}$, with a mean annual discharge of 109 $m^3\ s^{-1}$.

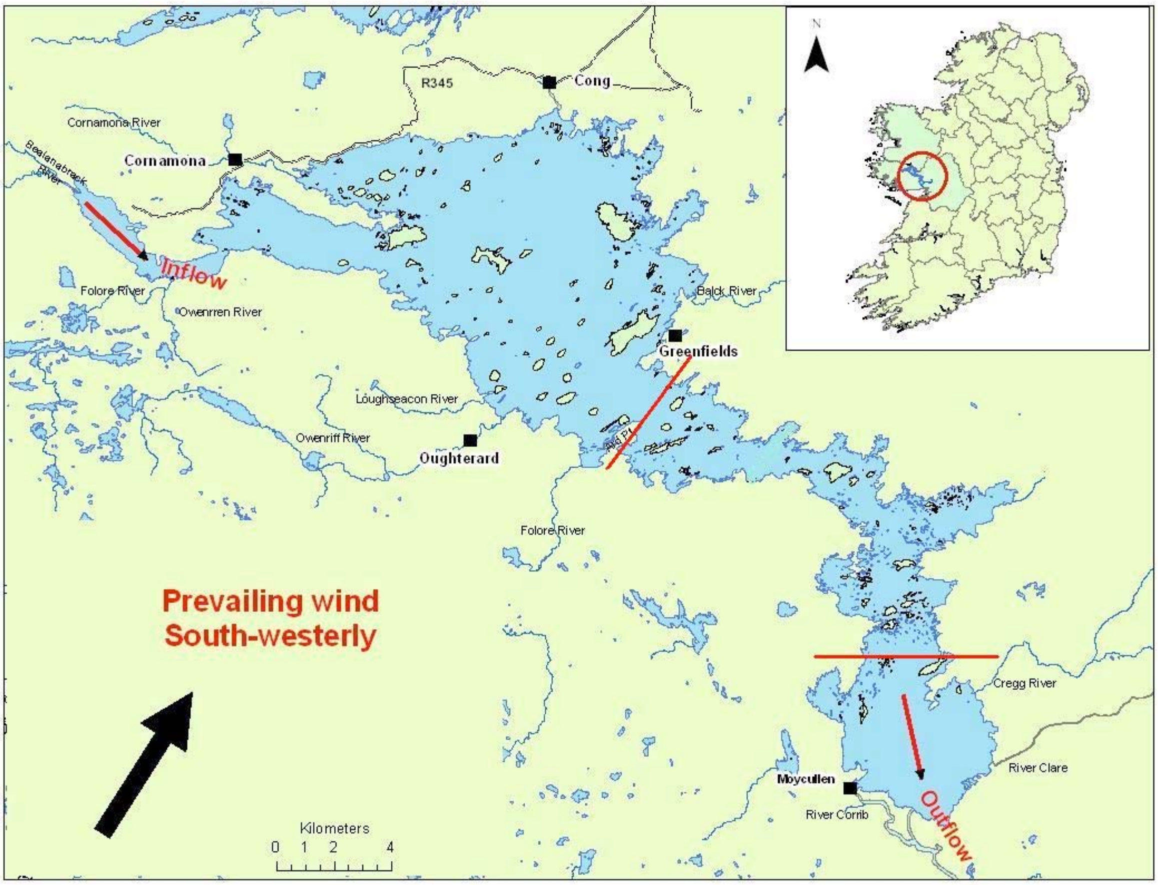

Figure 1. Map of Lough Corrib showing the principal tributary rivers and the main topographic divisions of the lake.

The lake forms a natural boundary between the undulating limestone area to the east and the hard, siliceous rock adjoining the western shore (Krause and King, 1994). The lake may be conveniently separated into three sections: the upper, middle and lower lakes (Figure 1). The large upper lake is deep, with a maximum recorded depth of 47 m. Littoral areas along the western shore are confined to sheltered bays on siliceous rock. The eastern portion of the lake is less steep and extensive littoral areas are present. These are sheltered from the prevailing winds, and consequent wave action, by the many small islands and jagged reefs. The middle lake represents a relatively narrow and shallow corridor that links the upper and lower lakes. It is characterised by countless small islands and prominent reefs. The lower lake is shallow, with few sections supporting a depth greater than 3 m. This sector of the lake is very exposed to the prevailing south-westerly winds.

The bathymetry of the lake is very irregular (depth in the upper lake: average - 8.44 m, maximum – 47 m; depth in the lower lake: average - 2.06 m, maximum - 9.3m) (O'Sullivan, 1996; Figure 2). The shorelines are generally characterised by relatively small and sheltered bays.

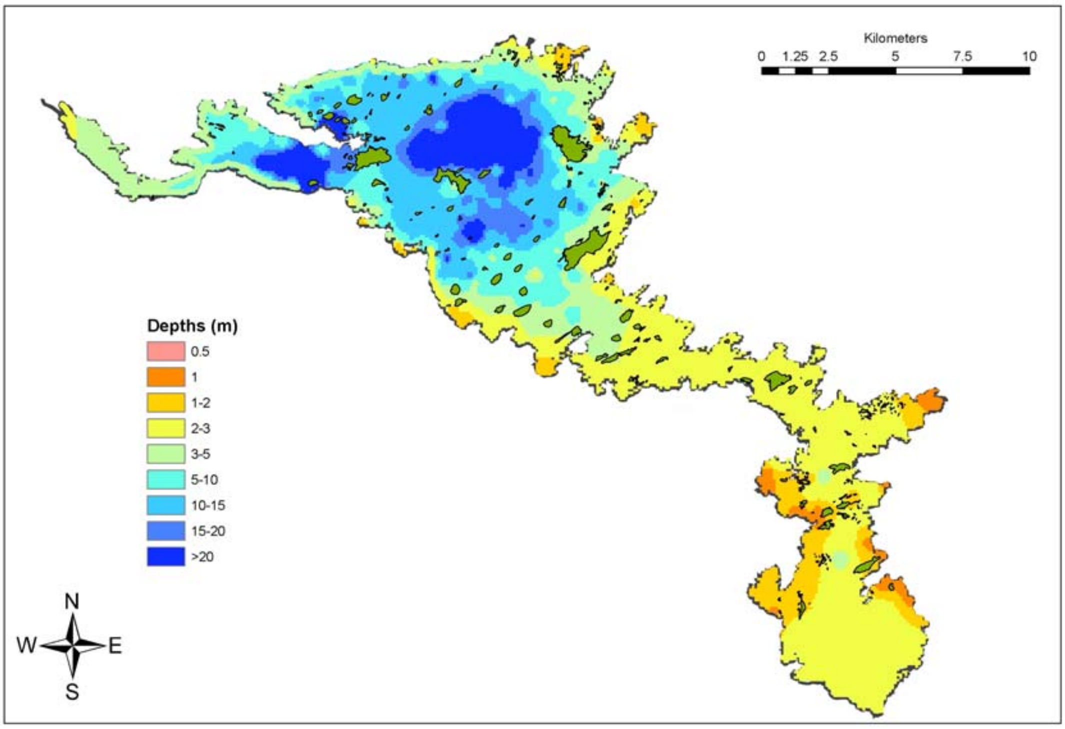

Figure 2. Depth contour map of Lough Corrib (developed by digitizing Ordnance Survey Map No. 1843).

The west of Ireland is characterized by unique meteorological conditions. High summer temperatures, above 20 ^{o}C (Met Éireann, 2007; Appendix II), result in the stratification of some lakes, producing a warm upper layer and a cold lower layer (O'Sullivan, 1996). Lough Corrib, which is influenced by Atlantic wind and rain, is oxygenated through the seasons and temperatures rarely remain above 20 ^{o}C for long.

Temperature measurements made in Lough Corrib over a three year period, between March 2001 and March 2004, suggest the presence of a weak and diffuse thermal stratification over the summer months, interspersed on a number of occasions by periods of complete vertical mixing (Cannaby, 2005). The level of stratification observed was not found to influence nutrient distribution or water quality (Cannaby, 2005), although it has been suggested that small changes in nutrient concentrations and flux pathways, due to eutrophication, may mean that stratification becomes more significant.

Lough Corrib is a moderately hard-water system of mesotrophic status (Champ, 1977), although in recent years localised pollution incidents have threatened the clean-water status of this waterbody. Much of the current threats from point source pollution are located towards the lower end of the lake.

The shallow, lime-rich waters of the southern basin of the lake support one of the most extensive beds of Stonewort (charophytes) in Ireland, with species such as *Chara aspera*, *C. hispida*, *C. delicatula*, *C. contraria* and *C. desmacantha* mixed with submerged Pondweeds (*Potamogeton perfoliatus*, *P. gramineus* and *P. lucens*), Shoreweed (*Littorella uniflora*) and Water lobelia (*Lobelia dortmanna*) (Krause and King, 1994; NPWS, 2001). The *Chara* beds are an important source of food for waterfowl and provide a myriad of microhabitat niches for an abundant and diverse macroinvertebrate population. By contrast, the northern basin contains more calcifuge isoetid species, including Shoreweed, Water lobelia, Pipewort (*Eriocaulon septangulare*), Quillwort (*Isoetes lacustris*), in addition to Alternate Water-milfoil (*Myriophyllum alternifolium*) and Slender Naiad (*Najas flexilis*). Large areas of reedswamp vegetation, dominated by varying mixtures of Common Reed (*Phragmites australis*) and Common Club-rush (*Scirpus lacustris*), occur around the margins of the lake.

Lough Corrib is of major conservation importance and includes 14 habitats listed on Annex I of the Habitat Directive. In addition, three fish species that are listed on Annex II of the Directive, namely Atlantic salmon (*Salmo salar*), sea lamprey (*Petromyzon marinus*) and brook lamprey (*Lampetra planeri*) are present in the lake (O’Keeffe and Dromey, 2004). Other aquatic species listed in Annex II that occur in

Lough Corrib include the Freshwater pearl mussel (*Margaritifera margaritifera*), White-clawed crayfish (*Austropotamobius pallipes*) and Otter (*Lutra lutra*) (Community Enterprise, 2004; NPWS, 2001). Rivers, mainly to the east of the lake, are included within the SAC as they are important for Atlantic salmon. These rivers include the Clare, Grange, Abbert, Sinking, Dalgan and Black to the east, as well as the Cong, Bealanabrack, Failmore, Cornamona, Drimneen and Owenriff to the west (NPWS, 2001).

Lough Corrib is an internationally important site for waterfowl. The lake supports internationally important numbers of Pochard and nationally important numbers of Coot, Mute Swan, Tufted Duck, Cormorant and Greenland White-fronted Goose. Other bird species of note recorded from or close to the lake recently include Hen Harrier, Whooper Swan, Golden Plover and Kingfisher. All of these species are listed on Annex I of the E.U. Birds Directive (NPWS, 2001).

The lake is an important national angling resource and a major tourist angling destination. It is the only Irish lake that is designated under the Freshwater Fish Directive (78/659/EEC). Lough Corrib is internationally recognised as one of the prime wild brown trout angling lakes in Europe. It supports significant stocks of brown trout and a large population of large ferox trout. Wild Atlantic salmon are commonly caught in the lake and use the tributary rivers for spawning purposes. In addition, commercial netting for eels (*Anguilla anguilla* L.) is carried out in the lake (Krause and King, 1994).

The lake supplies the industrial, farming and domestic water requirements for a large portion of County Galway and parts of County Mayo. Tourism is the mainstay in the west of Ireland. Lough Corrib and the other Great Western lakes continues to attract increasing number of foreign holidays-makers; for instance, tourists spent over €356 million in Co. Galway in 2006 (Failte Ireland, 2006). The combination of wilderness and pristine lakes, of which Lough Corrib forms an integral part, attract many of these visitors. Were the lake to be degraded by pollution, invasive species, or other factors, the resultant loss in tourist revenue, and conservation value, would prove catastrophic for the area.

5. *Lagarosiphon major* IN LOUGH CORRIB

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 by field staff from the WRFB. These site surveys, conducted by experienced Fisheries Board personnel with an in-depth knowledge of the lake, established that Rinerroon Bay was the most seriously affected bay in the lake. At that time *circa* 55% of the area of this bay (*c*. 12 ha) was overgrown with *Lagarosiphon.* The invasive submerged plant grew to a maximum depth of 4 m. At this depth, it occupied the full water column and created an extremely dense surface canopy (Plate 2). Individual stems to a length of 4.5 m were recorded in the bay. A diving survey was conducted to determine the biomass of the plant and to provide some basic metrics for *Lagarosiphon* under Irish conditions. The results determined that a fresh weight biomass of 13.8 kg m^{-2} of *Lagarosiphon* was present in Rinerroon Bay at that time. This represents an estimated overall weed biomass in this bay of 1,650 tonnes.

Plate 2. Extensive surface canopy of *Lagarosiphon major* in Rinerroon Bay, July 2005.

The field surveys revealed that the invasive plant has established 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 (Figure 3).

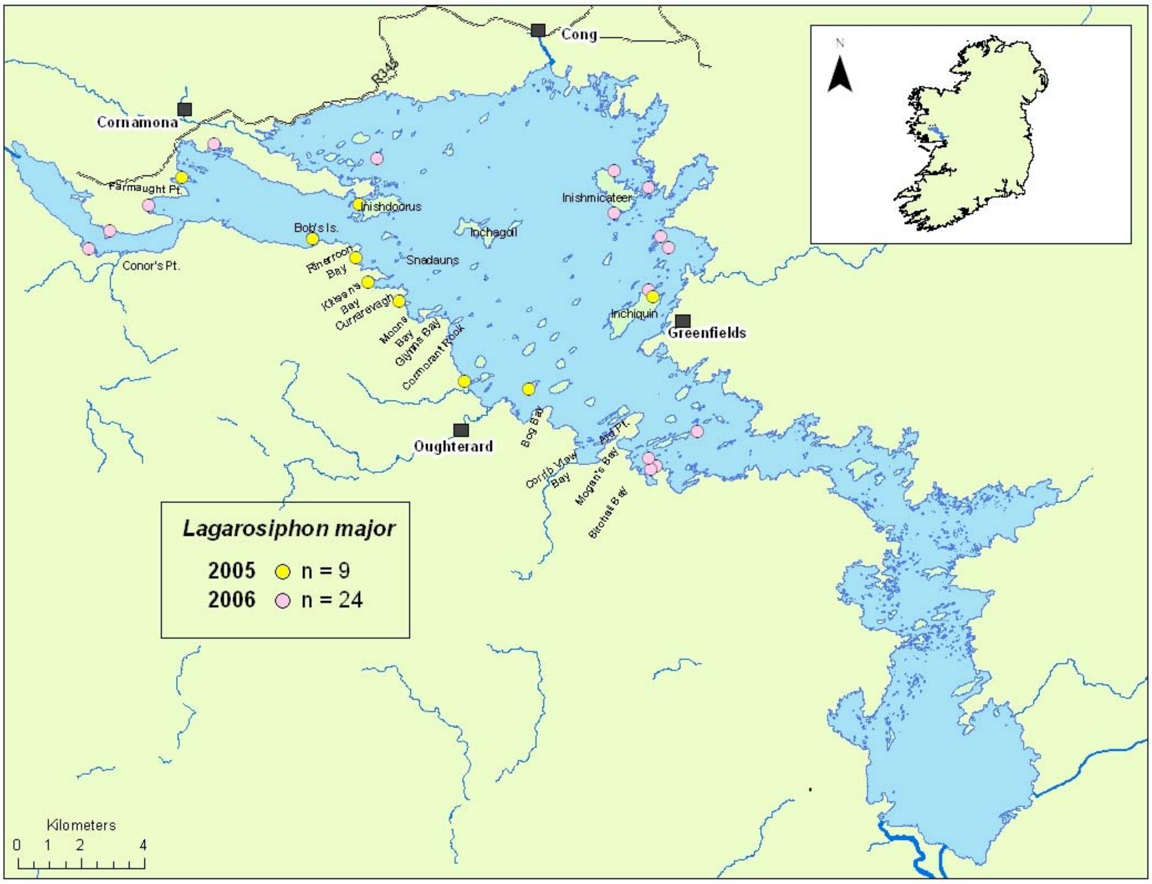

Figure 3. Distribution of *Lagarosiphon major* in Lough Corrib in 2005 and 2006.

More intensive surveys to accurately determine the distribution and spread of the weed in the lake were undertaken during 2006. These surveys were conducted over a 12-month season and Fisheries Board staff were assisted in their search for *Lagarosiphon* colonies by anglers and other lake users. The survey work revealed that the weed was more widely distributed than was originally anticipated. The number of bays or lake areas known to be infested increased from nine in 2005 to 24 by the end of 2006 (Figure 3). During 2006 new records were recorded in the middle lake, along the eastern shore and its associated islands, close to the northern shore and in the northern arm of the lake. No sightings of the weed from the shallow lower lake were recorded in 2006.

6. MATERIALS AND METHODS

The CFB employed one Research Officer (Dr. Silvana Acevedo) to coordinate the progress of the present study. She was supported by the staff of the WRFB in Lough Corrib for the duration of her field sampling period and was assisted by a bursary student from GMIT (Hilary Healy) for a 12-week period during the summer months. The field sampling and laboratory analysis were supervised by Dr Joe Caffrey. The macroinvertebrate study was conducted by Dr Jan-Robert Baars, UCD, with the field assistance of the survey team and the WRFB.

6.1. Physico-Chemistry of the Water

No water samples were collected for analysis as part of the present project as data from ongoing sampling programmes conducted by the WRFB were available (K. Rodgers, pers. comm.). Samples collected in the upper and lower lakes between 2005 and 2007 were analyzed for Chlorophyll-a (µg/l), Total Phosphorus (TP mg/l P), Molybdate Reactive Phosphorus (MRP mg/l P), Total Oxidised Nitrogen (TON mg/l N), conductivity (µs/cm), colour (Hazen), turbidity (NTU), hardness (mg/l $CaCo_3$) and alkalinity (meq/l). Total Phosphorus values above 0.063 mg/l P, MRP values above 0.02 mg/l P and TON values above 11.3 mg/l N are considered to be indicative of artificial enrichment.

The water temperature in Rinerroon Bay was continuously measured over a seven months period, between 13th February and 6th September 2007, using three moored temperature loggers (self-recording TGP-4017 Tinytag) (Plate 3). The accuracy of the logger is ±0.5 ^{o}C and the resolution is 0.01 ^{o}C, over the temperature range -40 ^{o}C to 85^{o}C. The temperature loggers have a capacity for 32,000 measurements. The loggers were set at a depth of 1.5 m and their positions were marked using a hand-held global positioning system (GPS) (Figure 4). Each logger was positioned either within or directly adjacent to *Lagarosiphon* beds.

Plate 3. Temperature loggers moored in Rinerroon Bay.

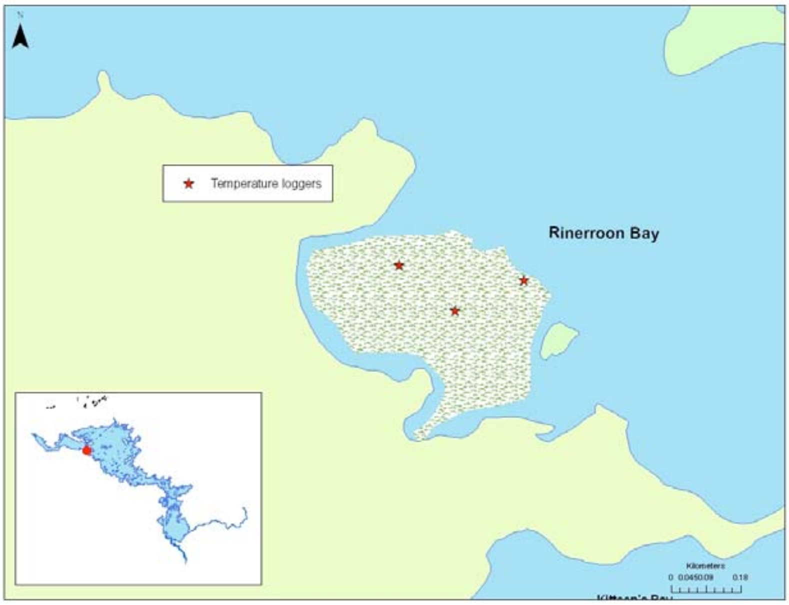

Figure 4. Location of the temperature loggers in Rinerroon Bay.

A YSI multimeter was employed during the project to record values for temperature (^{o}C), dissolved oxygen (DO) concentration (mg/l) and pH over a seven-day period. The multimeter took readings every 15 minutes. In Rinerroon Bay the instrument was positioned adjacent to moderately dense *Lagarosiphon* beds; in Kitteen's Bay it was centred in the middle of a dense *Lagarosiphon* stand, and in Moon's Bay it was located directly above a meadow of charophyte vegetation (Figure 5). The measurements were recorded between late July and September.

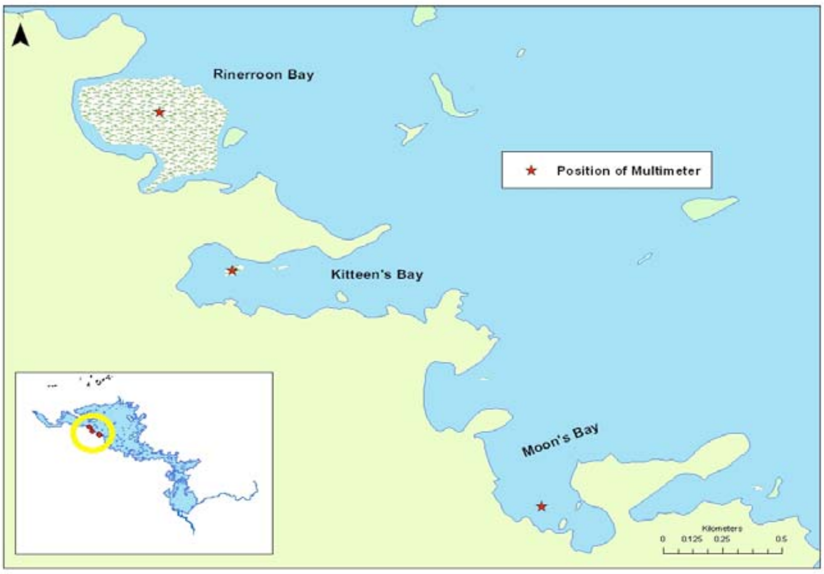

Figure 5. Location at which the multimeter was moored in Rinerroon, Kitteen's and Moon's Bays.

The mooring was specifically designed to hold the multimeter probe in mid-water (Plate 4, a and b). The multimeter was moored at a depth of 2.1 m in Rinerroon Bay, 1.8 m in Kitteen's Bay and 2.0 m in Moon's Bay.

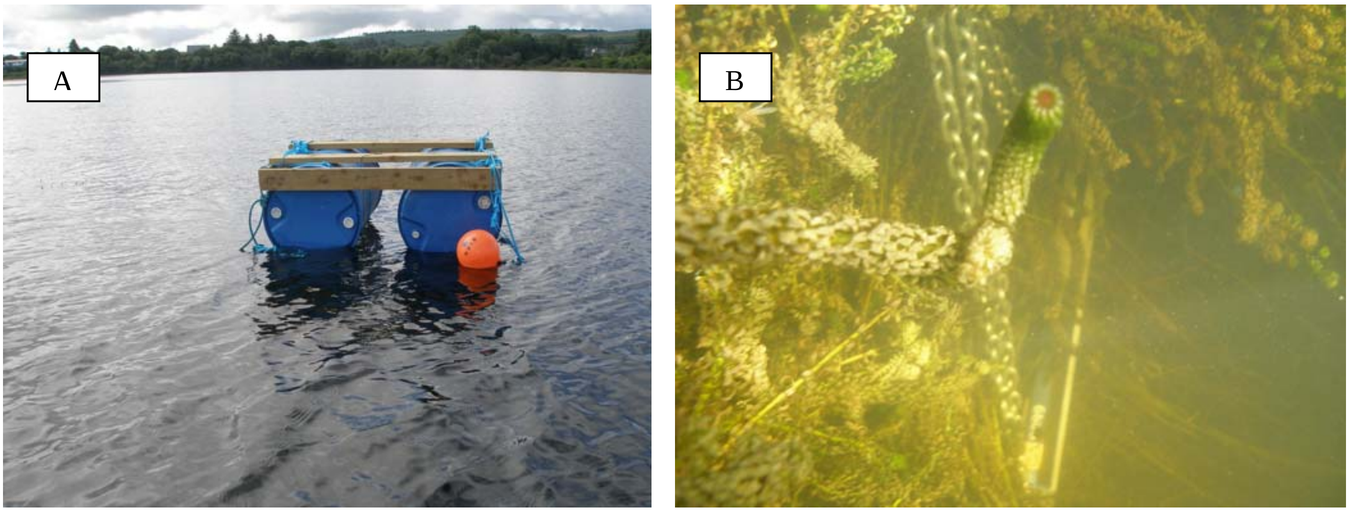

Plate 4. Photograph showing a) mooring used to hold the multimeter in mid-water and b) multimeter located in the middle of a dense *Lagarosiphon* stand in Kitteen's Bay.

6.2. Sediment Analysis

Samples for sediment analysis were collected at eight locations in the upper lake. These were Cormorant Rock, Moon's Bay, Snadauns Island, Kitteen's Bay, Currerevagh Bay, Glynn's Bay, Bob's Island and Rinerroon Bay (Figure 6). Duplicate samples were collected at each site in August 2007 using a Van Veen grab. The samples were given to Prof. Michael Hynes (NUIG) for x-ray fluorescence spectrometry analysis. The trace elements to be examined in this preliminary analysis will include aluminium (Al), copper (Cu), iron (Fe) and magnesium (Mg).

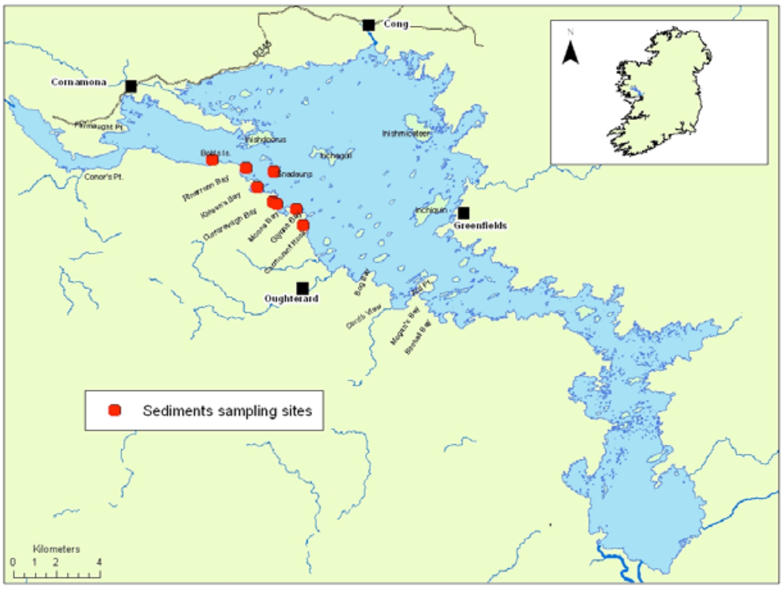

Figure 6. Sites from which samples for sediment analysis were taken in August 2007.

6.3. Distribution of *Lagarosiphon* in Lough Corrib

During the field sampling period (mid-June to early October 2007), all of the bays and most of the littoral areas in the upper, middle and lower lakes were sampled by the survey team. The littoral areas associated with many of the islands were also examined, although it was not possible, during the short field period, to sample all of the islands.

Plate 5. Glass-bottomed viewing core used to observe submerged vegetation in Lough Corrib.

A number of methods were employed to collect information on the aquatic plant distribution in the lake. These included observations made by Fisheries Board personnel while netting or otherwise sampling the lake. Observations by anglers and other lake users were also logged, following verification by the scientific team. Other methods employed included grapnel sampling along predetermined transects, viewing the lake bed using a glass-bottomed viewing tube, and scuba diving. The glass-bottomed viewing core (Plate 5) was used to physically observe the plant beds on the bottom or in the water column. Obviously, this was only practical in relatively shallow and clear water.

Grapnel sampling was the most effective method operated during the survey. Sampling was generally conducted from a 16 ft flat-bottomed boat powered by a 25 hp engine. WRFB staff, who know the lake intimately, accompanied the survey team during all sampling operations. Prior to sampling any area of the lake, GIS maps were prepared and laminated. On site, the surveys were conducted using a standardised 8-pronged grapnel attached to a 20 m length of rope (Plate 6). All the littoral areas along the lake margins were surveyed during this sampling period. In shallow bays a number of transects were established. The vegetation along these transects was sampled from the boat, moving slowly, using the trailed grapnel. 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*. If this species was present the sample site was positioned with a Global Positioning System (GPS) and photographed. A sample of the *Lagarosiphon* was retained for formal identification. All associated aquatic plants were identified and the approximate proportion of each was recorded. The depth was measured and the rough composition of the substrate was noted.

At all of the sites sampled during the survey GPS coordinates, depth measurements and a list of the aquatic plant species present were recorded. This data was logged into a computer on completion of each day's survey. The data generated was used to produce spatial distribution maps of *Lagarosiphon* in the lake, using Geographical Information System (GIS).

Plate 6. An 8–pronged grapnel used to sample *Lagarosiphon major* in Lough Corrib.

Where stands of *Lagarosiphon* were recorded, the approximate area of the lake occupied by the weed bed was calculated. GPS coordinates were taken at the outer limits of each stand and polygons were created using GIS-ArcCatalog. Using this data it was possible to calculate the approximate area (m^2) of *Lagarosiphon* present. This field operation proved difficult during windy conditions or when the water was turbid. The areas presented must, therefore, be regarded as approximate. Nor was time available during the summer to take measurements at all 64 sites and the objective was to record the approximate area occupied by the plant stands at as many sites as possible.

6.4. Macrophyte Survey

It was not intended to conduct a detailed macrophyte survey of Lough Corrib but primarily to determine the impact that the establishment and spread of *Lagarosiphon* in the lake has had on indigenous macrophyte species and assemblages. In the absence of detailed historic macrophyte studies or inventories from the bays that are currently overgrown with *Lagarosiphon*, comparisons were made with the aquatic flora resident in adjacent bays of similar aspect, chemistry and geology that have not yet been, or were only recently, colonised by *Lagarosiphon*. Most of the survey work conducted in 2007 concentrated on a few bays on the western shore of the upper lake, where the *Lagarosiphon* was first recorded and where founder population of the invasive species probably established.

Aquatic plant samples were collected along defined transects by boat using an 8-pronged grapnel (Plate 6). Three relatively adjacent bays were examined; Rinerroon was virtually overgrown with *Lagarosiphon,* Currerevagh was probably only recently colonised and supported < 5% bottom cover with *Lagarosiphon*, and no *Lagarosiphon* had yet been recorded from Moon's Bay. Species inventories and relative abundance values, as percentage bottom cover, were recorded along transects within these bays. This data was verified by divers. Quadrats (0.5 m^2, Plate 7) were used by divers to ascertain the proportions of species at specific locations within these bays. Species identification was conducted in the field for all but the charophyte species. These were returned to the laboratory for microscopic examination.

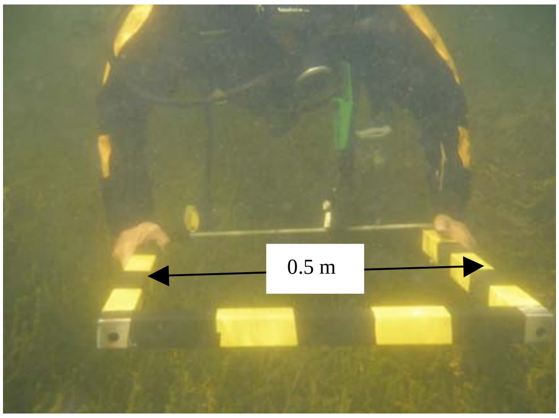

Plate 7. Quadrat (0.5 m^2) deployed by a scuba diver to estimate the percentage bottom cover of aquatic plant species in Lough Corrib.

6.5. Macroinvertebrates

The macroinvertebrate fauna was sampled in lake areas that supported no *Lagarosiphon,* in areas that were only recently infested with the weed and in bays where the weed was firmly established and where 100% *Lagarosiphon* cover was recorded. The methods employed in this phase of the study are presented in Appendix III.

6.6. Fish

Multimesh (monofilament) gill nets were employed in Lough Corrib to provide preliminary information on status and structure of fish communities in two discrete areas of the upper lake; one where *Lagarosiphon* dominates the aquatic flora (Rinerroon Bay) and one where no *Lagarosiphon* is currently present (Moon's Bay). The multimesh nets were each 60 m long, 1.5 m deep and had 12 panels ranging in mesh size from 0.8 to 5.0 cm. The netting operation was conducted in early October. At each site the nets were set in the afternoon and recovered the following morning. Four nets were deployed in each bay. In Rinerroon bay, the nets were set within or immediately adjacent to the *Lagarosiphon* beds. In Moon's Bay the nets were located above the natural *Chara*-dominated aquatic vegetation. The position of the nets in each bay is shown in Figure 7.

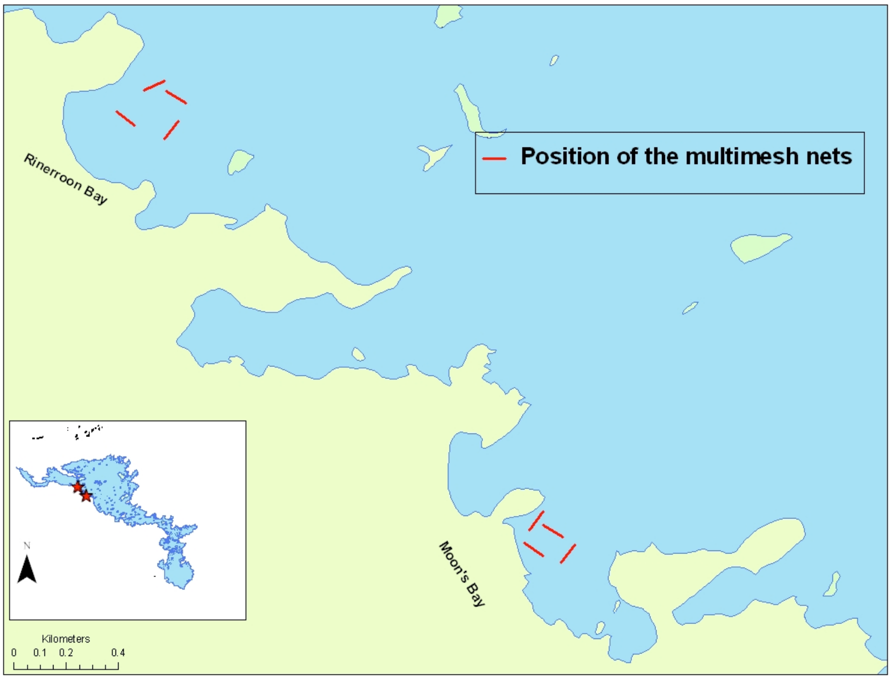

Figure 7. The position of multimesh nets in Rinerroon Bay and Moon's Bay, October 2007.

All of the fish captured in the nets were carefully removed, counted, identified to species level and returned alive to the water. The fish were measured (fork length, to the nearest centimeter) and weighed (to the nearest 0.1 g). Length-weight and length-frequency histograms were constructed for the most abundant species. Indices of stock abundance were calculated as catch per unit of netting effort (CPUE) and number of each fish species caught per unit of netting effort (NCPUE).

6.7. Habitat Preferences and Life Cycle Characteristics

Information in relation to habitat preferences and general life cycle or growth features of *Lagarosiphon* in Lough Corrib were gleaned primarily from observing the plant at a wide range of locations and in a variety of habitat throughout this large watercourse over the past two years. Time did not permit for much empirical work to be conducted on the autecology of the species during the present study.

6.8. Control Trials on *Lagarosiphon*

In December 2006 and January 2007 pilot trials to determine the most appropriate methods to contain, control and/or eradicate *Lagarosiphon* were conducted in Rinerroon Bay (densely infested) and in Currerevagh Bay (an adjacent, recently infested bay). The trials were conducted in designated 50 x 50 m plots. Control plots that would remain untreated were established adjacent to the treatment plots and would be used for comparative purposes (Figure 8). *Lagarosiphon* abundance, as percentage bottom cover within each plot, was estimated pre-treatment. Four weed control methods were trialed during this period. These were: manual removal using scuba divers (in Currerevagh Bay), approved herbicide (dichlobenil), light occlusion using black geotextile and mechanical cutting. The manual removal and herbicide treatments were conducted in December 2006, while the remaining operations were carried out in January 2007. It had originally been intended to trial suction dredging as a fifth control method and plots were established to monitor the course of this experiment also (Figure 8). However, the dredger brought on site had not got the capacity to remove the large volume of *Lagarosiphon* present. It was, therefore, decided to abandon this trial. The results from the pilot trial were quantitatively evaluated in September 2007, some

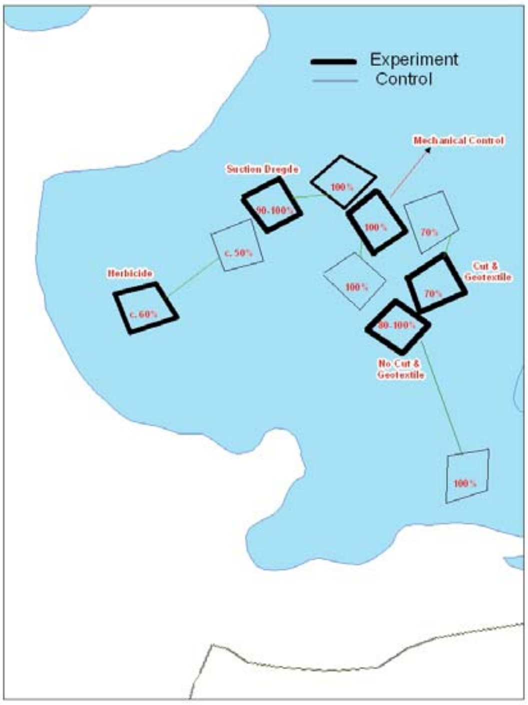

Figure 8. Location of the 50 x 50 m trial and control plots in Rinerroon Bay. The percentage bottom cover with *Lagarosiphon* at the commencement of the trial is presented.

eight (or nine, in the case of herbicide treatment) months after the control operations were effected.

Based on the results recorded from the pilot weed removal operations, it was decided to extend the mechanical cutting trial. Between 17th and 21st September 2007 contractors were commissioned to cut *Lagarosiphon* in Rinerroon Bay, to physically remove it from the lake and to dispose of the plant material distant from any natural watercourse. The area selected for treatment was demarcated using buoys and the percentage bottom cover was determined by divers prior to the commencement of cutting. Buoyed weed containment nets were set at the outer perimeter of the bay to stop cut vegetation from escaping to the lake (Plate 8). A V-blade cutting knife used, as in the previous operation, although on this occasion a large weed collecting boat with hydraulic lifting equipment was employed. The cut weed was brought ashore and disposed of distant from the lake or any other natural watercourse.

Plate 8. Containment net deployed in Rinerroon Bay prior to mechanical cutting in September 2007.

6.9. Meteorological data

A weather summary for the sampling season (June to October 2007) was obtained from the Irish Meteorological Office. The service provides information on rainfall, temperature, sunshine and prevailing winds for Ireland (specimen in Appendix II).

7. RESULTS

7.1. Physico-Chemistry

7.1.1. *Water chemistry*

Physico-chemical analysis of the water in Lough Corrib, provided by the WRFB, indicates that water quality conditions in the lake during this period were generally were good and no evidence of significant artificial enrichment was recorded (Appendix IV). In the lower lake, levels of Total Phosphorus (TP) ranged from 0.007 to 0.049 mg/l P (mean value 0.023 mg/l P). Molybdate Reactive Phosphorus (MRP) values ranged between 0.006 to 0.017 mg/l P (mean value 0.011 mg/l P). Total Oxidised Nitrogen (TON) values were very low, ranging from 0.121 to 1.318 mg/l N (mean 0.58 mg/1 N). Chlorophyll values ranged from 0.003 to 7.969 µg/l (mean 3.27 µg/l). In the upper lake, levels of TP ranged from 0.001 to 0.027 mg/l P (mean 0.016 mg/1 P). MRP values ranged between 0.006 to 0.016 mg/l P (mean 0.010 mg/l P). TON values were very low, ranging from 0.110 to 0.507 mg/l N (mean 0.33 mg/1 N). Chlorophyll values ranged from 1.562 to 11.761µg/l (mean 4.79 µg/l).

There was a gradient of increasing value for conductivity, alkalinity, hardness, colour and turbidity in the direction of surface water movement, from the upper to the lower lake (Appendix IV). This was consistent with the previous findings of Krause and King (1994). In the upper lake the water along the limestone-dominated eastern shore is more alkaline than that on the western shore, where siliceous rock predominates.

7.1.2. *On Site Multimeter sampling*

Dissolved oxygen (DO) concentration is the major parameter regulating the ability of a water body to support a sustainable aquatic ecosystem. YSI multimeter readings revealed that the greatest diurnal fluctuations in both DO and pH were recorded in Kitteen's Bay (Figures 9 and 10). In this bay, the multimeter probe was positioned within a dense stand of actively growing *Lagarosiphon*, which would probably explain the fluctuations recorded. A maximum variation between morning and evening values for DO of 2.2 mg/l, and for pH of 0.6 units, was recorded on Day 2. As might be expected, the gradient for DO closely mirrored that for pH in the water. Later in the week difference in DO values recorded between morning and evening was less marked.

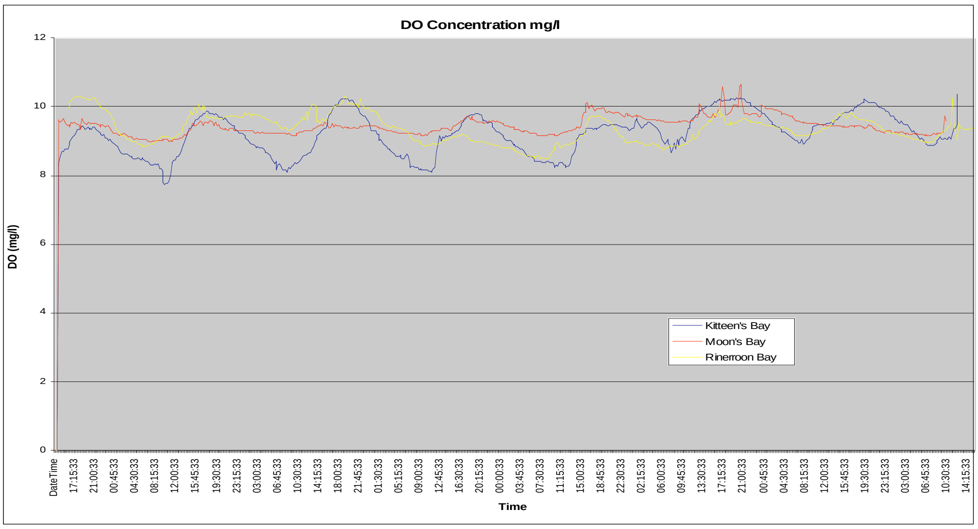

Figure 9. Dissolved Oxygen concentrations recorded using the YSI multimeter in Kitteen's Bay, Moon's Bay and Rinerroon Bay during sampling between July and September 2007.

The level of diurnal variation in DO and pH values was less marked in Rinerroon Bay (maximum *c*. 1.4 for DO and 0.35 for pH), where the multimeter probe was located in open water adjacent to moderately dense *Lagarosiphon* beds (Figures 9 and 10). It was noteworthy that there was minimal variation in parameter in the water above the charophyte beds in Moon's Bay when sampled in mid- August.

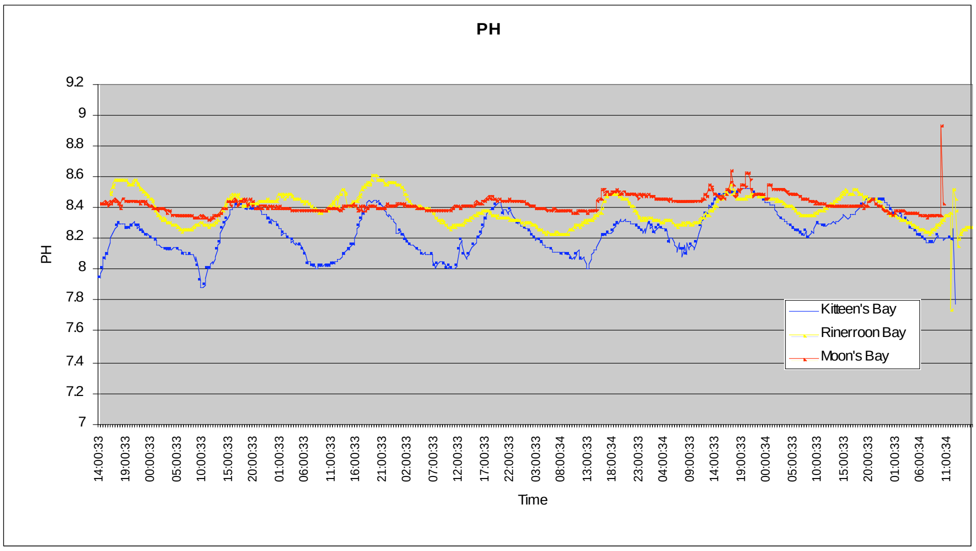

Figure 10. pH readings recorded using the YSI multimeter in Kitteen's Bay, Moon's Bay and Rinerroon Bay during sampling between July and September 2007.

The values for water temperature, recorded at a depth of 1.5 m, were relatively stable at each site throughout the sampling period (Figure 11). As might be anticipated, the water temperature was marginally higher during the afternoons than in the morning time. The consistently lower values for Rinerroon Bay reflect the fact that sampling here was conducted later in the season than at the other two sites.

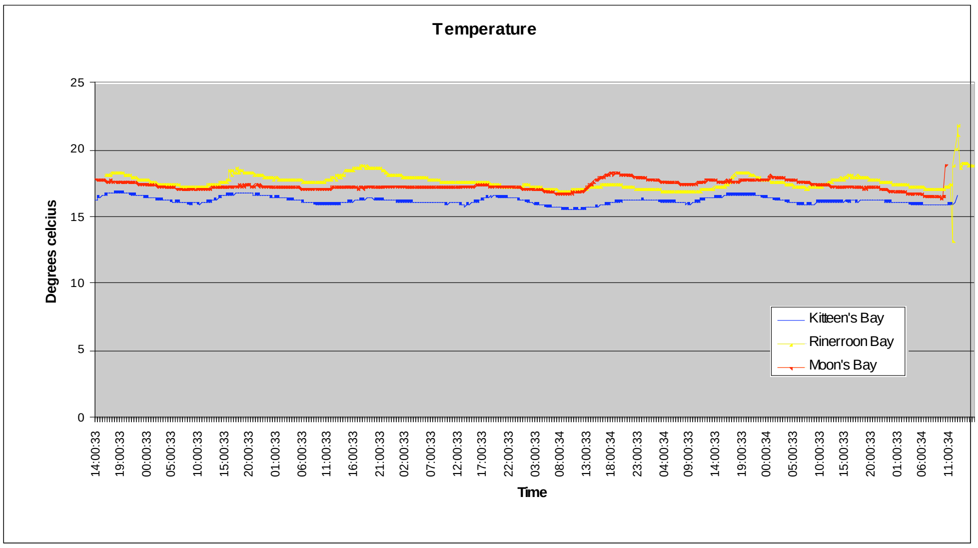

Figure 11. Temperature readings recorded using the YSI multimeter in Kitteen's Bay, Moon's Bay and Rinerroon Bay during sampling between July and September 2007.

7.1.3. *Temperature data loggers*

Results recorded by each of the three data during the seven month period between February and September 2007 were very similar (Figure 12). Water temperature values rose steadily from a low of 5.6 °C recorded in mid-February to a peak value of 22.9 °C recorded on 10th June. In mid-June water temperatures fell rather sharply and remained at *circa* 16.4 °C for the following month. Thereafter, temperatures rose slightly and remained at *circa* 17 °C until the end of the sampling period, in early September.

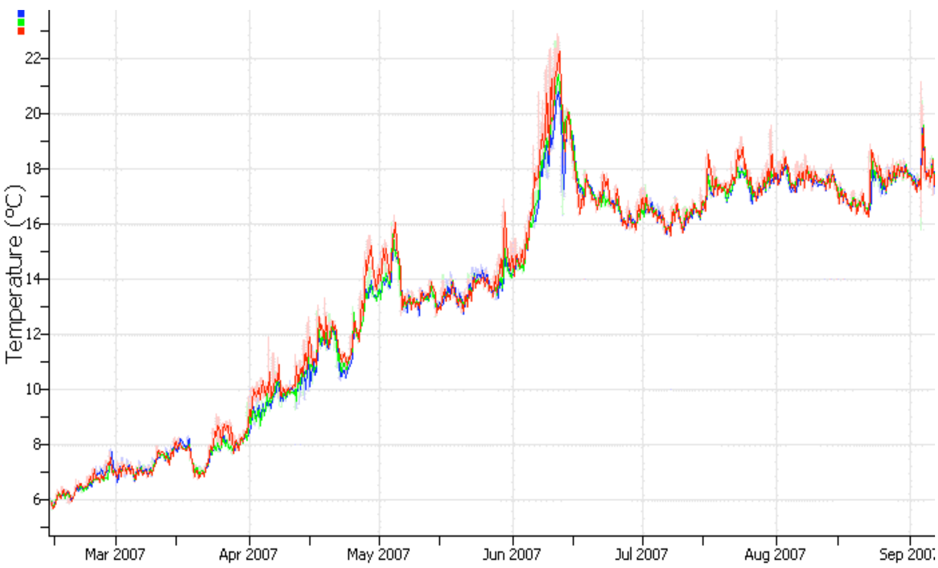

Figure 12. Temperatures recorded by the three temperature data loggers located in Rinerroon Bay during 2007.

7.2. Sediment Analysis

Sediment samples collected at eight sites on the upper lake during 2007 are currently being analysed in the Department of Chemistry, NUIG. When results become available they will be appended to the present document.

7.3. Distribution of *Lagarosiphon major* in Lough Corrib in 2007

Weather conditions during the summer of 2007, particularly in the west of Ireland, were not entirely conducive to survey work of the nature required by the present project (see Meteorological Data, Appendix II). Ideal conditions for conducting aquatic plant distribution surveys combine calm, bright weather with clear water. Under these conditions, it is possible to see much of the aquatic vegetation, particularly tall-growing species such as *Lagarosiphon,* from the boat. Strong winds, turbid and choppy water over prolonged periods during the 2007 sampling season reduced visibility in the water and made sampling from a boat difficult. Furthermore, sampling had to be abandoned on a number of days because of unsafe conditions for boating.

A total of 2,058 sites in the upper, middle and lower lakes where sampled by the survey team between mid-June and the end of September 2007 (Figure 13). It was not possible to survey all of the bays or shores as some were too shallow and rocky to safely access by boat. Grapnel sampling along transect lines or at random locations was the most effective sampling method, although use of the viewing core proved valuable in shallow and clear-water sections.

Plate 9. Underwater photograph of *Lagarosiphon major* in Lazy Bay on the east shore of Lough Corrib in July 2007.

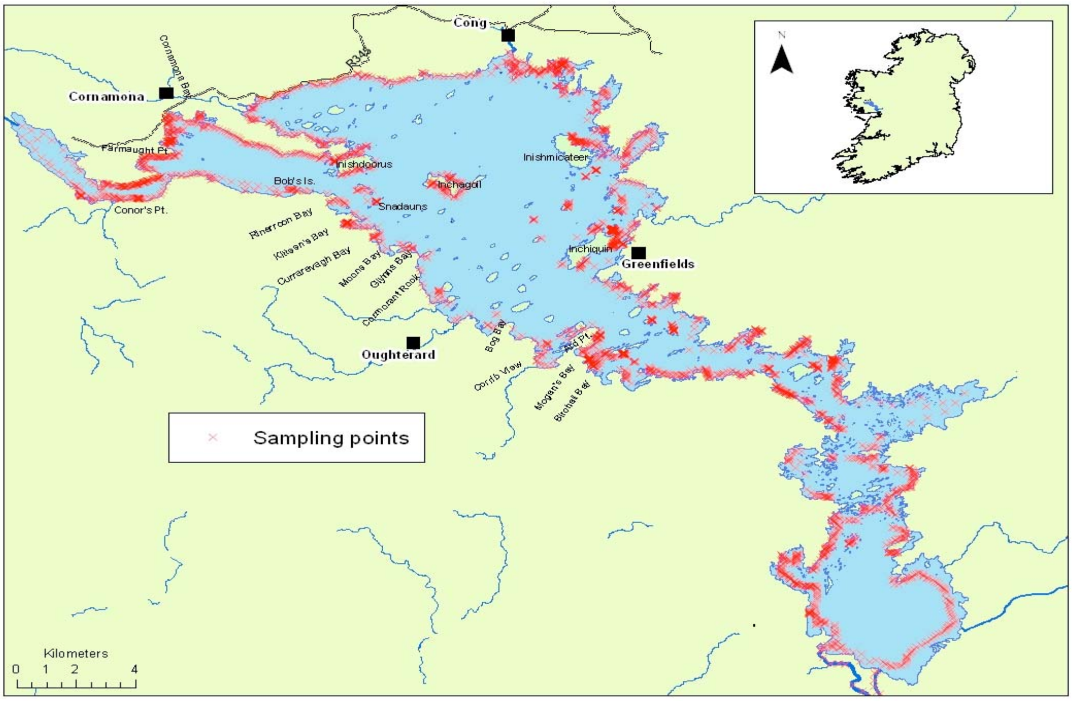

Figure 13. Sampling sites surveyed for the presence of *Lagarosiphon major* between mid-June and late September 2007.

It is clear from the results recorded during the present study that the distribution of *Lagarosiphon* in Lough Corrib has expanded considerably in 2007. The number of sites known to be infested with this highly invasive species increased from 9 in 2005 to 24 in 2006, as previously reported. The number of lake areas from which the plant was recorded in 2007 rose dramatically to 64 by the end of September (Figure 14 a).

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. A number of new sightings on the eastern and northern shores were also recorded (as per Plate 10). One interesting finding was the presence of new sites in the northern arm of the lake. These sightings suggest that, in terms of distribution, the plant is moving upstream, against the primary direction of flow. Whether this is as a result of fragments being transported on boats (or wind action) and establishing farther upstream or simply that previous surveys failed to identify the plant at these locations is unknown.

No specimens of *Lagarosiphon* have yet been recorded from the lower lake. Extensive grapnel and viewing tube surveys in this shallow lake failed to locate the species, although countless areas of the lake contained habitat that appears suitable for its establishment and growth. In areas where traditional survey techniques failed to locate *Lagarosiphon*, yet where habitat conditions were suitable, scuba divers conducted detailed transect surveys. No *Lagarosiphon* was recorded during these underwater operations.

While quantification of the number of sites at which *Lagarosiphon* was recorded in 2007 provides a good indication of the rate at which the plant population is expanding within the lake, it does not give any information on the relative extent of the individual plant stands throughout the watercourse. This information was collected for a total of 41 sites in Lough Corrib. (Time did not permit information at all 64 sites to be collected.)

Plate 10. Single rooting fragment of *Lagarosiphon major* in dense meadow of mixed *Chara hispida* and *C. glomerata* in Kitteen's Bay.

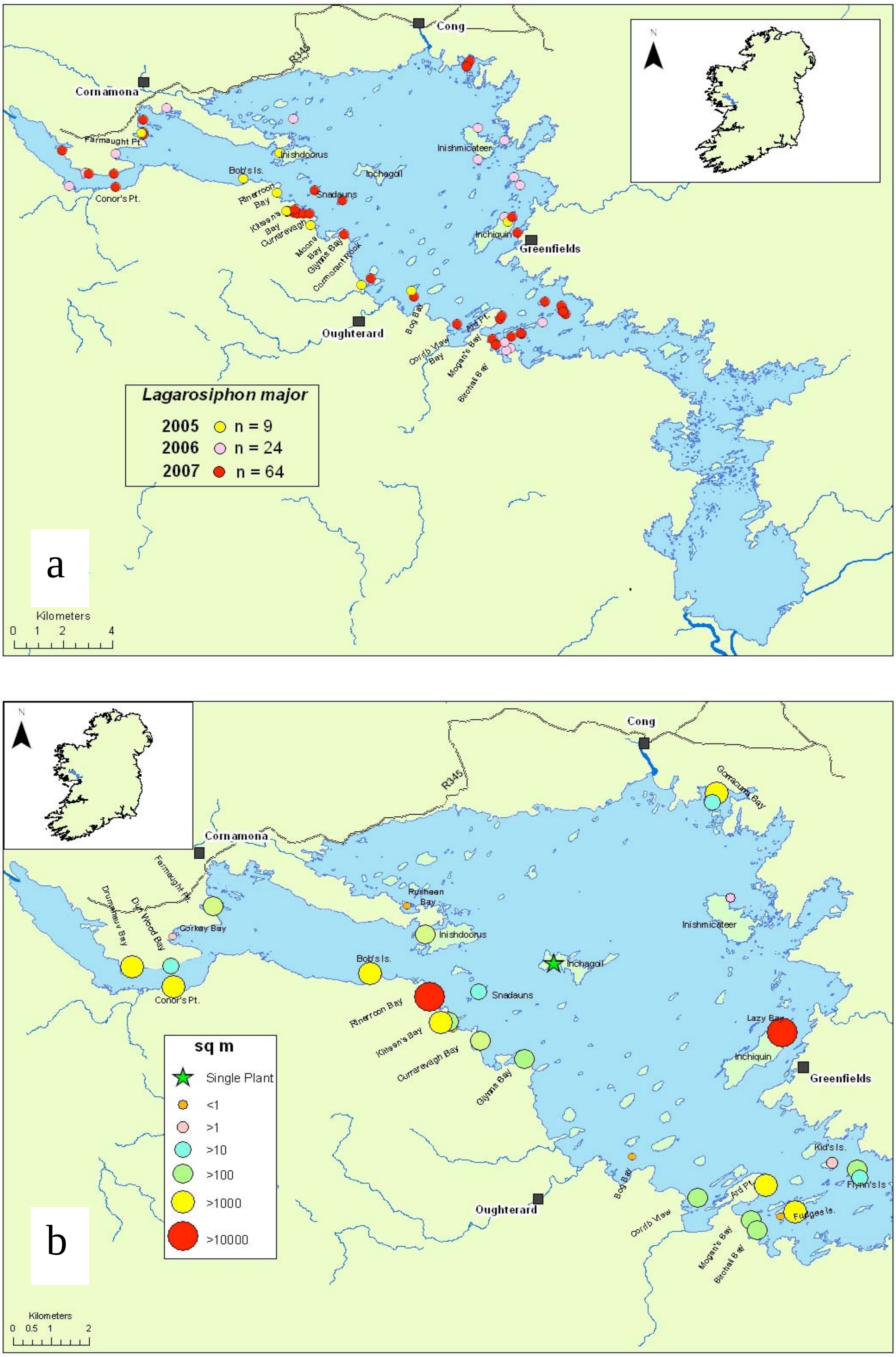

Figure 14. Map showing a) distribution of *Lagarosiphon major* populations in Lough Corrib in 2005, 2006 and 2007 and b) the relative abundance, as percentage bottom cover (m^2), of *L. major* populations in upper and middle Lough Corrib.

Table 1. Area of lake bed (m^2) occupied by *Lagarosiphon major* at 41 sites in upper and middle Lough Corrib in 2007.

Site	Area m^2	Site	Area m^2
Rinerroon	194,526	Snadauns Island	40
Lazy Bay	12,003	Flynns Island	37
Kitteen's Bay	5,523	Kids Bay	8
Bob's Island	3,969	Innismicatreer Island	4
Gorracurra Bay	3,081	Corkey Bay	<10
Kitteen's Bay	2,611	Birchall Bay	<1
Drumanauv Bay	1,749	Birchall Bay	<1
Ard Point	1,630	Birchall Bay	<1
Fudges Island	1,345	Bog Bay	<1
Conor's Point	1,305	Farnaugh Point	<1
The Caol	828	Farnaugh Point	<1
Birchall Bay	713	Flynn Island	<1
Glynns Bay	633	Flynn Island	<1
Currarevagh Bay	435	Fudges Island	<1
Birchall Bay	210	Fudges Island	<1
Corrib view	209	Kitteen's Bay	<1
Farnaugh Point	203	Kitteen's Bay	<1
Flynns Island	155	Kitteen's Bay	<1
Gorracurra Bay	77	Kitteen's Bay	<1
Doon Wood Bay	59	Kitteen's Bay	<1
		Ard Point	<1

The two most densely infested sites on Lough Corrib occurred on either side of the upper lake. These were in Rinerroon Bay on the west shore and in Lazy Bay, near Greenfields, off the east shore. At both sites *Lagarosiphon* grew extensively and occupied 100% ground cover over considerable lake areas (Table 1 and Figure 14 b). By far the largest population of *Lagarosiphon* in the lake was present in Rinerroon Bay, where the plant was first reported. In 2005 the plant occupied an area of 12 ha. By the summer of 2007 the plant had extended its range within the bay to 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.

While only two bays in the lake had a *Lagarosiphon* coverage of greater that 10,000 m^2, a further eight sites contained populations that covered between 1,000 and 10,000 m^2 (Table 1). Five of these sites were located on the western side of the lake (two in Kitteen's Bay), one on the eastern shore, in Gorracurra Bay, and two in the middle lake (Figure 14 b).

At a further eight of the sites where the lake bed area occupied by *Lagarosiphon* was measured, stands occupying between 100 and 1,000 m^2 were recorded (Table 1). Four of these lake areas were located in the middle lake, three on the western and one on the northern shore (Figure 14 b). An underwater examination of the sites revealed various degrees of colonization of the native charophyte meadows by tall, light occluding *Lagarosiphon* stands. At the remaining sites examined in 2007 only scattered, low-growing populations of *Lagarosiphon* were recorded. Many of the stands occupied less that 1 m^2 (Table 1) and had probably only recently been colonised.

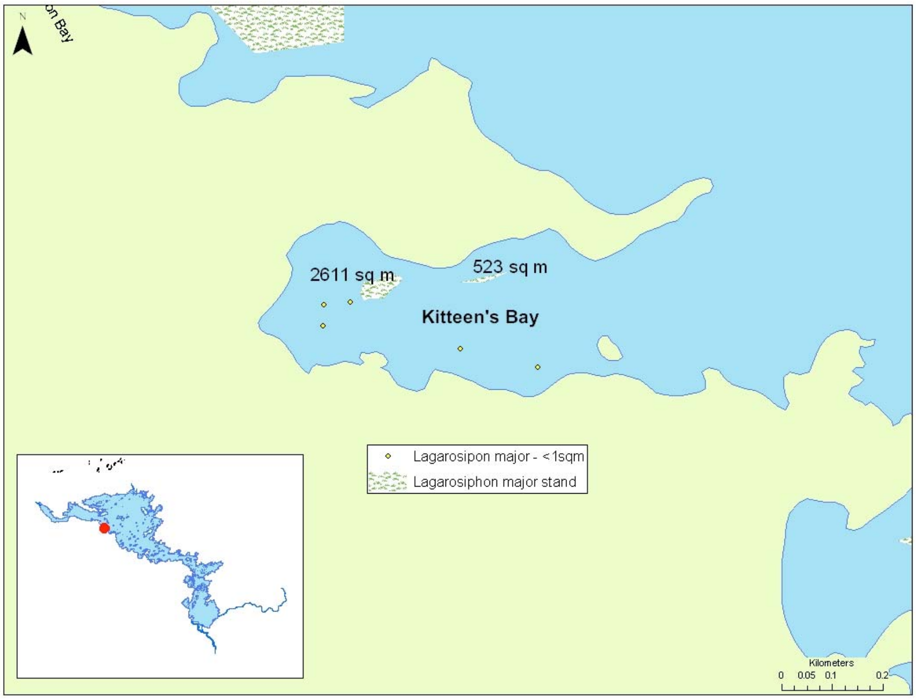

Figure 15. Map showing the locations of seven discrete *Lagarosiphon* populations in Kitteen's Bay in 2007.

A number of the bays, shorelines or islands that were infested with *Lagarosiphon* presented more than one established population, in addition to a number of new or potentially new colonies. For example, in Kitteen's Bay (north of Oughterard on the western shore), two discrete, large and well established populations (Table 1) and five small, isolated plant stands were recorded (Figure 15). Multiple populations were also recorded at Birchall Bay (Figure 16), Farnaugh Point, Flynn Island, Ard Point and Fudges Island. While the populations within these bays and littoral areas remained discrete during 2007, it is probable that (in the absence of timely control) they will ultimately expand and coalesce to overgrow each of these bays.

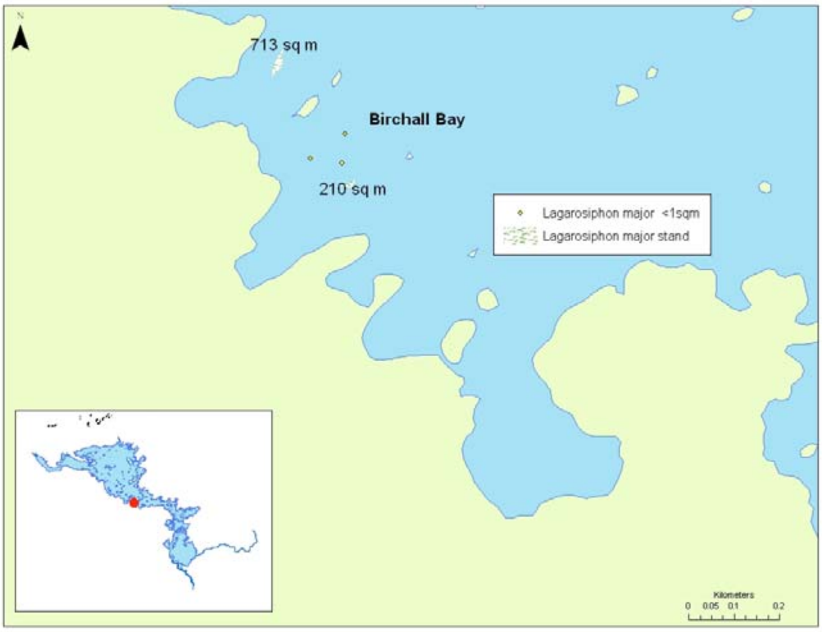

Figure 16. Map showing the locations of two established *Lagarosiphon* populations and three recently colonised stands in Birchall Bay in 2007.

7.4. Macrophyte Survey

Plate 11. Tall stems of *Potamogeton lucens* emerging from a low-lying meadow of *Chara glomerata* in Currerevagh Bay (water 3 m deep).

In most of the bays examined to determine the detailed distribution of *Lagarosiphon*, an abundant and diverse macrophyte flora was recorded. Charophytes were the dominant submerged plant group and 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. Other macrophyte species that produced locally dominant stands in the upper, middle and lower lakes were *Myriophyllum spicatum*, *Potamogeton lucens* (Plate 11), *P. perfoliatus* and *Elodea canadensis*. All of these species are capable of producing relatively dense monodominant stands and have stems that can reach the surface in relatively shallow (< 3 m) water. They also grow in mixed assemblages where they provide a diverse habitat structure for resident macroinvertebrate and fish species. These species, however, rarely grow with sufficient abundance to competitively exclude, through light occlusion, the dense understorey of charophyte vegetation. Other macrophyte species that were common throughout the lake included *Potamogeton gramineus, P. pusillus* and *Fontinalis antipyretica*. These species generally formed less dense vegetative stands although, in places, the moss *Fontinalis* created deep and intricate swards of low-growing vegetation. Macrophyte species that were more typically recorded in the lower lake included *Potamogeton pectinatus, Ceratophyllum demersum* and *Utricularia minor*.

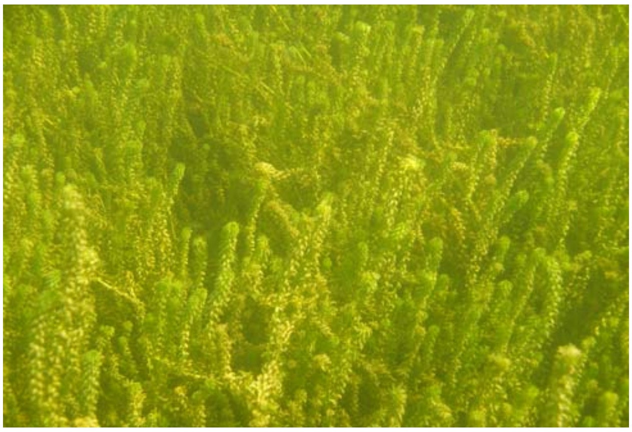

Plate 12. Monodominant expanse of *Lagarosiphon major* in Rinerroon Bay.

Two very different plant communities were encountered when macrophyte inventories were taken in bays dominated with *Lagarosiphon* (Rinerroon) and in bays with little or no *Lagarosiphon* (Currerevagh and Moon's). In Rinerroon Bay, which supported very extensive stands of *Lagarosiphon (circa* 85% bottom cover during the summer of 2007), few other macrophyte species were recorded with any abundance (Plate 12). Those that were present were struggling for existence, depauperate or confined to small areas where *Lagarosiphon* had not yet colonised. In the shallow margins, where most transects started, relatively thin strips of robust *Chara hispida* var *rudis* were recorded. These were rapidly invaded by the tall and dense stands of *Lagarosiphon* and, within 10 to 20 m of the shoreline, no charophyte vegetation was present. For the remainder of the transect, to the outer perimeter of the bay, *Lagarosiphon* was totally dominant. Occasional, single plants or small isolated stands of *M. spicatum, P. lucens* or *E. canadensis* were present. Quadrat analysis in Rinerroon Bay supported the results from transect surveys and revealed a total dominance of the canopy-forming invasive plant species (Table 2).

Table 2. Percentage bottom cover occupied by macrophyte species in 0.5 m^2 quadrats in Rinerroon Bay, Lough Corrib, in 2007.

	Quadrat Number									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Chara globularis	-	-	-	-	-	-	-	-	-	-
Chara hispida v. rudis	-	-	-	-	-	-	-	-	-	-
Elodea canadensis	<1	-	-	-	2	5	-	-	-	5
Isoetes lacustris	-	-	-	-	-	-	-	-	-	-
Lagarosiphon major	95	100	100	90	95	70	100	95	100	90
Myriophyllum spicatum	-	-	-	2	2	5	-	-	-	-
Potamogeton perfoliatus	-	-	-	-	-	-	-	-	-	-
P. lucens	5	0	-	-	5	5	-	-	2	-
P. pusillus	-	-	-	-	-	-		-	-	-

Currerevagh Bay supported an expanding, although as yet relatively restricted (*circa* 5% bottom cover), *Lagarosiphon* population in 2007. No *Lagarosiphon* was recorded in Moon's Bay during this season. Two *Chara* species dominated the submerged flora in these bays (Tables 3 and 4). A definite depth zonation was evident between these species. *C. hispida* formed dense carpets of relatively tall (to 0.4 m), robust and spiny vegetation in water from 1 to 2.5 m deep. In deeper water, still within the confines of these sheltered bays, equally dense, although more diminutive, meadows of *C. glomerata* grew to a maximum depth of 4.5 m. Within their respective depth zones, the two *Chara* species occupied between 75% and 100% bottom cover (Plate 13). While *Chara* species clearly dominated the flora in Currerevagh and Moon's Bays, other macrophyte species were locally prevalent (Tables 3 and 4).

Table 3. Percentage bottom cover occupied by macrophyte species in 0.5 m^2 quadrats in Currerevagh Bay, Lough Corrib, in 2007. Transects 9 and 10 were recorded from the small area within the bay that was occupied by *Lagarosiphon*.

	Quadrat Number									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Chara globularis	-	100	100	10	-	-	70	90	-	-
Chara hispida v. rudis	100	-	-	80	90	100	20	-	-	-
Elodea canadensis	10	-	-	15	10	10	-	-	-	20
Isoetes lacustris	-	-	-	-	-	-	-	-	-	-
Lagarosiphon major	-	-	-	-	-	-	-	-	85	70
Myriophyllum spicatum	10	5	5	-	25	-	10	15	5	5
Potamogeton perfoliatus	10	-	-	10	2	10	5	-	-	-
P. lucens	-	15	10	-	-	-	10	5	2	-
P. pusillus	-	-	-	-	-	-	<1	<1	-	-

Table 4. Percentage bottom cover occupied by macrophyte species in 0.5 m^2 quadrats in Moon's Bay, Lough Corrib, in 2007.

	Quadrat Number									
	1	2	3	4	5	6	7	8	9	10
Chara globularis	75	100	-	80	-	-	90	75	40	-
Chara hispida v. rudis	10	-	10	-	90	90	-	10	-	100
Elodea Canadensis	-	10	-	-	5	-	20	-	10	5
Isoetes lacustris	-	-	10	-	-	-	-	-	-	-
Lagarosiphon major	-	-	-	-	-	-	-	-	-	-
Myriophyllum spicatum	-	5	-	20	-	-	15	-	10	-
Potamogeton perfoliatus	-	-	-	-	-	15	-	-	20	-
P. lucens	-	-	-	-	25	-	-	20	-	-
P. pusillus	5	-	-	5	-	5	-	-	5	-

Plate 13. Dense low-growing carpet of *Chara hispida* var *rudis* in Moon's Bay, Lough Corrib in July 2007.

In the relatively small area of Currerevagh Bay colonised by *Lagarosiphon*, a different macrophyte community composition and structure was observed. The tall-growing invasive occupied between 70 and 100% bottom cover within this area and some canopy cover was present. In this *Lagarosiphon* zone, no charophytes were recorded. Two quadrat samples were taken within this zone to verify the observations from the transect surveys. These revealed a total absence of *Chara* vegetation and a reduced associated aquatic flora (Transects 9 and 10 in Table 3).

7.5. Macroinvertebrate Survey

The results from this phase of the study are presented in Appendix III.

7.6. Fish Survey

A total of five fish species were captured in the eight multimesh nets deployed in Rinerroon and Moon's Bays in October 2007. These were roach (*Rutilus rutilus*), perch (*Perca fluviatilis)*, pike (*Esox lucius*), bream (*Abramis brama*) and brown trout (*Salmon trutta*) (Figure 17). All five species were present in Moon's Bay, while bream were not recorded in Rinerroon Bay during this preliminary survey.

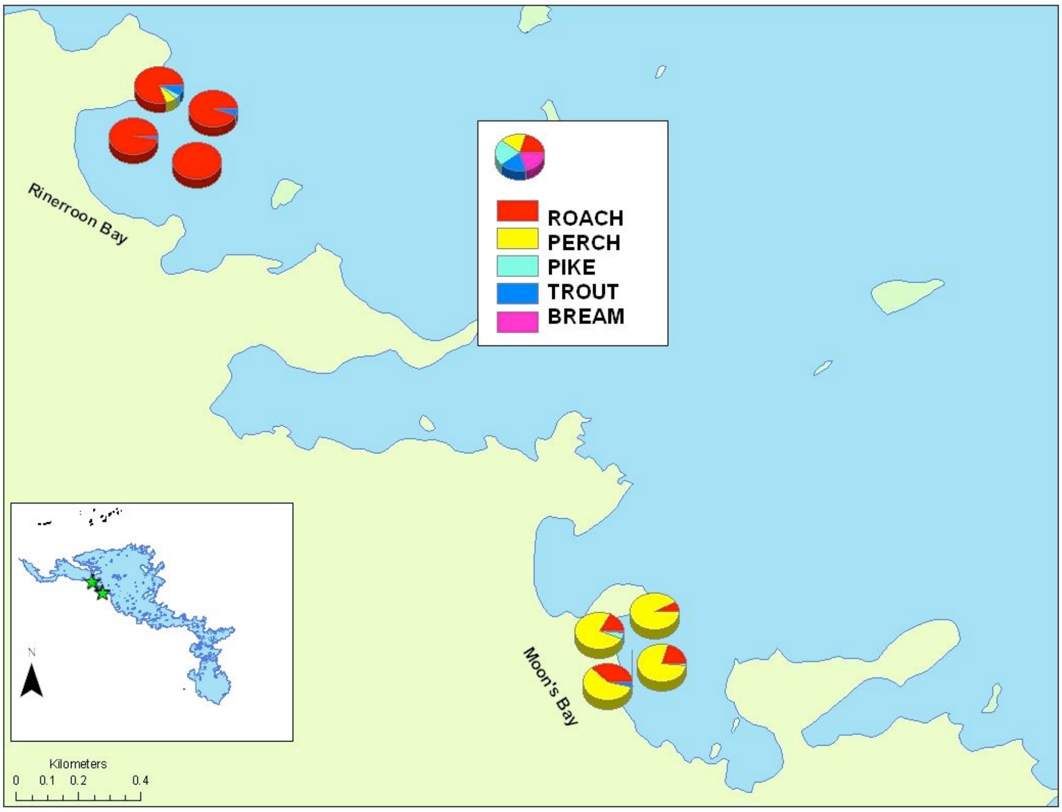

Figure 17. Relative representation of fish species caught in each of the multimesh nets deployed in Rinerroon and Moon's Bays in October 2007.

Roach was the most abundant species present in Rinerroon Bay during the survey (Figures 17 and 18). This species was caught in all 4 multimesh nets deployed (Figure 17). It represented 93.8 % of all of the fish caught in the nets. The roach captured ranged in fork-length between 10 and 30 cm and in weight from 10 to 600 g (Figure 19). The piscivorous pike was the next most numerous species present in the nets and represented 3.8% of all fish caught (Figure 18). The pike captured were generally small and ranged in fork length between 8 and 50 cm and in weight between 20 and 450 g. Perch was recorded in low number. Another piscivorous fish, the perch, represented just 1.6% of the fish captured (Figure 18). These fish were again small and ranged between 10 and 13m in fork-length 10 and 31 g in weight. Only one brown trout was caught. This fish measured 48 cm in fork-length and weighed 400 g.

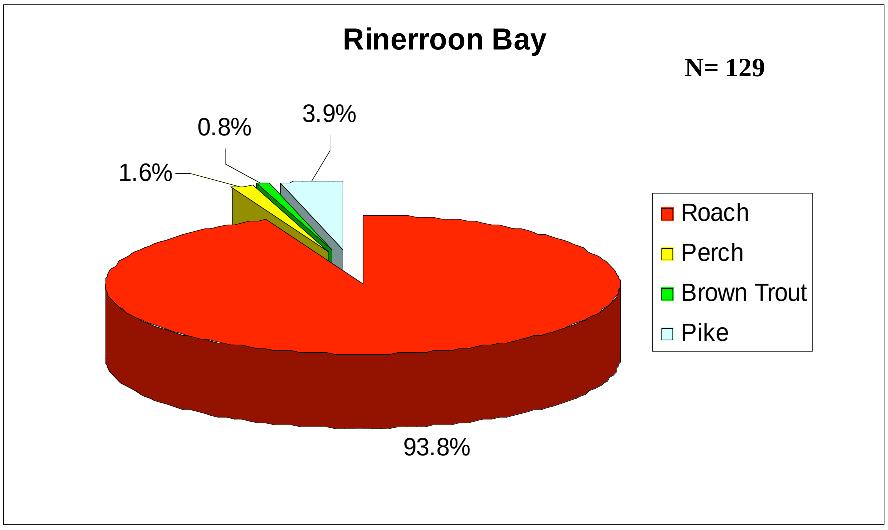

Figure 18. Relative representation of each fish species captured in the four multimesh net deployed in Rinerroon Bay in October 2007.

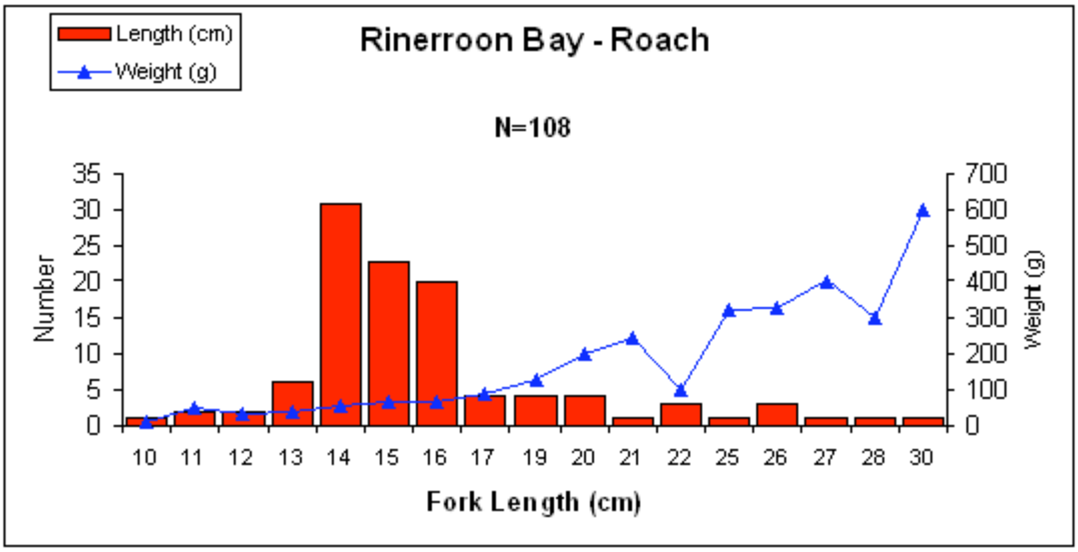

Figure 19. Length-weight and length-frequency distribution of roach captured in Rinerroon Bay in October 2007.

In the Moon's Bay sample, perch was the most numerous of the fish species captured, forming 83.4 % of all fish caught in the nets (Figure 20). The perch were generally small and ranged in fork-length between 6 and 31 cm and in weight from 5 to 100 g (Figure 21). Roach was the second most numerous species and represented 14.6% of the fish caught. The fish were of a similar size range to those taken in Rinerroon Bay and ranged in fork-length between 10 and 29 cm and in weight between 8 and 500 g.

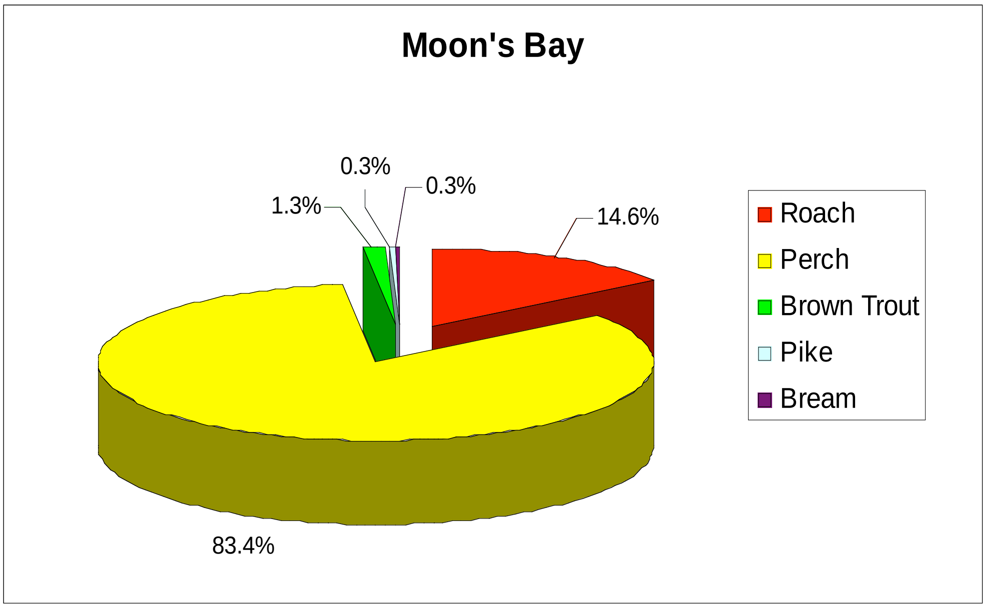

Figure 20. Relative representation of each fish species captured in the four multimesh net deployed in Moon's Bay in October 2007.

Four brown trout were taken in the nets. These fish ranged between 15 and 75 cm in fork-length and between 70 and 2,500 g in weight. Only one small pike (41 cm) and one bream (35 cm) were recorded from the nets.

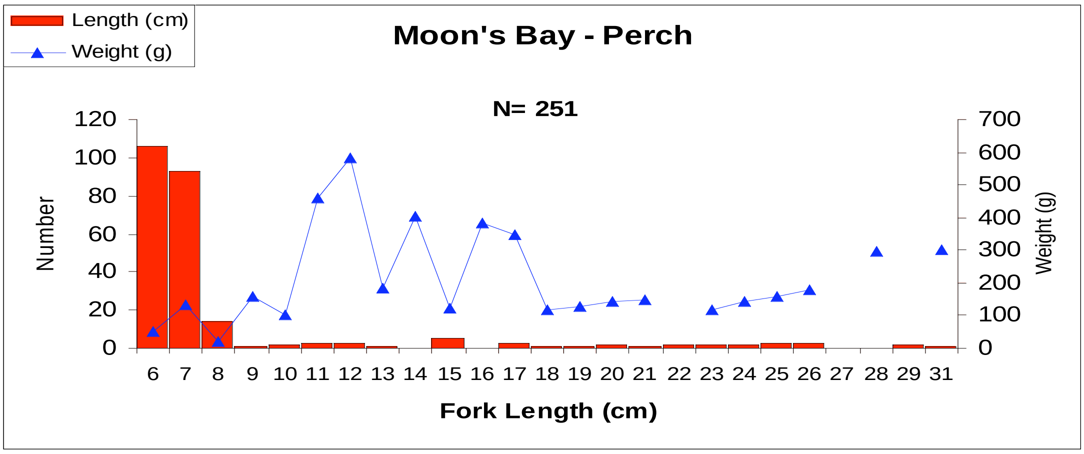

Figure 21. Length-weight and length-frequency distribution of perch captured in Moon's Bay in 2007.

The total number of fish caught per multimesh net (CPUE) was 31 in Rinerroon Bay and 75 in Moon's Bay. The catch for individual fish species (NCPUE) was highest for roach in Rinerroon Bay and for perch in Moon's Bay (Figure 22).

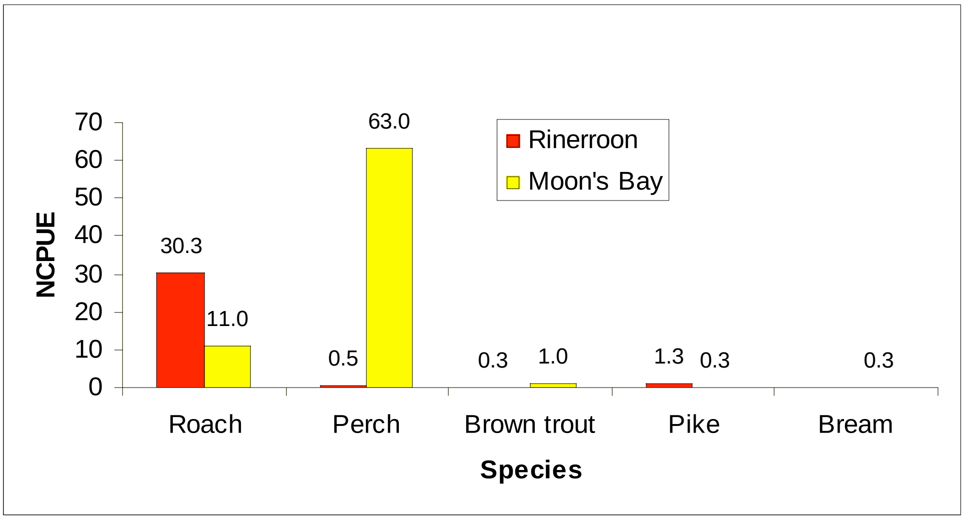

Figure 22. Relative number of each fish species captured in Rinerroon Bay and Moon's Bay in October 2007.

Plate 14. Perch (*Perca fluviatilis*) from Moon's Bay, Lough Corrib recorded during netting operation in October 2007.

7.7. *Lagarosiphon major* - Habitat and Life Cycle Characteristics

7.7.1. *Habitat*

An examination of the distribution of *Lagarosiphon* in Lough Corrib has shown that the plant is relatively widespread in the upper and middle lakes, particularly in sheltered, shallow bays and littoral areas. The plant is absent from rocky or boulder-strewn locations within the lake, particularly where these areas are exposed to the prevailing winds and consequent wave action. No *Lagarosiphon* was recorded from the lower reaches of the middle lake or from the lower lake itself.

Lagarosiphon grows most luxuriantly and establishes dense, monospecific vegetative stands in areas where deep deposits of fine silt and organic mud accumulate. One habitat that is ideal for colonisation by this deep-rooting plant is that provided where meadows of charophyte vegetation have established. The coarse *Chara* vegetation traps the *Lagarosiphon* fragments as they drift along the lake bed and permits time for the roots to penetrate the soft mud that has been deposited or accumulated beneath the *Chara* beds. Such charophyte meadows are extensive throughout Lough Corrib, a factor that probably contributed to the successful spread of the *Lagarosiphon* in this lake. This invasive plant is also capable of establishing and growing in more coarse-grained substrates. Along the highly calcified and rocky margins of Lazy Bay on the eastern side of Lough Corrib, where the second largest population of *Lagarosiphon* was recorded (see Section 7.3.), the plant has managed to establish and grow (Plate 15). Small stands of the plant have also been recorded growing in sandy areas, where the amount of organic mud and silt is minimal (Plate 16). While the plants present in these less favourable habitats may not be as healthy as elsewhere, they are capable of perpetuating the species in this part of the lake and of providing viable fragments to ensure further dispersal.

Plate 16. A single *Lagarosiphon* plant growing in sandy substrate off the east side of Inchagoill Island.

Plate 15. *Lagarosiphon* growing in a calcified and rocky section of Lazy Bay on the eastern side of upper Lough Corrib.

The plant has a wide depth tolerance and, in Lough Corrib, was recorded growing at depths from 0.12 to 6.5 m. In a number of small harbours and boat slipways around the upper lake, *Lagarosiphon* was found growing almost onto the shoreline (Plate 17). These areas tend to be quite sheltered and provide a relatively conducive habitat for colonisation by the plant. The deepest sighting for the plant was at Conor's Point, at the northern end of the upper lake, where an expansive population *Lagarosiphon* was present. The shoreline in this area is relatively steep and the *Lagarosiphon* formed a dense vegetative swathe parallel to the shore at a depth range of between 1.5 and 4 m. No surface canopy was present at the time the survey was conducted, although plants to 3 m long were recovered. Beyond a depth of 4 m, the density of the plant stands decreased significantly and, at 6.5 m, only a few, isolated plants were present.

Plate 17. *Lagarosiphon* growing on a coarse substrate in water less than 15 cm deep at a boat slipway in Rinerroon Bay.

7.7.2. Life Cycle Features

Plant reproduction in *Lagarosiphon*, outside its native range, is solely vegetative, *via* fragments. Stem fragments, detached from established plants, settle on the lake bed or amongst low-growing aquatic vegetation and produce new growth from deeply seated cortical buds. Growth and anchorage is most rapid and effective in shallow water (*c*. 2 m) where light can readily penetrate to the lake bed. A soft and deep mud substrate makes rooting more easy for the plant. Multiple branching of the single stem as it ascends in the water column produces the dense growth that is typical of the upper, near-surface mass of stems. Lateral spread of the colony occurs when vertical shoots lose buoyancy, sink to the bottom and act as 'rhizomes' in which cortical buds develop (Coffey, 1970). The horizontal shoots have greater storage reserves and, hence, grow faster than small, isolated fragments (Brown and Dromgoole, 1977). Observations in Rinerroon Bay, and in other bays where mature stands of *Lagarosiphon* are present, have revealed some unusual growth patterns. In 2005, when the presence of this invasive species in the lake was first confirmed, extremely dense, canopy-forming plants populated the bay from April to November. Active growth continued through the winter, with the plant showing no signs of die-back until May 2006. The die-back at this time followed a prolonged cold spell in April, accompanied by significant night-time frosts. In early May 2006 the surface vegetation turned an unhealthy brown colour and the leaves were shed from the tall, ascending stems. By June, the majority of the stems had collapsed and lay in tangled masses on the lake bed (Plate 18). Many detached, floating carpets of canopy vegetation were released at this time and these were dispersed, under the influence of wind and water currents, throughout the lake. During the summer months the relatively leafless and often discoloured stems produced small buds and occasional, long, single adventitious roots. Plant fragments on the lake bed, beneath the collapsed vegetation, continued to grow and maintained a dense ground cover. In September and October 2006 the numbers of buds, and their associated adventitious roots, produced by the stems increased significantly. As water temperatures and day length decreased, the vegetative vigour of the *Lagarosiphon* plants also increased. By November, even though water levels in the lake were approaching record highs, healthy plants again produced a dense surface canopy.

Plate 18. Underwater photograph showing collapsed stems of *Lagarosiphon major* in Rinerroon Bay in July 2006.

Active plant growth was maintained over the winter and spring months until early May 2007 when, following an unusually warm, dry and bright April, the plant again went into decline. As had happened in May 2006 following unusually cold weather, a large proportion of the stems collapsed and lost their leaves. The plants continued to grow through the summer period, although did not produced the volume or standing crop of vegetation that was present in the summer of 2005. Active regrowth of *Lagarosiphon*, from buds on depauperate stems and from rooted fragments, was again recorded in late October and November 2007.

7.8. *Lagarosiphon* Control

7.8.1. *Pilot Trials*

The progress of pilot control trials conducted on *Lagarosiphon* in Rinerroon and Currerevagh Bays in December 2006 and January 2007 was monitored during spring and summer 2007, and quantitatively evaluated in September 2007. Neither manual removal by scuba divers nor the use of the aquatic herbicide, dichlobenil, proved effective in reducing the percentage cover of *Lagarosiphon* in the treatment plots (Table 5). In respect of the manual control, this reflected the fact that the lake substrate in which the *Lagarosiphon* was rooted was extremely fine and was brought into suspension with the slightest disturbance (Plate 19). Visibility was, therefore, reduced to zero once the plant removal operation commenced. The treatment was abandoned because of the impracticality of the operation, combined with the fact that it was being conducted in winter when the water temperature was 7 ^{o}C.

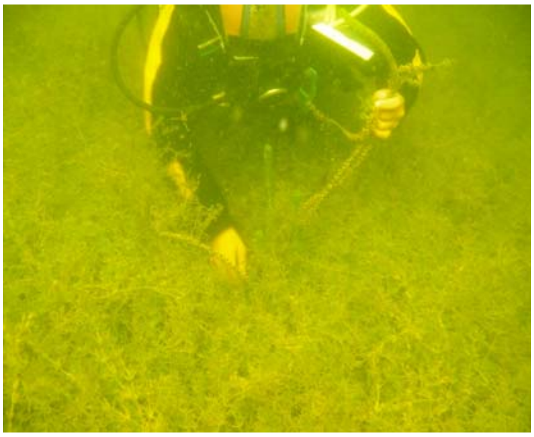

Plate 19. Effect on turbidity in the water of hand pulling *Lagarosiphon major* stems from within charophyte beds in upper Lough Corrib.

With regard to the herbicide treatment, *Lagarosiphon* occupied *circa* 60% cover in the 50 x 50 m treatment plot at the time of spraying and a dense surface canopy was present. It is probable that a significant proportion of the herbicide granules became trapped within the vegetation and failed to reach the lake bed, which is the site of activity for dichlobenil (Caffrey, 1993a and 1993b). The net result would have been a non-toxic dose of dichlobenil in the mud within the trial plot. In the months following treatment, the weed in the trial plot became chlorotic and limp, but did not die down fully. Active regrowth among the previously unhealthy plants resumed in late April. By September the percentage cover occupied by *Lagarosiphon* in the treatment plot had increased to 75% as a consequence of natural expansion of the population (Table 5).

Black geotextile was used to block incident light from contributing to plant photosynthesis in two 50 x 50 m plots (see Figure 8). In one plot the weed was cut prior to placing the geotextile while, in the second, no weed cut was applied. Considerable difficulty was experienced fixing the geotextile to the lake bed over this large area (2,500 m^2). In the cut plot the task proved less onerous and effective coverage of at least 80% of the plot was achieved by divers. Where large stands of tall-growing *Lagarosiphon* occupied the water column, it was virtually impossible to fix the geotextile to the lake bed. Here, less than 30% of the plot was effectively covered to the point of total light exclusion. The results obtained when the geotextile was lifted in September reflected the difficulties encountered in placing the light occluding material. Where the cut had been applied, no vegetation was present in the area of the plot that was effectively covered. By contrast, at least 50% of the plot that did not receive a cut prior to geotextile placement supported healthy *Lagarosiphon* (Table 5).

Table 5. Results from weed control treatments on the percentage bottom cover of *Lagarosiphon major* in 50 x 50 m plants in Rinerroon and Currerevagh Bays in 2007.

	Treatment Plants		**Control Plants**	
	Pre-treatment	**September 2007**	**Pre-treatment**	**September 2007**
Hand Removal	<5%	10%	0%	0%
Herbicide	60%	75%	50%	65%
Uncut & Geotextile	90%	50%	100%	100%
Cut & Geotextile	70%	0%	100%	100%
Mechanical Cut	100%	8%	100%	100%

A weed cutting boat fitted with a deep-cutting V-blade trailed on an 8 m-length of chain was used to apply the mechanical cut (Plate 20).The edges of the blade are not sharpened and are designed to pull or rip the vegetation by the roots rather than to cut it cleanly. Divers estimated that in excess of 95% of the *Lagarosiphon* was removed during this operation, which was conducted in January (Plate 21). The cut weed was immediately harvested and removed from the lake. In September, percentage bottom cover in this plot was *circa* 8%. At least some of this new growth resulted because fragments from adjacent uncut areas had settled and rooted in the area of lake bed that was exposed by the cutting. This high level of control was unexpected and possibly demonstrates the susceptibility of *Lagarosiphon* to the destructive effect of the V-blade.

Plate 20. V-blade used to cut *Lagarosiphon major* in Rinerroon Bay.

7.8.2. *Lagarosiphon Control in 2007*

7.8.2.1. *Hand Removal using Divers*

The initial trial where hand pulling of *Lagarosiphon* was tested was conducted in unfavourable conditions in Currerevagh Bay. To trial the effectiveness of hand pulling in controlling newly colonised or low-density sites, a site at Gorracurra Bay, located on the north-eastern shore of the lake (see Figure 14 b), was selected. In this large bay a relatively small (*c.* 80 m^2) and seemingly isolated population of *Lagarosiphon* was identified during survey work in July 2007. The operation was undertaken in September 2007. Having successfully removed the majority of the vegetation, it was discovered that a much larger

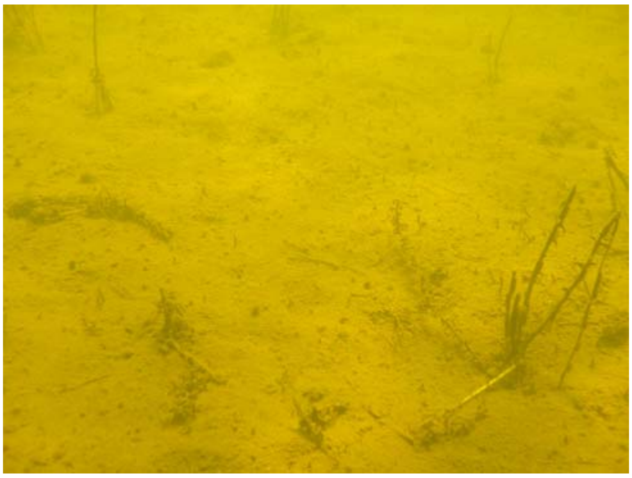

Plate 21. The bed of the lake in Rinerroon Bay following cutting using the V-blade in January 2007.

population of *Lagarosiphon* (estimated at 3,081 m^2) occupied another area of the same bay, some 600 - 800 m away from the cleared area. The plants in this stand were relatively low-growing and did not reach the water surface. This fact, combined with the poor weather conditions that operated when the original survey of this area was conducted, probably contributed to the omission of this *Lagarosiphon* stand. Accepting the fact that another stand of *Lagarosiphon* is present in the same bay, the efficacy of the hand removal will be monitored through 2008.

7.8.2.2. *Extended Mechanical Cutting Trial*

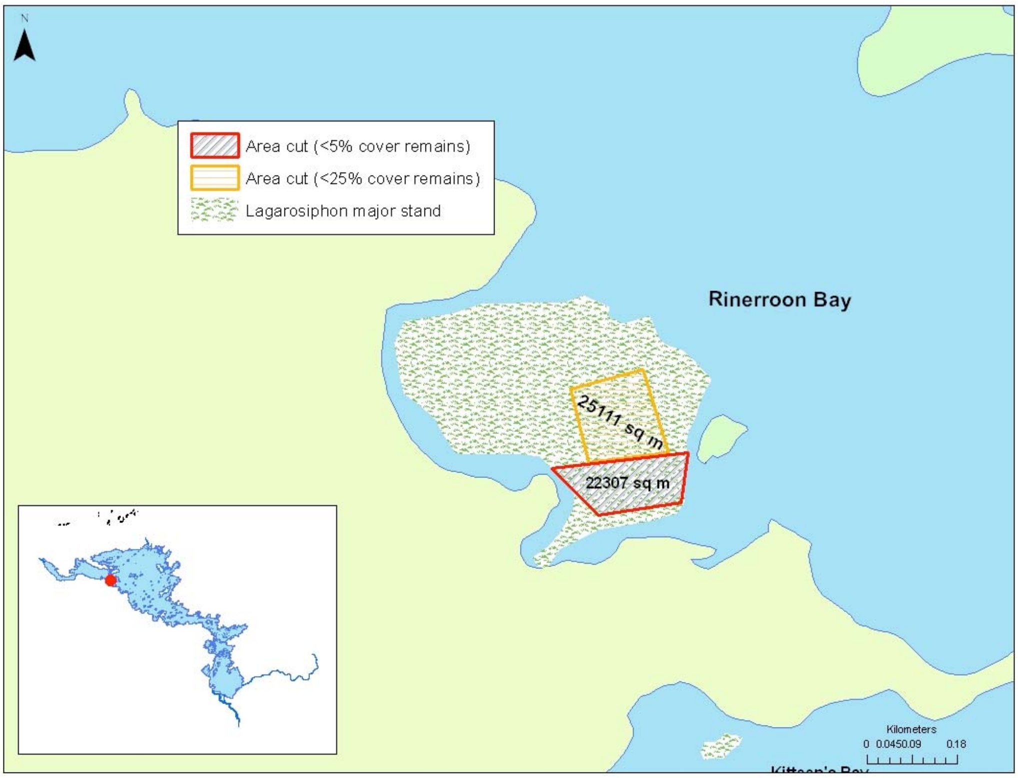

Figure 23. Map of Rinerroon Bay showing the section that was mechanically cut during the extended trial in September 2007.

Because of the positive results obtained using mechanical cutting, it was decided to extend this trial and to attempt to remove a large biomass of *Lagarosiphon* from a greater area of Rinerroon Bay. The V-blade was again used to cut or pull the rooted vegetation (see Plate 20). A large boat with a hydraulic arm was employed to remove the weed from the water and load it onto a land-based trailer (Plate 22 a). From here, the weed was transported away from the lake to an isolated green field site, distant from any natural watercourses (Plate 23).

Plate 22. a) Hydraulic lifter removing cut *Lagarosiphon* from Rinerroon Bay and b) loading it onto a trailer for transportation from the lake.

During the five days that the contractors operated on Rinerroon Bay, *Lagarosiphon* in a lake area measuring *circa* 4.7 ha was cut (Figure 23). A diving survey conducted during the operation revealed that a significant volume of *Lagarosiphon* remained in the treatment area following the first cut and that further cutting was required. However, sufficient time was only available to intensively cut 2.2 of the 4.7 ha initially targeted (Figure 23). In the aftermath of the extended cutting trial, divers estimated that less than 5% *Lagarosiphon* cover remained in the intensively cut section, while up to 25% cover was present on the remaining 2.5 ha of lake bed. It is estimated that up to 300 tonnes of vegetation was removed from the bay on this occasion.

Plate 23. Cut *Lagarosiphon* from Rinerroon Bay being stockpiled at a location distant from Lough Corrib or any other natural watercourse.

It was noticeable that a considerable volume of tough root material was protruding from or lying on the mud substrate following the cut. In addition, occasional large rafts of cut vegetation lay on the lake bed and did not immediately float to the surface.

7.9. Literature Review

A review of the literature dealing with *Lagarosiphon major* and its implications for the management of waterways worldwide is presented in Appendix V.

8. PUBLIC AWARENESS

Public awareness is an essential element of any campaign that proposes to eradicate an existing invasive species or to prevent the entry of a new invasive species into a lake or catchment. Prior to the commencement of the present project (June 2007), a considerable amount of education and public awareness work had been conducted in the Lough Corrib catchment in an effort to keep out the Zebra mussel (*Dreissena polymorpha*). Foremost in this campaign was the Western Region Zebra Mussel Control Initiative. The good work conducted by this Initiative provided a springboard for a new campaign aimed at alerting the widest possible audience of the threats posed by a new and highly aggressive invader in the form of *Lagarosiphon major*. Personnel and organizations linked to the WRZMCI have worked closely with the *Lagarosiphon* Task Force to produce awareness leaflets, press releases, calendars, lakeside notifications and an information website (www.alienspecies.ie), warning of the environmental, economic and social hazards posed by this plant (see Section 1).

During the term of the current project a number of initiatives to heighten public awareness of *Lagarosiphon*, and other high impact invasive species, were undertaken. The most high profile was a visit by a leading aquatic weed management expert from New Zealand (Dr John Clayton) to Lough Corrib. Dr. Clayton, a Senior Scientist with the National Institute of Water and Atmospheric Research (NIWA), has 30 years experience in researching the problems posed by *Lagarosiphon*, and other invasive weeds, in New Zealand hydrolakes. Through his research, Dr Clayton has managed to successfully eradicate *Lagarosiphon* from a number of important lake systems in New Zealand. Dr Clayton was invited to present a talk in the Galway Bay Hotel on 28th September and, subsequently, to visit Lough Corrib and view the problem firsthand.

Press releases from the CFB and the WRFB advertised the talk widely and gave some background on the nature of the problem. The event received considerable impetus when Mr Eamon O'Cuiv T.D. and Minister for Community, Rural and Gaeltacht Affairs agreed to address the forum (Plate 24). One hundred and forty invited guest and interested members of the public attended the talks. The forum was announced on local and national radio on the morning of the 28th, which probably contributed to the large number of attendees. The visit by Dr Clayton received considerable attention in the media following the event and, clearly, brought the invasives issue to the fore again.

Plate 24. From left to right: Dr Joe Caffrey (CFB), Professor Michael Hynes (NUIG), Eamon O'Cuiv, T.D. & Minister for Community, Rural Affairs, Gaeltacht and the Islands, Dr Greg Forde (WRFB) and Dr John Clayton (NIWA).

An information leaflet was produced and issued to anglers and angling clubs in the Lough Corrib catchment (Plate 25). Personal contact was made with anglers and boaters and their help was sought with reporting sightings of the plant and ensuring to clean all of their equipment. In addition, the CFB produced a 'Guide to the Identification of Aquatic Invasive Species in Ireland' (Caffrey and O'Callaghan, 2007), which provides a simple photographic aid to the identification of a number of invasive species, including *Lagarosiphon.* The Guide warns of the problems associated with invasives and describes how to avoid spreading them within the country.

Plate 25. Information leaflet issued to anglers and angling clubs throughout the Lough Corrib catchment.

During the summer a member of the survey team presented talks to and brought science and environmental students from NUIG to Lough Corrib to examine the *Lagarosiphon* and to see what impact it was having on indigenous biotic communities and on recreational exploitation in overgrown bays (Plate 26). In addition, Prof Michael Hynes (NUIG) presented a number of talks to community groups and to his students on the topic of invasive species, particularly those impacting on Lough Corrib.

Plate 26. Dr Acevedo with NUIG science students on the shore of Lough Corrib.

The mechanical cutting operation that was conducted in Rinerroon Bay in September 2007 captured the imagination of the public, to the extent that a crew from RTE was sent to film the proceedings and conduct interviews with those involved (Plate 27). The event received favourable coverage and further heightened awareness of the problems posed by the plant in Lough Corrib.

Plate 27. RTE filming staff from CFB and WRFB during the extended mechanical cutting trials that were conducted in Rinerroon Bay in September 2007.

The Invasive Species in Ireland Forum was set up in May 2006 to implement the recommendations of a review of invasive species on the island of Ireland (Stokes *et al*., 2004). One of the significant outputs from this forum has been the establishment of a website (www.invasivespeciesireland.com), which currently hosts a Case Study on *Lagarosiphon* in Lough Corrib.

9. DISCUSSION

The Convention on Biological Diversity (CBD), in its Guiding Principles, adopted a three-stage hierarchical approach to dealing with invasive species: prevention, early detection/surveillance and eradication/control. Control and eradication of an invasive species, once it has established, is often extremely difficult and costly, while prevention and early intervention are more cost-effective and generally more successful. Most current focus for control is on species that are established and causing ecological or economic problems. Consideration must be given to the fact that it may have been possible to stop these invasions occurring by intervening to prevent them passing through the phase of rapid expansion and becoming a problem of substantial proportions (Wade *et al.*, 2007).

Prevention will maximise the potential reduction in adverse impacts and minimise the cost associated with tackling invasions once they achieve a foothold. It is the least environmentally damaging intervention and can be applied widely. Possibly the most comprehensive approach is to identify the major pathways that lead to harmful invasions (i.e. minimise the risk of species introductions) and manage the risks associated with these. High biosecurity standards will go a long way to achieving this. Robust risk assessment (to identify the pathways that present the highest risks for entry of invasives), effective (and informed) horizon scanning (to identify the species that pose the greatest risk to ecosystems i.e. the high impact species) and a heightened awareness across all sectors are essential to maximise the opportunity for effective prevention (Defra, 2007).

As an island, Ireland has a substantial advantage over continental countries in imposing effective prevention measures in relation to invasive species. Effective prevention must focus on minimising the risk of introduction presented by all existing vectors and pathways including transport of goods by air or sea, aquaculture, ships ballast water exchange and the movement of travellers by air and sea (Defra, 2007).

Once a non-native species is present in a new country, there is a brief period when its chances of establishment will hang in the balance. However, the longer it goes undetected, the greater the opportunities that are afforded to it to reproduce and disperse. This reduces the chances of successful eradication and greatly increases the costs associated with control. 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 early detection is a contingency plan, which determines the action to be taken when an alien species has been recorded. Regular surveillance for invasive non-native species is necessary if control or eradication efforts are to be made at an earlier stage and to be more likely to succeed.

While it is unknown when *Lagarosiphon* first entered Lough Corrib, or what the primary vector was, it is clear that the plant is now well established and truly invasive. The exponential increase in the number of sites from which the plant was recorded over the past three years bears testimony to this (9 in 2005, 24 in 2006 and 64 in 2007).

In 2007 stands of varying sizes were located throughout the upper and middle lakes. Sixty-four sightings were reported from approximately 40 different bays, shoreline locations and islands. At some locations (e.g. Kitteen's Bay) seven discrete and spatially isolated populations were recorded (see Figure 15). It is probable that the five small (*c*. 1 m^2) stands present in this bay originated from fragments released by the two large *Lagarosiphon* stands (3,081 and 77 m^2). It is also probable that, in time, all seven stands will grow and coalesce to form an expansive monodominant vegetative mass, such as that present in Rinerroon Bay. This slow encroachment and progressive occupancy of expanses of water has already been witnessed with *Lagarosiphon* in lakes in New Zealand (J. Clayton pers. comm.).

During the summer of 2007 the ability to accurately record the detailed distribution of submerged stands of *Lagarosiphon* in Lough Corrib was compromised by poor weather conditions. For much of the survey period wind made the water choppy and increased turbidity in the water. This reduced visibility into the water column and increased dependence on grapnel sampling. In a lake as large as Lough Corrib (18,240 ha), it is not possible to sample all of the water that is suitable for *Lagarosiphon* growth, even though in excess of 2,000 sites were sampled during this season using the grapnel. This point was confirmed in Gorracurra Bay where the distribution survey revealed one stand of *Lagarosiphon* measuring *c*. 80 m^2. It was only later in the season, during calm and bright weather, that a much larger and hitherto unrecorded weed bed (> 3,000 m^2) was observed. It is, therefore, highly likely that many other stands of *Lagarosiphon* were missed during the survey, not due to any shortcoming on behalf of the survey team but to a combination of poor weather conditions and the vast area of water that is present in Lough Corrib.

In Rinerroon Bay, it is estimated that *Lagarosiphon* expanded its range by 7.4 ha and its standing crop increased by 1,028 tonnes in the two years between 2005 and 2007. This rapid rate of spread for *Lagarosiphon* has also been observed in New Zealand where, within 13 years of its first record, the plant came to occupy almost the full 161 km of littoral zone in Lake Taupo (Howard-Williams and Davies, 1988). This ability to spread so rapidly within a suitable habitat signifies the significant risk that the plant represents for the functioning of Lough Corrib as a fishery, as a conservation area or as a multi-purpose recreational resource.

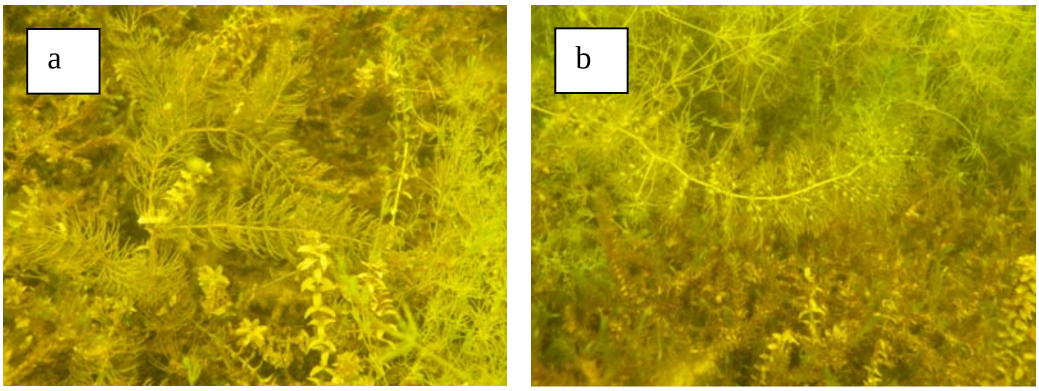

Plate 24. Underwater photographs show the abundant and diverse macrophyte community that occupies the bed of the lower lake. a) Charophyte beds are overlaid with *Ceratophyllum demersum* and *Elodea canadensis*; b) *Utricularia minor* growing on charophyte beds, with *E. canadensis* and *Fontinalis antipyretica* present.

The fact that no *Lagarosiphon* was recorded from the lower portion of the middle lake or from the entire lower lake is surprising. During the survey a large number of transects were examined, using the grapnel to sample the submerged vegetation. During calm conditions the glass-bottomed viewing tube proved most useful, as much of the lower lake is less than 3 m deep. Neither method uncovered any *Lagarosiphon* plants. Later in the season, a number of diving surveys were conducted, with the sole purpose of exploring the area for *Lagarosiphon*. While the total area surveyed using this method was small by comparison with the area of water present, no sign of the invasive plant was found.

An examination of the habitat and the macrophyte communities present in the lower lake suggests that it should be ideally suited to the establishment and growth of *Lagarosiphon* (Plate 24 a and b). Expansive charophyte meadows occupy the bays and much of the littoral in this lake. Beneath the *Chara*, a deep organic, soft mud is present. The shallow nature of the habitat ensures the presence of a plentiful supply of photosynthetically active radiation for plant growth. Considering the large numbers of fragments of *Lagarosiphon* that are released each year within the upper lake, it is inconceivable that no viable fragments have yet reached the lower lake. However, as yet, no *Lagarosiphon* stands have been recorded or reported. Further work on the distribution of this plant in the lower lake in 2008 is required. It will also be important to analyse the sediment in the lake to see if it contains any elements that might be antagonistic to the establishment of *Lagarosiphon*, or possibly lacks elements that are required for its growth and expansion.

The absence of *Lagarosiphon* in the lower lake somewhat reflects the position elsewhere in Ireland. The plant is widely sold as an oxygenator for use in aquaria and artificial ponds. It has been recorded with considerable abundance in artificial ponds and lakes in golf courses and demesnes throughout the country. And yet, Lough Corrib is the only significant natural watercourse in the country, north or south, that is known to contain the species. The reason for this is unknown.

The growth cycle exhibited by *Lagarosiphon* in Lough Corrib, since its presence was confirmed in April 2005, is difficult to explain. During the summer of 2005 the plant grew vigorously and produced an extensive surface canopy of tangled vegetation. Growth continued through the winter, but declined in May 2006 following a prolonged cold spell of weather. Active regrowth was not recorded until October, when water temperatures began to decrease sharply. A similar pattern of growth decline during the summer followed by regrowth and expansion in autumn/winter was observed in 2007. In work conducted on *Lagarosiphon* in the UK (in outdoor 3000 l capacity fibreglass tanks) the plant sustained 'slow growth' during the winter (McKee *et al*., 2002). No evidence of the summer decline was reported. No similar pattern has been observed in New Zealand, where the plant has been under study for 30 years (J. Clayton pers. comm.). This unusual growth pattern in Lough Corrib warrants further study.

In Lough Corrib, *Lagarosiphon* has adapted well to a wide range of physical and physico-chemical conditions. This adaptability has enabled the plant to actively compete with, and indeed to outcompete, native indigenous species and communities. The plant displayed a definite preference for a deep and organically rich substrate, but also established and grew on coarser substrates. Within mature stands, the dense shoots of *Lagarosiphon* reduce water flow and thus filter particulate matter, which accumulates at the shoot bases. These substrates have higher proportions of fine inorganic particles and organic matter (predominantly *Lagarosiphon* fragments) than adjacent uncolonised areas. In dense weed beds, therefore, nutrient regeneration from the accumulated sediments reduces or removes the dependence of growth on nutrient supply from the water. Thus, where a sufficient sediment base has been accumulated within the plant stand, it is capable of growing and expanding even in nutrient poor conditions. This may explain the prevalence of *Lagarosiphon* in the relatively nutrient and base-poor upper reaches of Lough Corrib.

Its depth tolerance was also wide, being recorded growing in water from 0.1 to 6.5 m deep. The maximum recorded depth for the species in a lake in the Aquitaine region of France was 5 m (Dutartre, 1986). The maximum depth, worldwide, that the plant has been recorded from is 6.6 m. This was in a clear-water lake in New Zealand. Research conducted in New Zealand has determined that, even at sites with sufficient light and substrate for growth, *Lagarosiphon* is unable to survive at pressures greater than 7 bar, which equates to a depth of *c*. 7 m (Coffey and Wah, 1988). Research conducted in a number of New Zealand lakes has shown that the rate of growth of *Lagarosiphon* does not necessarily correlate with the trophic status or water chemistry of the waterbody (Brown and Dromgoole, 1977). It is, therefore, considered that this species should be capable of growing in relatively nutrient poor and low alkaline conditions as well as in eutrophic waters.

One of the greatest competitive advantages that *Lagarosiphon* has over tall non-canopy forming native or naturalised species (e.g. *Myriophyllum spicatum, Elodea* *canadensis* and a number of *Potamogeton* species) is its ability to produce a dense surface canopy. The canopy formed by *Lagarosiphon*, where mature surface-reaching stands have become established, is able to shade out, and competitively exclude, even tall submerged species. It has been demonstrated that as little as 1% sunlight can penetrate a canopy of 0.5 m deep (Schwartz and Howard-Williams, 1993).

In addition to the competitive advantage conferred on *Lagarosiphon* by its growth form, research has demonstrated the competitive ability of *Lagarosiphon* fragments over those produced by other tall aquatic plant species (Rattray *et al*., 1994). Shoot fragments possess the ability to absorb nutrients from the water as well as using stored nutrients. Where nutrients are plentiful in the water, *Lagarosiphon* channels its growth resources into shoot extension rather than into root development. This is particularly advantageous, particularly in aquatic situations where light may be limiting. Other species appear to require the development of an extensive root system before manifesting shoot growth.

The impact that mature *Lagarosiphon* stands can have on indigenous biotic communities is best reflected in the results from the macrophyte survey conducted in Rinerroon, Currerevagh and Moon's Bays in 2007. While no detailed macrophyte species inventories are present for Rinerroon Bay prior to the establishment of *Lagarosiphon*, it is probable that the area supported a macrophyte community similar to that present in adjacent bays that have not yet been colonised by the invasive weed. This supposition is supported by evidence from Fisheries Board personnel and anglers who have knowledge of this area of the lake over many years. The littoral areas of most of the *Lagarosiphon*-free bays along the western shore of the upper lake are characterised by dense meadows of charophyte vegetation, mixed with tall stands of *Myriophyllum spicatum, Elodea canadensis* and a range of *Potamogeton* species. These abundant and lush vegetation meadows extend from close to the shore to a depth of *c*. 4.5 m. Where *Lagarosiphon* has achieved maturity and produces expansive surface canopy vegetation, indigenous plant species are unable to compete. No charophyte vegetation and only very small, localised stands of indigenous tall plant species were present in the *c*. 20 ha area that was overgrown with the invasive weed in Rinerroon Bay. This reflected the low light climate and the deep, often anoxic mud deposits that exist beneath the canopy. This represents a dramatic loss of macrophyte biodiversity in Rinerroon and in the other lake areas where *Lagarosiphon* has become well established. It further threatens the unique macrophyte assemblages for which Lough Corrib is renowned.

Preliminary results from the macroinvertebrate survey indicated that communities occurring in the littoral habitat of the bays examined were not affected by adjacent aquatic plant growth, whether native or invasive (Appendix III). In addition to the littoral fauna, the macroinvertebrates that were directly associated with four macrophyte species or groups (*Lagarosiphon major, Elodea canadensis, Potamogeton lucens* and members of the Charophyta) were examined. Within the plant material sampled, considerable differences in species composition and abundance were recorded. Particular differences were noted in the abundance of sedentary taxa, including Chironomidae and Mollusca. The most notable difference, however, reflected the significant increase in the abundance of certain macroinvertebrate groups, like Chironomidae and the Crustacean *Crangonyx pseudogracilis* (itself an invasive species), in bays where dense macrophyte populations have become established (e.g. Rinerroon Bay). The direct influence of *Lagarosiphon* in influencing this change, however, was not established (Appendix III).

The preliminary examination of fish stocks associated with *Lagarosiphon* in Rinerroon Bay and with a predominantly charophyte flora in Moon's Bay revealed quite different results. In the former bay roach was the dominant fish species (93.8%), while in Moon's Bay perch clearly dominated the fish fauna (83.4%). While these results are interesting, they represent only a single sampling event conducted late in the season. In order to make any conclusive comment on the affinities or potential associations of fish species or communities with specific vegetation types or growth forms, more intensive fish stock assessments throughout all seasons are required. It is probable, however, that the structure of the habitat produced in mature *Lagarosiphon* stands will better suit cyprinid, perch and pike populations than it will salmonid species. Salmonids have a preference for open water conditions while the cyprinids, perch and pike commonly seek the cover provided by dense weed beds. The latter species all spawn on submerged vegetation and the survival of their fry and fingerling stages is optimised within such habitats. Furthermore, these species are more tolerant of the physico-chemical conditions that can prevail within and adjacent to dense weed beds

Traditionally, Lough Corrib has been promoted worldwide as a prestigious wild salmon and trout fishery. It continues to attract large numbers of tourist and domestic salmonid anglers, particularly during the mayfly season. The resultant benefit to the local and national economy is significant. The potential impact that the expansion of *Lagarosiphon* populations could have on the conservation status of salmon and on the status of salmonid stocks in the lake is considerable. The impact on the revenue earning potential of the lake as a salmonid fishery should also be considered.

The physical presence of dense surface vegetation canopies in certain areas of the lake precludes or seriously restricts recreational exploitation at these locations. It is impossible to fish or to navigate craft through such thick vegetation and it may represent a health hazard for boaters whose engines are powerless to operate in such weeded conditions.

The pilot control trials undertaken in Lough Corrib to date have produced some interesting results. It is clear that hand pulling *Lagarosiphon* stems, using divers, will only be effective when targeted against small outlier populations in areas that are relatively geographically isolated from other *Lagarosiphon* stands. A strict protocol for use by divers has been developed following years of practice in tackling this invasive species in New Zealand (J. Clayton – *Lagarosiphon* in New Zealand, Appendix V) and considerable success has been achieved using this labour intensive and relatively costly control procedure.

The use of light occluding geotextiles has proved beneficial in controlling submerged invasive weed species in New Zealand (Clayton, 1996) and in southern California (Woodfield, 2006). A high level of control with *Lagarosiphon* was achieved in Rinerroon Bay when the tall vegetation was cut prior to the material being laid. However, the material was difficult to fix to the lake bed and, where not pinned securely, it buoyed towards the surface and created a hazard for motorised craft. It is considered that, during the trials, too big an area (2,500 m^2) for treatment was selected. In future trials smaller weeded areas (possibly < 400 m2) will be targeted and a range of light occluding materials, including one biodegradable product, will be tested.

Mechanical cutting in January 2007 using a V-blade trailed on a chain behind a boat provided a high level of effective weed control. Cutting can have the effect of stimulating regrowth among cut plants and generally only achieves short-term control (Caffrey, 2003). The V-blade, however, is designed to pull or rip the vegetation at root level from the lake bed, inflicting the maximum amount of trauma to the plant. Work by Clayton and Franklyn (2005) had shown that *Lagarosiphon* cannot regrow from root material left in the lake bed. Hence, a cut as applied using a V-blade should significantly restrict the level of regrowth and may result in the death of the cut vegetation. By September 2007, some 8 months after the cut had been applied, very little regrowth (8%) among the cut plants was recorded. The bulk of the growth recorded in the trial plot resulted from fragments that had colonised the area from adjacent uncut stands. While the cut using this method was easy and relatively quick to apply, the collection of the cut weed proved time-consuming and added significantly to the overall cost of the operation.

The extended trials conducted in September 2007 removed approximately 300 tonnes of *Lagarosiphon* from an area of Rinerroon Bay measuring 4.7 ha. The operation was conducted by contractors and cost approximately € 40,000. While the operation was costly, it served to demonstrate that large areas of water containing a high standing crop of vegetation can be cleared, with obvious advantages for the lake and its overall management (e.g. reduced risk of detachment and spread of fragments, removal of a physical barrier to boat movements and angling, and the provision of an opportunity for recolonisation by native biotic communities). The weed that was cut was transported away from the lake and possibilities for its subsequent use (e.g. composting, feeding to livestock) will be explored in the coming months.

A number of useful lessons were learned from the extended cutting trials. In future operations, a GPS plotter will be fixed to the weed cutting boat to accurately direct the operator and to ensure that swaths of vegetation are not left uncut. Relatively small plots of weed should be tackled at one time and these should be clearly demarcated using buoys or on the GPS. Divers should be used to assess the efficacy of the cutting operation after each day's work. The results from the diver survey will direct subsequent operations and ensure that the maximum amount of weed is removed from the lake bed. Drags or rakes must be employed to remove the cut material that fails to surface following a cut.

Clayton (2003) recorded the rapid re-establishment of native vegetation cover following suction dredging and hand removal of *Lagarosiphon* beds. No recolonisation of indigenous species was recorded in the eight months that followed weed cutting in the 50 x 50 m trial plot. The reason for this is unclear but may relate to the fact that the seed reserve in the substrate has been exhausted or that the anoxic conditions present in this mud have impacted the indigenous seed bank. The ability of native species to recolonise in these cut areas requires investigation.

In order to achieve control of *Lagarosiphon* in Lough Corrib, an informed and determined effort over a number of years will be required. Invasion ecology theory recommends that control efforts should focus on populations on the margins of range expansion as the most effective method of slowing or preventing further invasion (Moody and Mack, 1988). This approach alone will not work in Lough Corrib as the mature *Lagarosiphon* stands will continue to provide an inoculum of viable fragments to colonise new lake areas and to reinfest those areas where effective control had been achieved. It will, therefore, be necessary to target the new, low density and localised populations while simultaneously addressing lake areas where mature, monodominant and high biomass stands are present. In the latter areas, if the funding or infrastructure is not available to implement plant control or removal, focus must be directed towards containing the plant (e.g. through the use of containment nets or floating barriers) and restricting movement by boaters into or out of these areas (e.g. by providing buoyed access lanes, where necessary) while awaiting control.

While it will be important to continue to explore new and innovative methods to control *Lagarosiphon* in Lough Corrib, particularly in respect of the opportunities afforded by biological control, there are sufficient tried-and-tested methods currently available to enable effective weed control to commence. With proper funding and a coordinated effort from relevant organisations, great strides towards significantly reducing the level of *Lagarosiphon* infestation in the lake can be made. It may not be possible to totally eradicate *Lagarosiphon* from this large expanse of water but it should be possible to achieve the following fundamental goals:

- to limit the spread of the plant within the upper and middle lakes;
- to ensure that no *Lagarosiphon* becomes established in the lower lake and, if it does, to have a sufficiently robust surveillance system that its presence will be rapidly detected and appropriate control implemented;
- to eradicate new and low-density infestations;
- to significantly reduce the large biomass of vegetation at densely infested sites using mechanical control techniques;
- to progressively reduce the weed biomass present at these sites using more refined methods (e.g. light occluding geotextile or localised herbicide) until only localise populations exist;
- to provide conditions for, and expedite, the natural recolonisation of previously infested areas by native species; and
- to ensure that the lake can be used for water-based recreation and amenity as it was before *Lagarosiphon* arrived in the lake.

In November 2007 funding was provided by NPWS to purchase a weed cutting boat. The boat will be based on Lough Corrib on a 12-month basis and will be dedicated to *Lagarosiphon* control. It is proposed to have a number of Fisheries Board staff on Lough Corrib trained in the use of the new weed cutting boat. This will confer significant advantages on the overall control operation and will provide the flexibility that is required to effectively and efficiently deal with an aggressive invasive like *Lagarosiphon*. It should further help in achieving the level of weed control that is commensurate with the requirements of conservation authorities, the Fisheries Board, anglers, boaters and other interested parties. As the boat will be based on the lake, it will be possible to deploy it at any time of the year, once weather conditions are favourable. This will remove the necessity to engage contractors who are costly, rarely have a true appreciation of the problem or the nature of its impact on biotic communities or habitats, and generally require substantial notice before they can attend on site.

The availability of trained Fisheries staff confers a number of other important advantages. These staff are dedicated to achieving what is in the best interest of the lake. Furthermore, the staff have an intimate knowledge of the lake, the underwater conditions in different areas of this expansive waterbody, the currents, prevailing weather conditions, etc. This detailed knowledge of the lake and its diverse habitats, combined with the flexibility to operate the weed cutter at short notice, confers an advantage in the task of effectively controlling *Lagarosiphon* in Lough Corrib. It further significantly reduces the costs associated with long-term control programmes.

It is probable that repeated weed cutting and removal operations at sites where mature, surface canopy-forming stands of *Lagarosiphon* occur will be necessary. When weed biomass is substantially reduced, other less destructive control measures may be implemented to refine the level of control.

In addition to controlling the spread of *Lagarosiphon* within Lough Corrib, it is necessary to commit to reducing the risk of spreading the invasive weed to other watercourses in the country. This problem with interlake dispersal is particularly important with plant species that reproduce solely *via* fragments. Distribution of these species is significantly associated with human activities, such as boating and fishing (e.g. commercial eel fishermen). The risk associated with unintentional dispersal of *Lagarosiphon* from artificial ponds must also be considered. Public awareness and education programmes that spell out the environmental, social and economic risks associated with invasive species are critical for effective management of invasive species.

It will be important to develop appropriate legislation to underpin whatever preventative measures are deemed to be necessary. Towards that end, it is encouraging that the Minister of the Environment, Heritage and Local Government recently agreed to make regulations under the Wildlife Act of 1976 to prohibit the possession or introduction of *Lagarosiphon major* (PQ No. 23098/07). It is strongly recommended that the Minister and his officials extend the regulations to include all invasive species on the high impact list (see Appendix I) and consult widely with interested parties before constructing the legislation.

In order to effectively redress the problems posed by *Lagarosiphon* in Lough Corrib and to have a realistic opportunity of effectively controlling its growth and spread within the lake, while eradicating it from isolated locations, it is important that a single coordinating body or organisation assumes overall responsibility. This concurs with the view espoused in the recent Invasive Non-Native Species Framework Strategy for Great Britain (Defra, 2007). This body will provide a scientific team that will document the presence, distribution and spread of *Lagarosiphon* in the lake, conduct scientific research and co-ordinate appropriate prevention (biosecurity), control, eradication and/or containment procedure, as appropriate. This body would further provide the point of contact for information on these species, as well as providing a rapid reaction service to respond to new reported sightings. It will be vital for this body to maintain close synergies with Government departments, interested agencies and a wide diversity of stakeholders.

Success in a long-running and costly campaign to avert the threat to the Californian coastline posed by the invasive seaweed, *Caulerpa taxifolia*, was attributed to 'the rapid response by a coordinated task force consisting of federal, state and local representatives, invasive species experts, marine resource scientists and local stakeholders. The success hinged upon the early detection of the infestations, prompt acquisition of adequate funding and the timely actions of the task force' (Woodfield, 2006). In this instance, the weed was totally eradicated.

Adequate funding over a period of at least five years is now required to ensure that long-term control of *Lagarosiphon* in Lough Corrib is achieved. If this long-term commitment is not given, future weed control cost will dramatically escalate and the opportunity to prevent serious impact to native communities and to conservation and recreational values will be lost.

.

10. PROPOSED PROGRAMME FOR ONGOING RESEARCH

Very little is yet known about the autecology of *Lagarosiphon* in Irish waters, and even less is known about the adventive traits that confer such a definite competitive advantage upon this over our native species. Nor have the impacts that the growth and spread of this invasive weed is having on our natural environment been quantified. A programme of scientific research is required to address these basic issues. Research is also required to quantitatively examine the efficiencies of the range of weed control methods that are available for use in our watercourses on non-native species. The impact that these control procedures can have on native communities must also be quantified. Research is further required to provide quantitative data that will inform management decisions and that will underpin future invasive species policy and action.

In December 2006 and January 2007 funding was provided to conduct a pilot *Lagarosiphon* control trial in Lough Corrib. The only other funding allocated to *Lagarosiphon* research in Ireland was provided for the current, short-term (June to December 2007) project. If the problem with *Lagarosiphon* in Lough Corrib, and the potential threat of it impacting other lakes in the country, is to be seriously addressed, long-term funding (for at least five years) will be required. This commitment will provide the expertise and infrastructure to enable the project to be conducted in a professional manner and it will provide the continuity that contract staff require to fully engage in a worthwhile project of this nature.

The proposed research programme may be conducted under a number of headings.

10.1. Monitoring

It will be important to continue surveillance monitoring throughout upper, middle and lower Lough Corrib in order to accurately record the detailed distribution of *Lagarosiphon* in the lake and to update GIS distribution maps for the species. These surveys will identify locations that were missed during the 2007 survey and will also register sites where the weed has recently colonised. The assistance of all lake users will be enlisted in an effort to generate the maximum amount of useful information on the distribution of this invasive plant in the lake. A particular focus will be concentrated on the lower part of the middle lake and on the lower lake, where no *Lagarosiphon* has yet been recorded.

The rate and extent of spread of the plant in individual bays and littoral areas will also be quantified. This will involve mapping the extent of existing stands, using GPS, and comparing results on an annual basis. Work on this aspect of the programme commenced in 2007. Further useful information will be generated by quantifying the standing crop of *Lagarosiphon* that exists in the various locations throughout the lake.

10.2. Life cycle characteristics

A combination of on site and laboratory investigations will be required, over time, to provide the level of information required on the life cycle characteristics and strategies of *Lagarosiphon* in Lough Corrib. Some details relating the autecology of the species in southern Africa and in New Zealand is available, but this may bear little similarity to the traits exhibited by the species under Irish aquatic conditions.

Studies to determine the habitat and environmental preferences of the plant are urgently required. These will explore the depth, light, temperature, pH and water chemistry preferences of the plant in different parts of the lake. On site and laboratory studies will be conducted. It will also be necessary to investigate the tolerance of the plant to substrates of differing physical and chemical characteristics.

The physiology of the plant will be investigated under laboratory conditions and will provide information on the level of dependence of the plant, or of plant fragments, on nutrients in water and in the sediment. This will involve a large amount of chemical analysis of the lake water, sediment and plant material. Factors that contribute to growth during the plant’s expansion phase and factors that contribute to the demise of populations will be investigated.

The phenology of the plant will be examined over a number of seasons in an attempt to establish the seasonal trends in biomass production, stem collapse (as observed in 2006 and 2007), release of viable fragments, adventitious root development and other related areas.

The growth and survival of plant fragments is an important matter, as fragments are the sole mechanism used by *Lagarosiphon* for dispersal. An element of this work will be conducted in collaboration with GMIT, Galway.

10.3. Impacts on native communities and habitats

In 2007 some preliminary research into this complex area was conducted. A great deal more quantitative investigative work needs to be conducted if a true understanding of the nature and extent of these impacts is to be revealed.

The impact of photosynthesis and respiration in and adjacent to dense *Lagarosiphon* stands on the water and its dependent biotic communities is unknown. Research has shown that photosynthesis can elevate pH to values over 10 in small ponds (CEH, 2004). This contributes to the success of the plant in mixed communities, as few submerged macrophytes can photosynthesise effectively in such high pH environments. The extent of diurnal fluctuations in DO, pH, CO_2 and other parameters within *Lagarosiphon* stands at various stages of vegetation expression will be examined.

The impact on native macrophyte species and communities is central to the impact the invasive plant will have on the ecology of Lough Corrib. It will be necessary to conduct a detailed macrophyte species inventory in all three sectors of the lake and to identify the community assemblages that characterise these areas. The impact that *Lagarosiphon*, at all stages of its development and expansion, has on these species and assemblages will be quantified. The mechanisms, by which the native species are excluded, whether chemical or physical, will be examined.

The direct and indirect impacts that *Lagarosiphon* has on macroinvertebrate diversity and production will be investigated.

Likewise, the direct and indirect impacts on fish species and communities will be studies throughout the lake. The utilisation of *Lagarosiphon* stands for spawning, as a nursery habitat for fry, as concealment for predators or as shelter for fodder fish will be examined. The possible exclusion of salmonids from areas that are densely vegetated with *Lagarosiphon* growth will also be studied.

Stable isotope analysis will be used to assess the impact that the presence of *Lagarosiphon* has on food webs within the lake. This work will be conducted in collaboration with Queen's University, Belfast.

10.4. Control and eradication

It is important to continue to explore new and innovative methods of weed control, as they become available. It will also be necessary to continue to trial as wide a range of weed control methods as are available in an effort to develop a suite of procedures that can be targeted against *Lagarosiphon* in all conceivable situations and at all stages of growth.

Biological control has been used, with considerable success, to effectively control a broad range of aggressive aquatic plant species. In recent years, a weevil was introduced in England to control the spread of Water fern (*Azolla filiculoides*), with great effect. The use of biological control in Ireland must be explored, particularly against such highly invasive species as *Lagarosiphon*. In collaboration with UCD and a third level institute in South Africa, the possibilities of using biological organisms to control this invasive plant in Lough Corrib will be examined.

Based on the evidence of results presented in the present report, it will be possible to dramatically reduce the volume of *Lagarosiphon* in the lake and to eradicate the plant from a large number of bays and littoral areas. Continued treatment over a period of years should create conditions in the lake where native communities can grow and proliferate, with minimal impact from this invasive plant. It will be important, however, to formulate a coordinated and comprehensive control plan, in consultation with stakeholders, and to commence activities as soon as possible. Areas within the lake that are to be treated using various control techniques will be identified and a planned programme of control and evaluation will be implemented.

The use of hand pulling *Lagarosiphon* stems by divers in bays with low-density populations will be expanded. The protocol developed by Dr John Clayton (NIWA) for applying this technique to its best effect will be adopted (see Appendix VI).

Trials will be conducted using a variety of light occluding geotextiles, including one product that is biodegradable. The trials will be conducted on smaller plots (probably < 400 m^2) than those used in the trials conducted in 2007. The product(s) that provides the most effective control of *Lagarosiphon* will be used to treat new and localised infestations around the lake.

The localised use of approved herbicides will continue to be explored.

Large-scale weed cutting using the NPWS-funded boat will commence early in 2008, when weather conditions are favourable. Bays that contain large volumes of *Lagarosiphon* will be targeted for treatment in the initial phase of activity in order to reduce the inoculum for fragments that these plant stands represent. It will be important to set up containment nets around these stands to minimise the escapement of fragments during and after cutting. Divers will assess the efficacy of the actual cutting operations to ensure that the maximum amount of weed is removed.

Resulting from the control trials and operations, a best practice guide for *Lagarosiphon* control will be produced.

10.5. Recolonisation by native species

In the aftermath of control operations, the rate of natural plant and macroinvertebrate recovery will be monitored. Where necessary or practical, the process of natural recovery will be expedited by transplanting species or assemblages from adjacent bays or littoral areas. The nature, composition and extent of the seed bank beneath *Lagarosiphon* stands in different areas of the lake will be examined to gauge the potential for natural recovery of the habitat.

10.6. PR and education

Information for incorporation into PR and education material will be compiled. Leaflets, guides and identification flashcards will be produced. Presentations will be made at stakeholder meetings, workshops, seminars and scientific and management conferences. Information literature and peer reviewed scientific papers will be published. Opportunities to highlight the risks posed by invasives and actions that should be taken to avoid the introduction and/or spread of these species will be sought and availed of.

ACKNOWLEDGEMENTS

The authors would like to thank the National Parks and Wildlife Service (NPWS), the Western River Basin District (WRBD) and the Office of Public Works (OPW) for joint funding the project. Special thanks are extended to Hilary Healy (GMIT) who conducted a summer studentship on the project. We would also like to acknowledge the help and dedication to the project of the staff from the Western Regional Fisheries Board, under the direction of Dr Greg Forde and Martin Butler. The advice and guidance of Prof. Michael Hynes was greatly appreciated. The assistance of Kevin Gallagher, John Coyne and Nicola O'Gorman, all from the Research Section of the CFB, is also gratefully acknowledged. Thanks also to Dr Matthew Jebb of the National Botanic Gardens and Dr Jim King (CFB) for their technical assistance in identifying some of the *Chara* species. Thanks to Paul McLoone, Rossa O'Briain, Dan O'Callaghan and Sandra Doyle for assistance in compiling the document. We would further like to express our appreciation to Trevor Champ for his constructive comments.

11. REFERENCES

Berry, A. and Dabrowski, T. (2007) Proposal for site selection on large lakes through modeling: Modelling of Lough Corrib. MarCon Computations International Ltd. 30pp.

Bowmer, K.H., Jacobs, S.W.L. and Sainty, G.R. (1995) Identification, biology and management of *Elodea canadensis*, Hydrocharitaceae. *Journal of Aquatic Plant Management* 33: 13-19.

Brown, J.M.A. & Dromgoole, F.I. (1977) The ecophysiology of *Lagarosiphon* in the Rotorua Lakes. Proceedings of the *30th New Zealand Weed and Pest Control Conference*, 130 – 134.

Caffrey, J.M. (1993a) Aquatic weed management practices using dichlobenil: and Irish experience. *Polish Archives of Hydrobiology* 40 (3-4), 255 – 266.

Caffrey, J.M. (1993b) Plant management as an integral part of Ireland's aquatic resources. *Hydroecologie Applique*, 77 – 96.

Caffrey, J.M. (1994) Spread and management of *Heracleum mantegazzianum* (Giant hogweed) along Irish river corridors. In: *Ecology and Management of Invasive Riverside Plants* (eds. L.C. de Waal, L.E. Child, P.M. Wade, J.H. Brock). Wiley, Chichester, 67 - 76.

Caffrey, J.M. (2001) The management of Giant hogweed in an Irish river catchment. *Journal of Aquatic Plant Management* 39, 28 – 33.

Caffrey, J.M. (2003) The comparative efficacy of weed cutting machines in canal habitats. *32nd Robson Meeting*, St Ives, Cambridgeshire, UK. Abstract.

Caffrey, J.M. (2005) Non-native freshwater plants in Ireland. Proceedings of the *14th International Conference on Aquatic Invasive Species*, Key Biscayne, Florida. Abstract.

Caffrey, J.M. (2007) *Lagarosiphon major* in Irish watercourses. Proceedings of the *15th International Conference on Aquatic Invasive Species*, Nijmegen, Holland. Abstract.

Caffrey, J.M. (2007) *Lagarosiphon major* in Lough Corrib – Management Options. *38th Annual Institute of Fisheries Management*, Westport, Ireland. Abstract.

Caffrey, J.M. and O'Callaghan, D. (2007) *A Guide to the Identification of Aquatic Invasive Species in Ireland.* Central Fisheries Board, Swords, Dublin. 31pp.

Cannaby, H. (2005) *The Physical Limnology of Lough Corrib*. Ph.D Thesis, National University of Ireland, Galway. 287pp.

Centre for Ecology and Hydrology (2004) Information Sheet. *Lagarosiphon major*. Centre for Ecology and Hydrology, Wallingford, England. 2pp.

Champ, W.S.T. (1977) Trophic status of fishery lakes. In: (eds. Downey and Ni Uid.), *Lake Pollution Eutrophication Control.* Stationery Office, Dublin, 65 – 78.

Clayton, J. (1996) Aquatic weeds and their control in New Zealand lakes. *Lake and Reservoir Management* 12, 477 – 486.

Clayton (2003) The history and principles of managing *Lagarosiphon major*, an invasive aquatic weed in Lake Wanaka. Internal report, NIWA, New Zealand. 6pp.

Champion, P. and Clayton, J. (2001) A risk assessment model for aquatic weeds in New Zealand. In: (eds. RH Groves, FD Panetta and JG Virtue), *Weed Risk Assessments* 194 – 202.

Coffey, B.T. and Wah, C. (1988) Pressure inhibition of anchorage-root production in *Lagarosiphon major* (Ridl.) Moss: a possible determinant of depth range. *Aquatic Botany* 29, 289 – 301.

Cook, C.D.K. (1982) Pollination mechanisms in the Hydrocharitaceae. In: (eds. JJ Symoens, SS Hooper and P Compere), *Studies on Aquatic Vascular Plants* Royal Botanic Society of Belgium, Brussels, 1-15.

Defra (2007) *The Invasive Non-Native Species Framework Strategy for Great Britain*. Defra, London. 47pp.

Dutartre, A. (1986) Aquatic plants introduced in freshwater lakes and ponds of Aquitaine (France): Dispersion and Ecology of *Lagarosiphon major* and *Ludwigia peploides*. Proceedings of the *EWRS/AAB 7th Symposium on Aquatic Weeds*, Loughborough, England, 93 – 98.

Environmental Protection Agency (EPA) (2004) *Alien Species Risk Analysis (Republic of Ireland). Guidance for the Assessment of Pressures and Impacts in Accordance with Article 5 of the Water Framework Directive (WFD).* Environment Protection Agency, Dublin.

Howard-Williams. C. and Davies, J. (1988) The invasion of Lake Taupo by the submerged water weed *Lagarosiphon major* and its impact on the native flora. *New Zealand Journal of Ecology* 11, 13 -19.

Johnstone, I. M., Coffey, B.T. and Howard-Williams, C. (1985) The role of recreational boat traffic in interlake dispersal of macrophytes: a New Zealand case study. *Journal of Environmental Management* 20, 263 – 279.

Krause, W and King, J.J. (1994) The ecological status of Lough Corrib, Ireland, as indicated by physiographic factors, water chemistry and macrophytic flora. *Vegetatio* 110, 149 – 161.

Langston, M.J. (1990) *The Pattern of Spread and Distribution of the Introduces Aquatic Plant Lagarosiphon major in Great Britain*. BSc Thesis, Department of Human Sciences, Loughborough University of Technology, England. 36 pp.

McKee, D., Hatton, K., Eaton, J.W., Atkinson, D., Atherton, A., Harvey, I. and Moss, B. (2002) Effects of simulated climate warming on macrophytes in freshwater microcosm communities. *Aquatic Botany* 74 (1), 71 – 83.

Moody, M.E. and Mack R.N. (1988) Controlling the spread of plant invasions: the importance of nascent foci. *Journal of Applied Ecology*. 25: 1009 – 1021.

Obermeyer, A.A. (1964) The South African species of *Lagarosiphon*. *Bothalia* 8, 139 – 146.

OECD. (1982) *Eutrophication of Water: Monitoring, Assessment and Control*. Organisation for Economic Cooperation and Development, Paris.

O'Keeffe, C. and Dromey, M. (2004) Designation of sites for fish under the EU Habitats Directive. Biology and Environment. Proceedings of the *Royal Irish Academy* 104B(3), 103-105.

O'Neill, K. and Stokes, K. (2004) *The Impacts and Effects of Invasive Species in Ireland and the Mechanisms of their Introduction and Spread.* Consultation document for a workshop on invasive alien species.

O'Sullivan, R. (1996) *Lough Corrib - a Cause of Concern*. Lough Corrib Angling Federation. 147pp.

Rattray, M.R., Howard-Williams, C. and Brown, J.M.A. (1994) Rates of early growth of propagules of *Lagarosiphon major* and *Myriophyllum triphyllum* in lakes of differing trophic status. *New Zealand Journal of Marine and Freshwater Research* 28, 235 -241.

Reynolds, S. (2002) Higher plant introductions to Ireland in the late 20th Century. In: (eds. Moriarty, C. & Murray, D.A.). *Biological Invaders. The Impact of Exotic Species.* Royal Irish Academy, Dublin. 79 – 86.

Scalera, R. and Zaghi, D. (2004). *Alien Species and Nature Conservation in the EU. The Role of the LIFE Program.* LIFE Focus, European Communities, Luxembourg. 56pp.

Schwartz, A.M. and Howard-Williams, C. (1993) Aquatic weed-bed structure and photosynthesis in two New Zealand lakes. *Aquatic Botany* 46, 263 -281.

Smith, R.L and Smith, T.M. (2003) *Elements of Ecology: 5th Edition.* Pearson Education Inc., San Francisco, 682 pp.

Stokes, K., O'Neill, K. and McDonald, R. A. (2006) *Invasive Species in Ireland*. Report to Environment and Heritage Service and National Parks and Wildlife

Service Quercus, Queens University. Environment and Heritage Service, Belfast and National Parks and Wildlife Service, Dublin. 151pp.

Wade, P.M., Darby, E.J. Courtney A.D. and. Caffrey, J.M. (1997) *Heracleum mantegazzianum*: a problem for river managers in the Republic of Ireland and the United Kingdom. In: (eds. Brock, H. et al.), *Plant Invasions*. Backhuy Publishers, Leiden, 139-152.

Wade, P.M., Booy, O. and White, V. (2007) *Invasive Plant and Alien Animal Species*. CIRIA, London. 2nd Draft.

Woodfield, R. (2006) Invasive seaweed threatens California's coastline – an update. *Ballast Exchange* 6, 10 – 11.

ELECTRONIC REFERENCES

Community Enterprise, 2004:

http://www.galwaycity.ie/AllServices/CommunityEnterprise/ProjectsandSchemes/GalwayCityAtlas2004/FileEnglish,670,en.pdf

EPA, 1982. Lake Water Quality:

http://www.epa.ie/rivermap/report/lakewaater/html

Global Invasive Species Database, 2007:

http://www.issg.org/database/species/ecology.asp?fr=1&si=403&sts=

National Botanic Gardens, 2008. Ireland's Plant Conservation Strategy. Target10. Managing Invasive Species:

http://www.botanicgardens.ie/gspc/targets/news/lagarosiphon.htm

National Parks and Wildlife Service. Lough Corrib, 2001, Lough Corrib, site synopsis. Site code : 000297:

http://www.npws.ie/media/Media,3914,en.pdf

Met Éireann, 2007:

http://www.met.ie

Natura, 2000. Sites for Nature Conservation:

http://www/environ.ie/en/Publications/Heritage/NatureConservation/FileDownload,2183,en.pdf

APPENDIX I

***List of known high impact invasive aquatic species for use in classifying ecological status in Ireland.**

Species	Common Name
Lagarosiphon major	Curly leaved waterweed
Dreissena polymorpha	Zebra mussel
Didemnum spp.	Ascidian species
Leuciscus cephalus	Chub
Elodea nuttallii	Nuttall's waterweed
Spartina anglica	Smooth cord-grass
Impatiens glandulfiera	Indian balsam
Eriocheir sinensis	Chinese mitten crab
Fallopia japonica	Japanese knotweed
Hydrocotyle ranunculoides	Floating pennywort
Sargassum muticum	Wire weed
Azolla filiculoides	Water fern
Heracleum mantegazzianum	Giant hogweed
Anguillicola crassus	Swim bladder nematode
Myriophyllum aquaticum	Parrot's feather
Crassula helmsii	New Zealand pigmyweed
Leuciscus leuciscus	Dace
Lemna minuta	Least duckweed
Nymphoides peltata	Fringed water lily

* List presented in the draft 'UK Classification Scheme for Surface Waters', produced in September 2007 by the UK Technical Advisory Group on the Water Framework Directive.

APPENDIX II

Specimen Summary Sheet

Monthly Weather Summary

The Weather of July 2007

Another very wet month in east and south; mostly cool but sunny.

After the very wet weather of most of June in the east and south of the country, rainfall totals for July were again exceptionally high in the same areas. Like the previous month, high pressure remained well to the south of the country, allowing an uninterrupted succession of depressions with their associated frontal systems to move over Ireland until near the end of the month. These produced spells of rain or showers

each day, with some locally heavy falls causing flooding, while there were severe thunderstorms and reports of tornadoes on a number of days. At least 1mm or rain was measured on each day at one or more stations in the period between June 11th and July 29th- a total of 49 days. Summer rainfall totals so far (June and July) are more than 250% of normal over parts of Leinster; Dublin (Phoenix Park)'s two-monthly total of 297mm is the highest for this period in its 170-year-old record. Totals for this month were more than three times the July normal in parts of Dublin and it was the wettest July for between 19 and 47 years in many places. There were between 14 and 25 wetdays recorded (days with 1mm or more rainfall) compared with the normal range for July of between 9 and 14. Mean air temperatures overall were near or a little below normal generally and it was the first month since March 2006 that temperatures were not above the 1961-90 normals at all stations. There was little variation in temperatures during the month; they were near or below normal throughout almost all of July, with daily maxima only very rarely rising above 20°C. Despite the frequent spells of rain, sunshine totals were above normal everywhere and it was a very sunny month in coastal counties of the west and north. Malin Head's total of 212 hours was its highest for July since 1955. The sunniest weather of the month was during the last three days.

1st to 29th: Low pressure centred over or close to Ireland brought a continuation of the very unsettled weather of much of June. Rain or showers were recorded each day, with widespread heavy falls in the period 8th/9th and on the13th, while isolated heavy falls, often in association with thunderstorms, were recorded on the 1st, 16th and in the periods 18th to 20th and 25th to 26th. Tornadoes or related phenomena (funnel clouds and waterspouts) were also observed from a number of locations on several days: the 8th, 16th, 19th and 26th. There were also long sunny spells at times, mainly between showers, especially in the periods 6th to 8th and 14th to 18th in western areas, but temperatures were near or below normal throughout, with a lack of high daily maxima. Winds were mostly westerly in the periods 1st to 13th and 25th to 27th, while they were generally light and variable in direction at other times; the strongest winds were associated with a depression which moved over the north of Ireland on the 5th and 6th.
30th to 31st: High pressure over the country brought dry and settled weather with light winds. There was very sunny weather on both days, but nightime temperatures were below normal under clear skies.
Wind and elements: Mean windspeeds for the month were between 6 and 10 knots *(11 and 19 km/hour)*, near or above normal generally for July. The strongest winds at all stations were in the period 5th/6th, when gale gusts were widely recorded; the highest gust, 54 knots *(100 km/hour)*, was measured at Belmullet on the 5th. Thunderstorms were frequent during the month, being recorded on the 1st, 2nd, 5th, 8th, in the period 14th to 22nd and on the 26th; they were particularly widespread on the 1st, 8th, 16th, 17th, 19th and 26th. Hail was recorded on the 16th, 18th and 26th. Fog was most widespread in the period 11th to 12th, on the 15th and 20th.

APPENDIX III

Preliminary investigation into the potential impact of the exotic invasive aquatic weed *Lagarosiphon major* (Ridl.) Moss on the benthic macroinvertebrate fauna of Lough Corrib

Report compiled by:

Jan-Robert Baars[1], Hugh Feeley[1], Silvana Acevedo[2], Hillary Healy[2], Mary Kelly-Quinn[1], Joe Caffrey[2]

[1] School of Biology and Environmental Science, Science Education and Research Centre (West), Freshwater Ecology Research Group, University College Dublin, Belfield, Dublin, Ireland

[2] Central Fisheries Board, Swords Business Campus, Swords, Co. Dublin, Ireland.

Executive summary

Through increasing globalisation non-native species are becoming a large component of our urban and rural ecosystems. Free-floating and emergent aquatic weeds are now a recognised threat to our native fauna and flora particularly to river systems, ponds and mesotrophic freshwater lakes. Although these weed infestations seem to have an obvious impact on native ecosystems few studies have documented the impact particularly on faunal diversity. This study investigated the potential impact *Lagarosiphon major* is having on the benthic invertebrates in Lough Corrib. Shallow littoral habitats were sampled using kick samples and activity traps to determine the potential impact adjacent *L. major* infestations were having on the invertebrate communities. In addition, macrophyte samples (4*l*) within vegetated stands were collected by divers to assess the invertebrate communities associated with four plant species, including two native (*Potamogeton lucens* & Charophyte spp.) and two invasive weed taxa (*L. major* & *Elodea canadensis*).

Preliminary results indicate that the invertebrate communities occurring in the littoral habitats were not being affected by adjacent weed infestations. There were however notable differences in the species composition and abundances of invertebrates within the plant material of native and exotic plant taxa. Particular differences were noted in the abundance of sedentary taxa including Chironomidae and various molluscs. If the abundance, including biomass and area occupied, of each of the macrophyte taxa are considered the macroinvertebrate communities in bays with significant weed infestations are undergoing extensive change. In bays like Rinerroon Bay in Lough Corrib, where *L. major* occupies in excess of 10 000m^2 the abundance of some invertebrate groups like Chironomidae and *Crangonyx* sp. (Crustacea) is extremely high.

With the exception of a phytophagous Lepidoptera (*cf*. Pylaridae) there were no organisms which were causing notable damage to the alien weed species *L. major* and *E. canadensis* emphasizing the need to re-establish the natural balance by importing very specific biocontrol candidates to control this weed in Ireland. This study has highlighted the importance of understanding the impact of these exotic weeds in order to prioritise our management response to this growing ecological problem, and classical biological control should be considered in future.

Introduction

Through increasing globalisation non-native species are becoming a large component of our urban and rural ecosystems. European countries have seen decades of deliberate movement of plants and animals some of which have been to our benefit but a small proportion have caused significant ecological impacts and a larger number are potentially invasive (Stokes *et al*. 2004). Free-floating and emergent aquatic weeds are now a recognised threat to our native fauna and flora particularly to river systems, ponds and mesotrophic freshwater lakes. Our international obligation through the ratification of the Convention on Biological Diversity (Decision VI/23 in 1992; http://www.biodiv.org/decisions/default.asp?lg=o&dec=VI/23) requires the implementation of effective control strategies to reduce the impact of weeds on our native flora and fauna. As a requirement of the Water Framework Directive all freshwaters should attain good ecological status, which necessitates the eradication of weed species.

The weed *Lagarosiphon major* is a relatively new aquatic plant which by all accounts is in its lag phase of invasion in Ireland. With only a relatively small number of known localities (Reynolds, 2003) the recent spread in Lough Corrib provides adequate evidence of its invasive potential in Ireland. Studies which accompany this report investigate the spread of this weed in Lough Corrib, and provide valuable insight into its potential to spread to similar lakes. Although invasive exotic weeds usually have an obvious impact on native ecosystems few studies have documented the impact particularly on faunal diversity (Samways *et al*., 1996; Douglas and O'Connor, 2003; Myers and Bazely, 2003; Harris *et al*., 2004). Some evidence from terrestrial systems show that invasive species do have a negative impact on diversity both with regard to plants and animals and ecosystem processes (Samways *et al*., 1996; Myers and Bazely, 2003; Harris *et al*., 2004; Yelenik *et al*., 2004; Schooler *et al*., 2006). The most prominent mechanism of negative impact from invasive weeds is through competition with native fauna and flora and the alteration of the habitat to the detrimental effect on native species. Habitats undergo considerable changes, somewhat comparable to agro-ecosystems under extensive monocultures. Native plants under these conditions are out-competed as invasive species have a competitive advantage through opportunities for rapid, post-invasion evolution selecting for higher fitness traits and because they have escaped from natural enemies in their country of origin.

This small study investigates the potential impact *L. major* is having on the benthic invertebrates which occur in the littoral habitats within affected bays and within the weed infestations. The adjacent bays which are un-occupied by the weed are also likely to be affected in terms their ecology, particularly when the nearby infestations are considerable in area. As the weed also provides a very different architecture the presence of large impenetrable stands is likely to change the invertebrate communities in both species composition and abundances. This may have a knock on effect on the ecosystem and potentially the ecological functioning of localized areas within the lake depending on the levels of infestation. As there are no such studies on invasive aquatic weeds reported in the literature, this preliminary work provides useful baseline information on the potential impact exotic weeds have on aquatic ecosystems, particularly the newly emerging weed *L. major*.

Material & Methods

Macroinvertebrate Sampling

Several sampling techniques were employed to determine the impact of *L. major* infestations on the benthic invertebrate fauna both within the weed bed (collecting plant samples) and adjacent shallow littoral zones (kick and activity traps).

Littoral habitats

Standard methodologies were employed for sampling the littoral habitats (Mackay *et al.*, 1984) using an open-net to collect a kick/sweep sample for a duration of two minutes. Samples were collected across a 30m shoreline, to include as many microhabitats as possible (including macrophyte stands) to a depth of ca. 1m. A total of three samples were taken at each of eight sites with varying levels of *L. major* infestations (Table 1; Figure 1) on the 16th July (2007). Samples were preserved in 70% IMS and sorted in the laboratory. Invertebrate 'activity' traps (Figure 2A) were deployed on the 12th of July 2007, to collect the mobile, cryptic and nocturnal invertebrate fauna at eight sites along the shallow littoral and deep littoral zone adjacent to the weed infestations. At each site, fourteen traps in 3 transects (4 traps in each transect) were deployed perpendicular to the shore. Two additional traps were positioned in the shallow part of the bay (< 1.0m) giving a total of five along the shallow littoral zone and nine traps in three transects perpendicular to the shore with varying water depth below the traps (>1.5 to 4.0m). The traps were evenly spaced along each transect with the furthest about 20m from the shore. The traps were recovered on the 16th of July 2007. The trap contents were washed with sieved freshwater, placed in labelled plastic containers and fixed with 70% ethanol for further analysis at the laboratory.

Table 1: Sites where invertebrate samples were collected and corresponding area of *Lagarosiphon* infestations within the bays

Site	*Lagarosiphon* abundance
Cormorant Rock	Not recorded
Moon's Bay	Not recorded
The Sanadauns Island	>10m^2
Kitteen's Bay	>10m^2
Currarevagh Bay	>100m^2
Glynn's Bay	>100m^2
Bob's Island	>1000m^2
Rinerroon Bay	>10000m^2

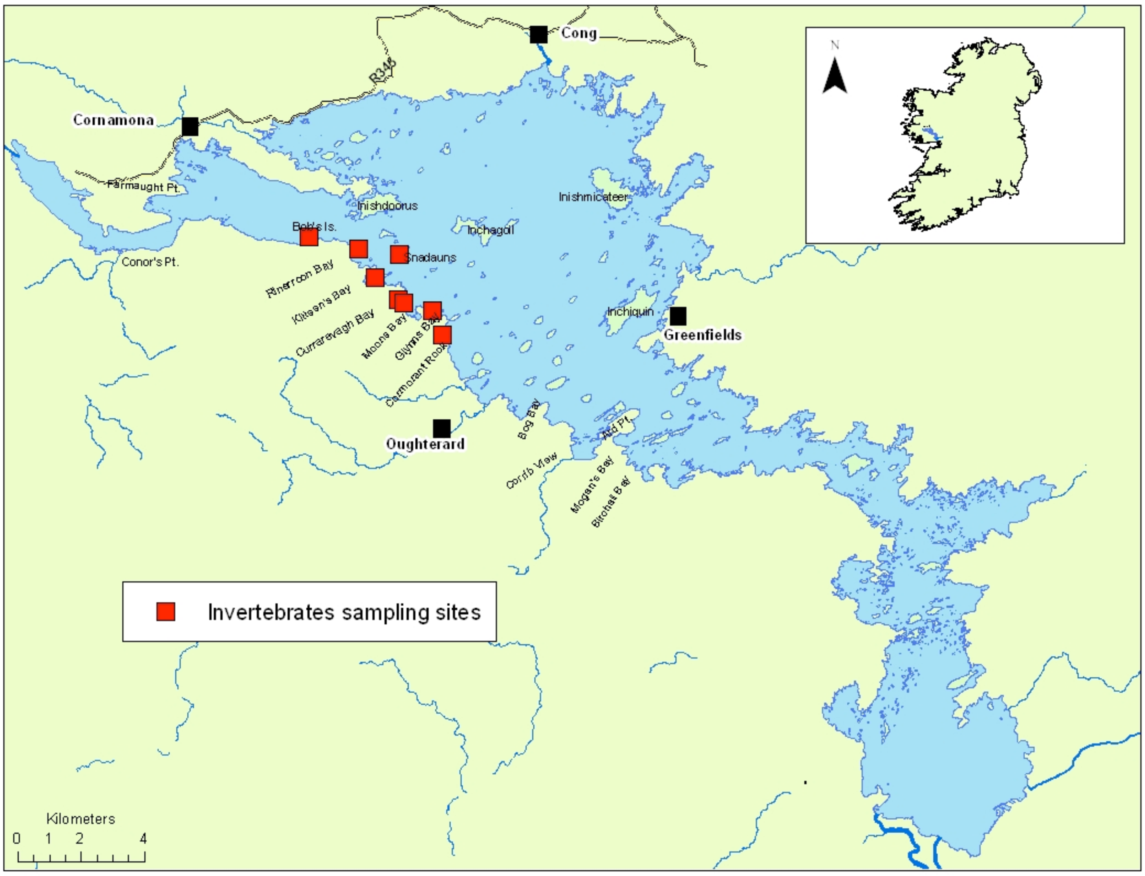

Figure 1: Location of the eight sampling sites in Lough Corrib.

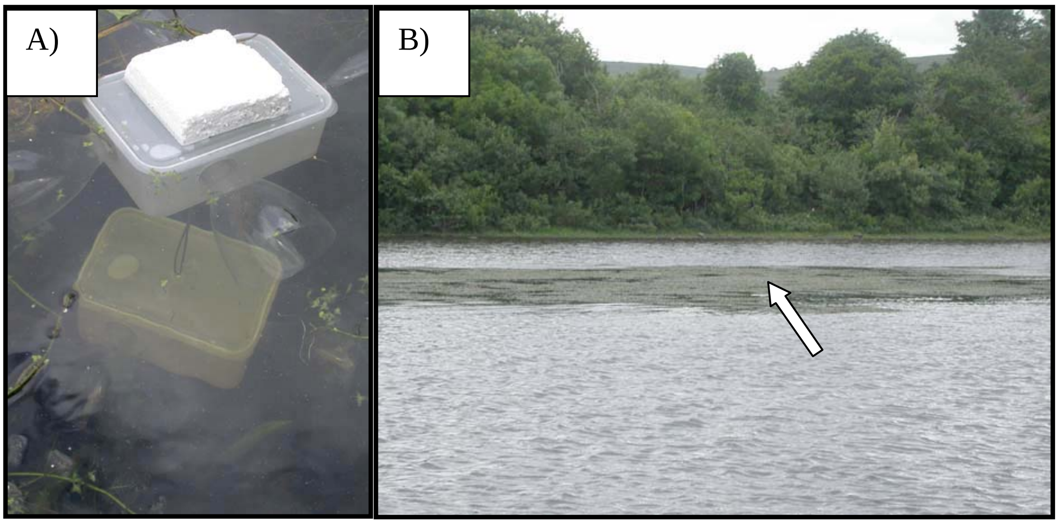

Figure 2: A) Example of an activity trap used to assess the invertebrate fauna within the littoral habitat adjacent to weed infestations and clear bays, **B)** Rinerroon Bay infestation of *Lagarosiphon major*, arrow indicating position of plant samples taken to determine faunal associations on native and introduced plant species. The other three plant species were found within ten meters of this infestation.

Fauna associated with macrophyte species

To determine the invertebrate fauna associated with the introduced and native aquatic macrophytes, samples were taken of four plant species/types. Three replicate samples of each plant type were hand collected by divers across three sites (Table 2). A known volume (4*l*) was collected in bags under water to prevent the loss of associated invertebrates. Not all the species occurred within each site and species had to be collected as per their availability at the study sites (Table 2). Samples were largely taken from large stands of each type (Figure 2B), but in some instances single plants had to be collected moving between areas within a site. This was either as a result of low densities at the site or the growth characteristics of the species (e.g. *Potamogeton lucens* L.). Plant samples were all placed on ice and returned to the laboratory for processing. Plant samples were hand washed over sieves to remove the macroinvertebrates, and the remaining material was sorted in white trays. Samples with excessive plant material were submerged in a salt solution to remove the majority of the invertebrates. Samples with an excessive abundance of Chironomidae were sub sampled using standard EPA sub sampling techniques.

Table 2: Number and site details of hand collected samples of two native and two exotic plant species in three bays in Lough Corrib.

Plant species	Bob's Island	Rinerroon Bay	Kitteen's Bay
Native species			
Potamogeton lucens	-	3	3
Charophyte (including 2 species)	-	3	-
Exotic species			
Lagarosiphon major	3	3	3
Elodea canadensis	3	3	3

All the macroinvertebrates were sorted from samples in the laboratory and specimens were identified to the lowest taxonomic level, usually to species/genus. The exception to this included Chironomidae and Oligochaeta.

Analysis

The species data from kick samples were log transformed for analysis [$\log_{10}(x+1)$]. The ordination used was a two-dimensional, non-Metric Multidimensional Scaling (NMMDS), conducted in Community Analysis Package (CAP 3.0) (Seaby *et al.*, 2004) with a PCA starting point, Bray-Curtis distance and 1000 iterations. Differences in various factors (e.g. number of each taxa) between plant species and sites were assessed using graphing techniques (STATISTICA Base).

Results & Discussion

A total of 59 taxa were recorded from the kick samples taken in the littoral habitats in 8 bays in Lough Corrib (Table 3). Species from the major invertebrate groups were recorded, including those usually associated with water bodies of good ecological status, including *Diura bicaudata* L. (Plecoptera), *Ecdyonurus dispar* (Curtis) and *Heptagenia* spp. (both Ephemeroptera). The Trichoptera, Coleoptera and Mollusca were well represented in terms of taxa richness, and the freshwater Crustacea were in high abundance across most of the sites.

When the species compositions of the eight sites were compared differences were noted. As expected these samples were naturally variable, but the numbers of taxa collected were very similar between the sites (Figure 3). There was no evidence that the species richness was being affected by the presence of the exotic species within the adjacent bay, either negatively or positively (Table 2). The least number of taxa was collected in Moon Bay and is attributed to the lack of variability in the substrate within the littoral habitat. Although the number of taxa were similar across sites, when the species compositions were compared sites were relatively different (Figure 4). This is supported by the NMDS plot which shows a spread of sites along the two axes (Figure 4). However, there was no clear trend indicating that bays with high densities of *Lagarosiphon major*, in bays such like Bob's Island, were affecting the species composition of the littoral habitats. It is more likely from on site observations that the impact of dense stands of *L. major* is more localized within the stands. Nonetheless differences in the littoral habitats in Rinerroon Bay were expected due to the extent of the infestation, but was not shown in the results.

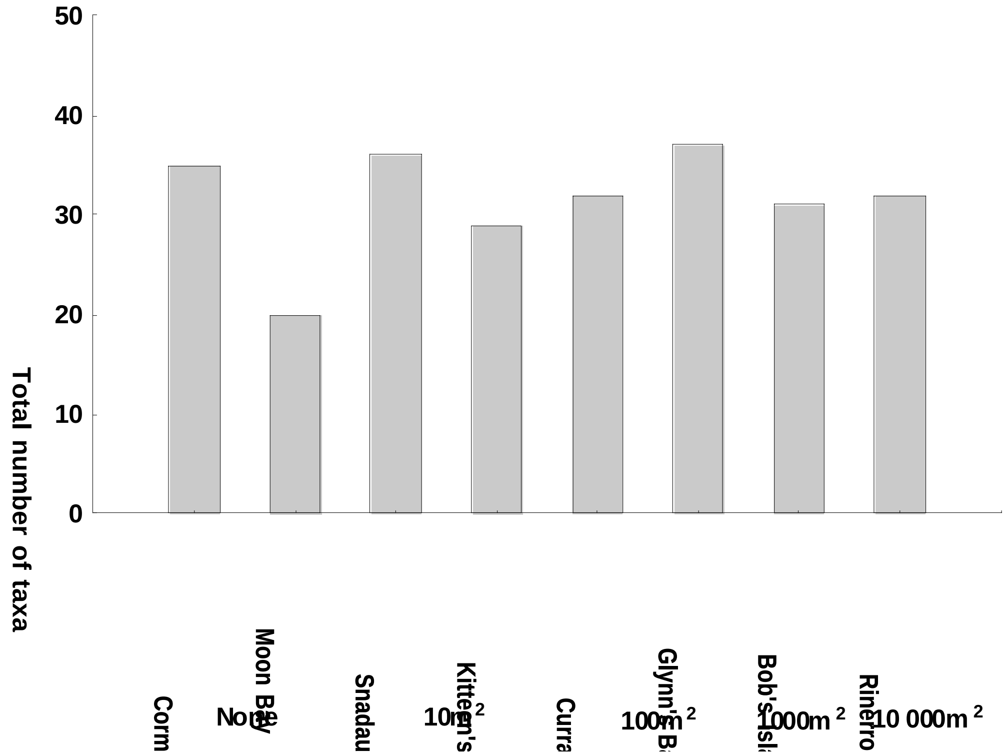

Figure 3: Total number of taxa collected from 8 bays in Lough Corrib ranked according to increasing area of infestation of *Lagarosiphon major* (None to 10 000m²).

Table 3: List of invertebrates recorded in the kick samples from eight bays with varying levels of infestation of *Lagarosiphon major* in Lough Corrib, July 2007.

Order	Family	Species	CR	MB	SB	KB	CB	GB	BI	RB
Plecoptera	Leuctridae	*Leuctra fusca* (L.)	10.0	-	2.7	-	0.3	6.0	5.0	2.7
	Perlodidae	*Diura bicaudata* (Linnaeus)	0.3	-	1.7	-	-	0.3	-	-
Ephemeroptera	Baetidae	*Cloeon spp.*	0.3	1.3	-	0.3	-	1.0	0.3	-
	Heptageniidae	*Ecdyonurus dispar* (Curtis)	62.7	3.3	170.7	25.3	56.0	17.3	56.0	64.0
		Heptagena spp.	1.3	0.7	6.3	0.3	2.7	4.0	4.0	3.7
	Ephemerellidae	*Seratella ignita* (L.)	4.0	-	22.7	2.7	4.3	2.0	57.3	4.0
	Ephemeridae	*Ephemera danica* Muller	9.3	-	1.0	-	-	1.7	3.0	1.3
	Caenidae	*Caenis luctuosa* (Burmeister)	59.3	5.3	15.0	14.3	22.3	18.3	6.0	11.3
Trichoptera	Psychomyiidae	*Tinodes waeneri* (L.)	13.3	11.7	19.0	23.7	19.3	21.3	4.0	19.0
		Lype phaeopa (Stephens)	102.7	3.7	47.3	1.7	25.3	28.0	-	7.3
		Metalype fragilis (Pictet)	17.7	0.3	1.3	0.3	1.7	2.7	-	6.7
	Polycentropodidae	*Polycentropus kingi* McLachlan	6.7	9.0	2.7	0.7	-	-	-	8.3
		Holocentropis picicornis (Stephens)	0.7	-	-	-	-	-	-	-
		indet.	0.7	-	1.0	-	-	-	-	-
	Glossomatidae	*Agapetus fuscipes*Curtis	-	-	0.3	1.7	-	-	0.3	1.3
		Glososoma spp.	-	-	-	-	-	0.3	-	-
	Lepidostomatidae	*Indet.*	-	2.0	-	-	-	-	-	-
	Limnephilidae	*Drusus annulatus* (Stephens)	2.3	-	8.3	-	-	0.3	4.0	-
		Potamophylax spp.	-	-	-	0.3	-	-	-	-
		Halesus radiatus (Curtis)	-	-	0.7	0.3	0.3	-	0.3	0.7
		Limnephilus spp.	-	-	0.3	2.0	-	-	0.7	0.3
	Sericostomatidae	*Sericostoma personatum* (Spence)	5.3	-	12.7	-	2.0	3.0	0.3	2.3
	Leptoceridae	*Mystacides azurea* (L.)	-	-	-	-	-	2.0	-	-
		Indet.	3.7	0.3	2.3	0.3	1.0	2.3	1.7	0.3
Megaloptera		*indet.*	-	-	-	-	-	3.0	-	-
Coleoptera	Haliplidae	*Haliplus fulvus* (Fab.)	0.3	-	-	-	-	-	-	-
		Haliplus spp.	1.0	5.0	6.0	38.0	7.3	21.3	31.7	41.3
	Gyrinidae	*Gyrinus spp.*	-	-	-	0.7	-	-	-	-
	Dytiscidae	*Stictonectes duodecimpustulatus* (Fab.)	-	-	-	-	-	0.7	-	-
		Potamonectes spp.	0.3	-	-	-	-	-	-	-
		Hydroporinae	-	-	4.3	-	0.3	1.0	-	0.7
	Hydraenidae	*Hydraena* spp.	-	-	-	-	3.0	0.3	-	3.0
	Elmidae	*Oulimnius tuberculatus* Mull	5.7	-	7.0	5.0	2.7	1.3	1.0	1.3
		Esolus parallelipepidus (Muller)	3.7	-	3.0	-	3.0	2.0	1.0	-
		Limnius volckmari (Panz.)	79.0	-	116.7	9.7	16.3	16.7	33.3	16.7
	Dryopidae	*indet*	-	-	-	-	1.0	-	0.3	-
Lepidoptera	Indet	*indet*	-	-	-	-	-	-	0.3	-
Diptera	Tipulidae	*Tipula* spp.	-	-	2.7	-	-	-	-	-
	Pedicidae	*Antocha* spp.	4.7	-	0.7	-	0.7	0.7	-	0.3
	Dolicopodidae	*indet.*	-	-	0.3	-	-	-	-	-

CR- Cormorant Rock; MB- Moon Bay; SB- Snadaun Bay; KB- Kitteen’s Bay; CB- Currarevagh Bay; GB- Glynn’s Bay; BI- Bob’s Island; RB- Rinarroon Bay.

Order	Family	Species	CR	MB	SB	KB	CB	GB	BI	RB
Table 3 cont.										
Diptera	Empididae	*Wiedemannia/ Clinocera*spp.	5.3	-	2.0	-	-	0.3	-	-
	Chironomidae	Chironominae spp.	2.3	-	1.0	4.0	1.0	1.7	0.3	1.7
		Tanypodinae spp.	4.3	-	1.0	-	1.7	1.0	-	0.3
Hirudinea	Glossiphoniidae	*Glossiphonia complanata* (L.)	0.7	0.3	-	-	0.3	-	-	-
		Helobdella stagnalis (L.)	-	-	-	-	0.3	1.0	-	-
	Erpobdellidae	*Erpobdella octoculata* (L.)	0.3	-	2.0	243.7	0.7	2.7	-	0.7
Crustacea	Gammaridae	*Gammarus duebeni* (Lillj.)	223.3	11.0	1553.0	656.3	546.0	57.3	2047.0	178.0
	Aselidae	*Asellus aquaticus* (L.)	18.7	6.7	47.7	50.0	24.3	208.0	16.7	562.7
		Asellus meridianus (L.)	0.3	-	0.0	2.0	-	-	6.3	8.3
Acari	Araeneae	*indet.*	-	-	-	-	0.3	-	-	-
Annelida	Oligochaeta	*Indet*	-	-	1.0	0.7	-	-	0.3	0.3
Odonata	Zygoptera	Odonata	-	-	-	1.0	0.3	-	0.7	-
Hemiptera	Corixidae	*indet.*	0.7	4.0	0.3	6.3	8.7	0.7	31.0	4.0
Mesogastropoda	Hydrobiidae	*Bithynia leachi* (Sheppard)	2.0	1.0	-	0.7	-	-	1.3	0.3
Basommatophora	Lymnaeidae	*Lymnaea stagnalis* (Linn.)	-	0.3	-	-	-	0.7	0.3	-
		Lymnaea peregra (Mull.)	0.3	8.3	-	0.7	0.7	8.0	1.0	2.0
		Lymnaea sp.	-	-	1.0	-	0.3	-	-	-
		Hydrobia ulvae (Pennant)	-	-	0.7	-	-	-	0.3	-
	Physidae	*Physa fontinalis* (Linn.)	1.0	-	-	-	-	1.3	-	-
	Planorbidae	*Planorbis* spp.	-	1.3	-	2.3	0.3	-	-	1.7
Bivalva	Pisidiidae	*Pisidium* spp.	-	0.3	0.3	-	-	0.3	-	-

CR- Cormorant Rock; MB- Moon Bay; SB- Snadaun Bay; KB- Kitteen's Bay; CB- Currarevagh Bay; GB- Glynn's Bay; BI- Bob's Island; RB- Rinarroon Bay.

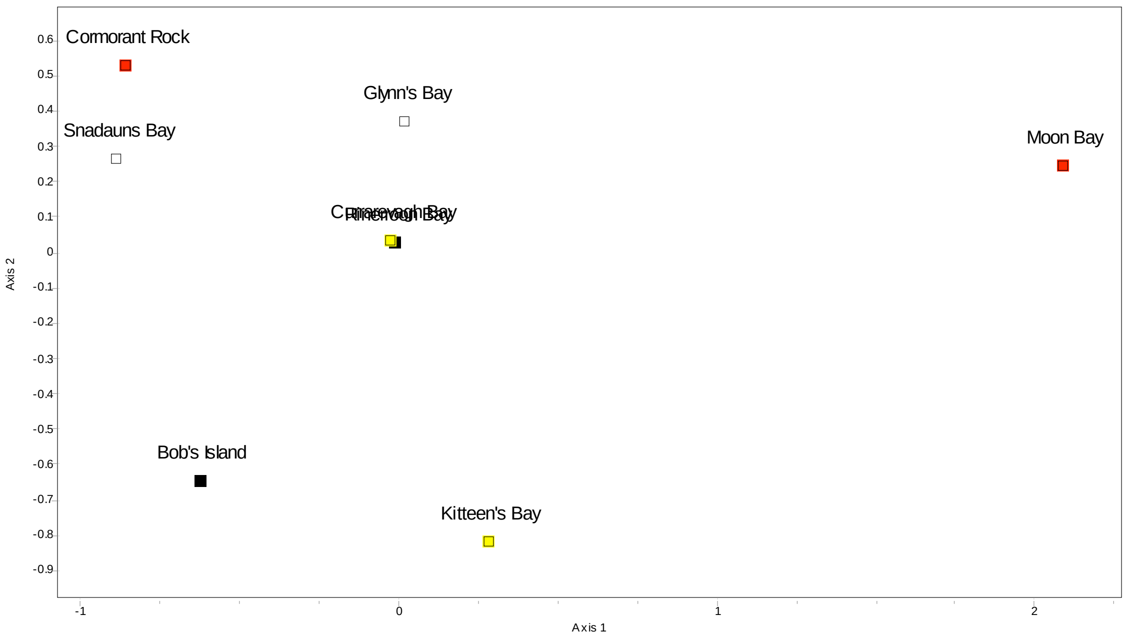

Figure 4: An NMDS plot indicating the relationship between sites using the invertebrate species recorded in replicated kick samples collected in eight bays in Lough Corrib with varying levels of infestation of *Lagarosiphon major*.

Activity traps in littoral habitats

The activity traps deployed did not return significant numbers of invertebrates. The majority of the traps were within open water (near the surface) and the most numerous organisms collected were perch fry, *Perca fluviatilis* L. The contents of activity traps are often significantly affected by predatory taxa such as fish and the results may not reliably reflect changes in the invertebrate fauna due to the exotic weed species. The samples collected were therefore discarded and are not discussed further. However, these traps have proven very effective in collecting invertebrates amongst macrophyte vegetation in other lentic habitats (JR Baars unpublished data) and should be included in further studies to collect the active and nocturnal species within the infestations of *L. major*.

Fauna associated with macrophyte species

A total of 30 taxa were collected from plant samples taken from four aquatic macrophyte taxa. Numerous invertebrate groups were collected, but a number of groups were considered poorly represented as a result of the method employed to collect the plant samples. There was a distinct lack of fast, active species like *Haliplus* adults and Crustacea, which were noted to occur in containers which kept the plant material before placing into sample bags. Taxa included were considered to be more associated with the plants and were generally more sedentary, like *Chironomidae* spp. Some active taxa were included probably as a result of entanglement in the material. Trends in Figure 4 indicate that the structure of the plant material may have influenced the reliable collection of all the taxa associated with the four aquatic macrophyte species. More taxa were collected on Charophyte spp., *L. major* and *E. canadensis* compared to *P. lucens* (Figure 5).

When the invertebrate communities were compared there were clear differences between the macrophyte taxa (Figure 6). The communities associated with *L. major* and *E. canadensis* were quite similar, but those on the Charophyte and *P. lucens* were notably different. The Charophytes were split into two in Figure 5 as it was noted that the species collected as 'Charophyte spp.' were represented by two different species. One (Charophyte 1) had a dense short growth form, whereas the second (Charophyte 2) had an elongate and relatively open growth form. The invertebrates collected from these seem notably different, although were represented by small sample replicates, and should not be over interpreted.

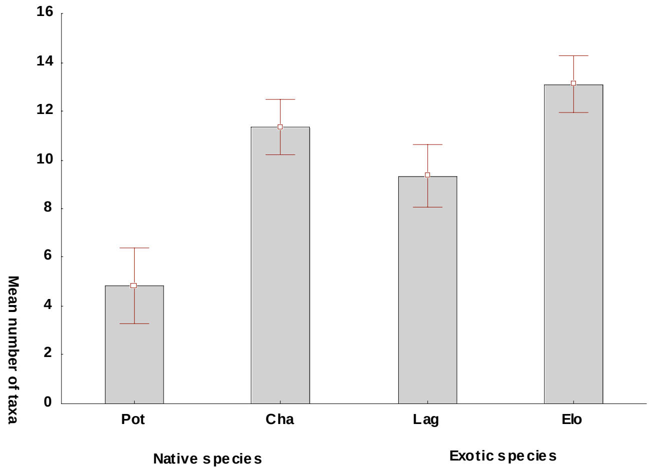

Figure 5: The mean number of taxa collected in each sample of four aquatic macrophyte species, including Pot- *Potamogeton lucens*; Cha- Charophyte spp.; Lag- *Lagarosiphon major*; Elo- *Elodea canadensis*.

Table 4: List of invertebrate species, and mean number associated with four aquatic macrophyte taxa collected in Lough Corrib.

			Native		Exotic	
Order	SubOrderFamily	Genus/Species	Pl	Ch	Lm	Ec
Ephemeroptera	Caenidae	*Caenis luctuosa* (Burmeister)	0.3	-	1.9	0.2
Trichoptera	Polycentropodidae	*Holocentropis picicornis* (Stephens)	-	0.3	0.3	0.1
		Holocentropis dubius (Rambur)	6.3	0.3	1.3	0.6
	Ecnomidae	*Ecnomus tenellus* (Rambur)	-	-	-	0.1
	Lepidostomatidae	*Lasiocephala basalis* (Kolenati)	-	1.7	0.1	0.4
	Leptoceridae	*Mystacides longicornis* (L.)	0.8	1.7	0.2	0.3
		Oecetes spp.	1.3	0.7	0.3	2.8
		Indet.	0.3	-	-	1.3
Coleoptera	Haliplidae	*Haliplus* spp.	-	38.7	-	0.9
	Gyrinidae	*Gyrinus* spp.	3.5	-	2.8	0.3
	Curculionidae/Chrysomelidae	Indet.	0.8	-	-	1.4
Lepidoptera	cf. Pyralidae	Indet.	30.0	-	7.1	4.7
Diptera	Chironomidae	Chironomidae spp.	1340.8	249.0	604.4	411.1
		Tanypodinae spp.	-	-	0.9	-
Hirudinea	Glossiphoniidae	*Glossiphonia complanata* (L.)	-	10.3	0.3	3.4
		Helobdella stagnalis (L.)	-	1.0	-	1.4
	Erpobdellidae	*Erpobdella octoculata* (L.)	0.8	-	0.6	1.6
		Piscicola geometra (L.)	-	-	-	0.1
Crustacea	Gammaridae	*Gammarus duebeni* (Lillj.)	-	0.3	0.7	0.2
		Crangonyx spp.	-	48.0	15.1	0.6
	Asellidae	*Asellus aquaticus* (L.)	0.5	11.3	10.6	1.2
Annelida	Oligochaeta	Indet.	0.8	0.3	1.1	0.6
Odonata	Zygoptera	Indet.	0.3	-	0.4	0.3
Mesogastropoda	Hydrobiidae	*Bithynia leachi* (Sheppard)	0.3	24.7	7.0	8.2
		Bithinella scholtzi (Schmidt)	-	-	-	0.1
Basommatophora	Lymnaeidae	*Lymnaea stagnalis* (Linn.)	-	-	-	0.3
		Lymnaea peregra (Mull.)	1.0	32.3	4.7	4.8
	Physidae	*Physa fontinalis* (Linn.)	-	0.3	0.2	-
	Planorbidae	*Planorbis* spp.	0.3	22.3	2.0	3.8
Bivalva	Pisidiidae	*Pisidium* spp.	-	9.3	0.2	3.0

Pt – *Potamogeton lucens*, Ch – Charophytes, Lm – *Lagarosiphon major*, Ec- *Elodea canadensis*.