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Article

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MANAGEMENT OF *LAGAROSIPHON MAJOR* (RIDLEY) MOSS IN LOUGH CORRIB—A REVIEW

Joe Caffrey, Michael Millane, Stephanie Evers and Helen Moran

ABSTRACT

Lagarosiphon major is a priority invasive species first recorded in a natural Irish watercourse, Lough Corrib, in April 2005. The weed has subsequently expanded its range significantly within the upper and middle lake but, as of 2010, has not been recorded in the large lower lake. In Lough Corrib the temporal growth pattern exhibited by *L. major* is at variance with that displayed in its country of origin. In southern Africa the plant grows most vigorously in summer, whereas in Corrib it achieves its best vegetative expression during the colder and darker winter months. This temporal growth pattern significantly influences practical weed control programmes, as it has proved to be far more efficient to cut and harvest *L. major* stands when the stems are erect and buoyant, even if it does mean that cutting operations must be conducted during the more inclement winter months. A combination of traditional and innovative weed control methods are used to control *L. major* in the lake. These include manual removal using scuba divers, mechanical cutting and harvesting, chemical control and light exclusion using a natural jute matting material. In 2008 *L. major* occupied *c.* 92ha of lake bed, while some 8,500ha is deemed to be suitable for its establishment and growth. Control work to date has reduced the area of lake occupied by this aggressive weed to *c.* 35.9ha.

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INTRODUCTION

Invasive non-native species (synonym alien species) are defined as species whose introduction and/or spread threaten biological diversity or have other unforeseen impacts. They occur in all major taxonomic groups, including animals, plants, fungi and micro-organisms. Invasive species represent one of the greatest threats to biodiversity worldwide (Vitousek *et al.* 1996), second only to that caused by direct habitat destruction (Scalera and Zaghi 2004). They can also cause appreciable damage to agricultural systems, human populations and the wider economy (Liebhold *et al.* 1995; Liebman *et al.* 2001; Pimentel *et al.* 2005). Their introduction is acknowledged to be one of the major causes of species extinction in freshwater ecosystems. Because rivers, lakes and watercourses generally provide efficient conduits for the dispersal of many invasive species, these habitats are particularly vulnerable to the spread of invasive species.

Lagarosiphon major (Ridley) moss (curly-leaved waterweed) is a high impact invasive species in freshwater systems (Caffrey and Acevedo 2008). It is native to southern Africa, where its biomass can interfere with commercial navigation and water-based recreation (Newman 2004). *Lagarosiphon major* is a perennial, submerged aquatic plant distinguished from closely related *Elodea* species by the leaves, which alternate spirally along the stems. Outside its native range, only female plants are known (Cook 1982) and all reproduction is by fragmentation or vegetative reproduction. In Ireland *L. major* is legally sold as an oxygenating plant for use in artificial watercourses. As a consequence, the plant is present in garden ponds, aquatic features on golf courses and in enclosed, artificial lakes throughout the country.

Lagarosiphon major was first recorded in a natural watercourse in Ireland, Lough Corrib, in 2005. Lough Corrib SAC and SPA is a site of major conservation importance and includes fourteen habitats and six aquatic species, listed in Annex I and Annex II, respectively, of the EU Habitats Directive. When first discovered the weed was confined to a number of sheltered bays on the western shore of the upper lake (Fig. 1). It has since expanded its range significantly and, by 2010, was present in more than 150 bays and littoral areas in the upper and middle lake. No established *L. major* plant stands have yet been recorded in lower Lough Corrib.

At sites where *L. major* successfully establishes, it rapidly produces a large biomass and competitively excludes native aquatic macrophyte species and communities (Caffrey and Acevedo 2008; Caffrey *et al.* 2010). It also alters habitat conditions for indigenous macroinvertebrate and fish communities (Baars *et al.* 2009; Caffrey *et al.* 2010). This ecosystem alteration creates habitats that are

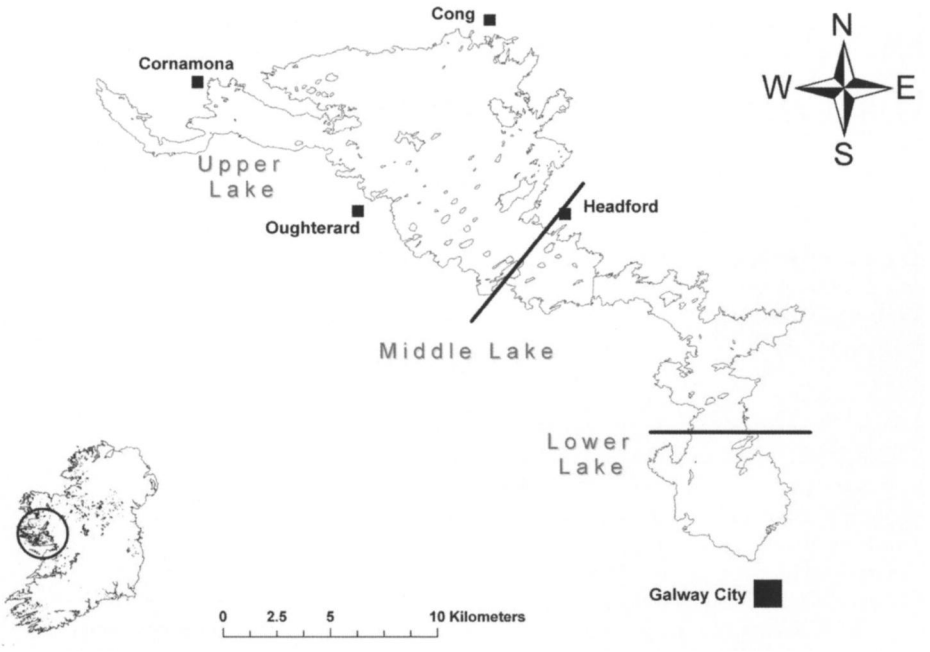

Fig. 1—Map of Lough Corrib showing the main topographic divisions of the lake (from Krause and King 1994).

favoured by pike (*Esox lucius* L.), perch (*Perca fluviatilis* L.) and a range of cyprinid fish species, to the detriment of native wild brown trout (*Salmo trutta* L.) and Atlantic salmon (*Salmo salar* L.), for which the lake is currently internationally renowned (Caffrey *et al.* 2010).

This paper describes the basic biology, ecology and current status of *Lagarosiphon major* in Lough Corrib. It also describes the range of weed control methods and procedures that have been targeted against the weed in an effort to eradicate, control or restrict the spread of this highly invasive species. Results from these ongoing control operations are presented and their relevance for future management of the weed in Lough Corrib or elsewhere in Ireland are discussed.

MATERIALS AND METHODS

Information on the distribution and status of *L. major* in Lough Corrib (area 178km^2) was collected using a range of methods that included grapnel sampling along predetermined transects, viewing the lake bed through a glass-bottomed viewing tube, snorkelling and scuba diving. All littoral areas (<6m deep) throughout the lake have been surveyed in most years since 2005. The presence or absence of *L. major* at each site was recorded using GPS. Surveys were conducted each year between 2005 and 2008, and in 2010.

From 2007 to 2010, the general morphology and growth habits of *L. major* at selected sites in the upper lake have been observed. Information on the growth status of the plant (i.e. stems erect or collapsed, stems with or without adventitious roots, canopy present or absent) was collected by scuba divers at least seasonally.

The efficacy of a range of traditional and innovative weed control methods targeted against *L. major* has been evaluated in the lake since 2007. Pilot trials were initially conducted in January 2007 at sites which the weed grew abundantly and from where it was most likely to spread to other areas within the lake. Four weed control methods were trialled at this time. These were: manual removal using scuba divers, approved herbicide (dichlobenil), light exclusion using black plastic, and mechanical cutting and harvesting. The methodology adopted is described in Caffrey and Acevedo (2008). Results from these trials informed the course of future weed control methodologies and strategies.

Ongoing monitoring of the efficacy of the principal weed control methods being used to control *L. major* in the lake is necessary if significant weed regrowth is to be detected. This best level of detection is achieved using a combination of boat-towed snorkelling and scuba diving, where the percentage cover of *L. major* on site immediately post-treatment and in the months following this treatment is recorded. Where the weed has been cut from large areas of the lake (>4ha) this assessment is made by recording the percentage cover and relative abundance of *L. major* cover along transects that traverse the bay. In areas where localised weed control was the chosen method, the sites (marked using GPS) were surveyed by

scuba divers in the months following treatment and the percentage cover of *L. major*, if present, was again recorded.

Because of the practical difficulties encountered with using black plastic sheeting for light-exclusion trials, an alternative solution was sought. A natural and biodegradable material was found to replace the plastic sheeting commonly used. Rolls of jute matting (5m wide × 900m long, *c.* 200g m^{-2}) were sourced and trialed on *L. major* in Lough Corrib. Jute is a natural vegetable fibre and the matting used is loose-woven and durable. Another beneficial characteristic of the product for application in large lake situations is the fact that it saturates on contact with water and rapidly sinks, thus limiting the impact that wind can have on its accurate placement. The methodology used for the trial is described in Caffrey *et al.* (2010).

RESULTS

Results from distribution surveys conducted throughout Lough Corrib between 2005 and 2010 demonstrated that *L. major* has significantly expanded its range since it was first reported in 2005. The number of sites known to be infested with this invasive plant increased from nine in 2005 to 159 in 2010. The original infestation was concentrated on the western shore of the upper lake. Range expansion, however, resulted in the establishment of viable populations of the plant in most suitable parts of the upper and middle lake by 2008 (Fig. 2). No specimens of *L. major* were recorded from the lower lake between 2005 and 2009, although sampling in this shallow water-course (mean depth 2.5m) has revealed that most areas are suitable for *L. major* establishment and growth (Fig. 3). In a detailed survey of the lower half of the middle lake (from south of Lee's Island) and the lower lake conducted in 2010, 459 sites were examined and no living *L. major* plants were recorded.

Lagarosiphon major demonstrated a rapid growth rate at suitable sites in Lough Corrib. In 2005 the plant occupied an area of 12ha in Rinnerroon Bay, where it was first recorded. By the summer of 2007 the plant had expanded its range within this bay to 19.45ha. Based on the fresh weight biomass for *L. major* recorded in 2005 (Caffrey 2006; 2007), this represents an increased biomass over the two year period of 1,028 tonnes.

In most littoral areas of the lake where *L. major* was absent, an abundant and diverse indigenous macrophyte flora was recorded. Charophytes were the dominant macrophyte community present and commonly occupied extensive, low-growing meadows, providing up to 100% bottom cover. The principal species present were *Nitella flexilis* (L.) C. Agardh, *Chara globularis* Thuillier, *C. rudis* (A. Braun) Leonhardi, *C. virgata* Kützing and *C. vulgaris* (L.). Other macrophyte species that produced locally dominant stands in the lake included *Myriophyllum spicatum* L., *Potamogeton lucens* L., *P. perfoliatus* L., *P. pusillus* L., *P. gramineus* L. and *Elodea canadensis* Michaux. In contrast, in those areas where *L. major* grew abundantly, few if any indigenous macrophyte species were recorded

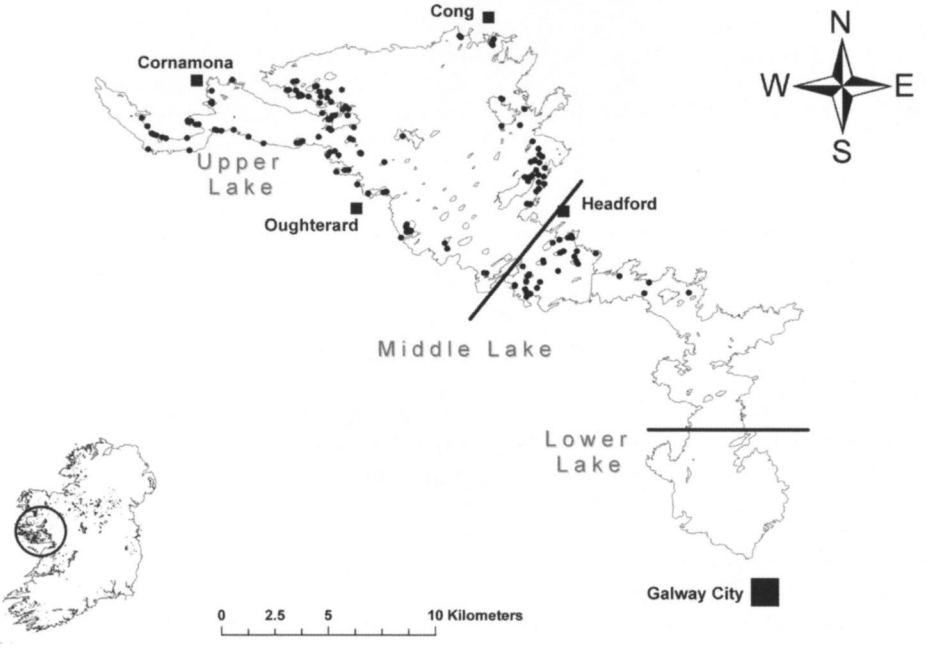

Fig. 2—The distribution of *Lagarosiphon major* in the upper and middle lakes of Lough Corrib in 2008 (● L. major sites).

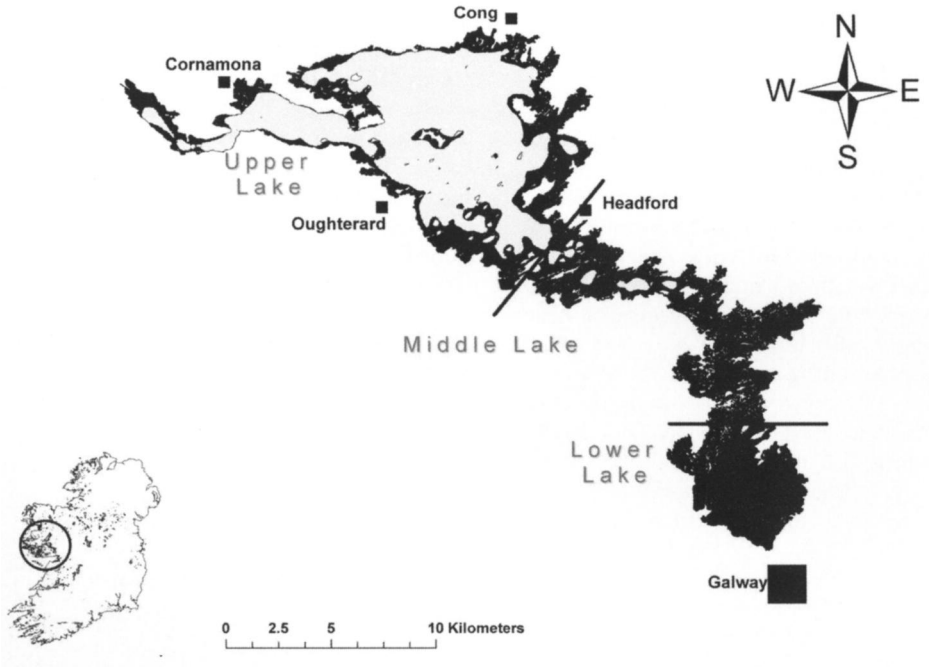

Fig. 3—Map of Lough Corrib showing the area of lake bed that is suitable for the establishment and growth of *Lagarosiphon major*.

(Caffrey and Acevedo 2007; 2008; Caffrey *et al.* 2009). Those that were present were depauperate or confined to localised areas where sufficient incident light penetrated through the dense surface vegetation canopy.

Investigations into the morphology and growth habits of *L. major* in Lough Corrib revealed a temporal pattern that is not recorded for this species in its place of origin or in most other countries where it has become established (J.-R. Baars, pers. comm.; Cook 2004). In Lough Corrib the plant grows vigorously and produces tall and highly branched stems during the colder and darker months (October to May). It is during this stage that its characteristic dense surface canopy layer is formed. As water temperature increases and day length extends, the stems lose their buoyancy, produce large numbers of adventitious roots (some up to 0.4m long), and collapse towards the lake bed. Throughout the summer months nodal growth among the collapsed stems produces large numbers of young plants that rise towards the surface. As water temperatures decrease below *c.* 10°C, vigorous regrowth among the whole *L. major* population resumes and surface canopy status is again achieved (Caffrey *et al.* 2009; Millane *et al.* 2010).

Since the presence of *L. major* was first confirmed in Lough Corrib in 2005, considerable research effort has focused on developing a suite of practical methods that could be used to control or eradicate this aggressive invasive weed, or at least limit its spread within the lake. Site trials have been conducted over the last five years using a number of traditional weed control methods. Modifications to these and the use of more innovative methods have also been trialled.

The principal weed control methods that are currently operated in Lough Corrib include manual removal by scuba divers, mechanical cutting and harvesting, herbicide treatment and light exclusion. The possibility of using biological control, where natural enemies from *L. major's* country of origin (southern Africa) are targeted against it, is being explored (Baars *et al.* 2010; 2011). The life cycle and adventive traits of *L. major* are also being studied in anticipation of finding a 'weak link' in the plant's life cycle that could become the target of strategic control operations.

The temporal growth pattern exhibited by *L. major* significantly influences the practical weed control programmes that have been developed to control or eliminate it in the upper and middle lake. One manifestation of this is that mechanical cutting and harvesting operations should be conducted during the more inclement winter months, when the plant stems are erect and buoyant.

Mechanical cutting provides a method for rapidly removing obstructive vegetation from a watercourse. The results tend be short term, however, as weed regrowth can again present obstructive stands within weeks of the initial cut (Caffrey 1993a). Most of weed cutting boats that are available for use on aquatic weeds employ reciprocating blades that cut to a depth no greater than 1.8m below the water surface. The consequence of this 'shallow' cut is that incident light can readily

penetrate to the cut vegetation and stimulate active regrowth (1993b). In 2007, trials were conducted in Lough Corrib using paired V-blades, aimed at applying a deep cut (to the bed of the lake). These blades are attached to a length of chain (normally 8m long) and pulled along the lake bed behind a weed cutting boat. The outer edges of the blades are blunted so that the vegetation is ripped from the substrate rather than being cleanly cut. This causes greater trauma to the plant and also uproots a considerable amount of root material from the soft substrate. Results from trials conducted in Lough Corrib and from research conducted in New Zealand have demonstrated that regrowth among *L. major* plants is significantly reduced where the plant is cut at root level (Clayton and Franklyn 2005; Caffrey *et al.* 2008). The cut weed is harvested and brought ashore. The trials revealed that regrowth in the cut plots was less than 10% after seven months and much of this resulted from the regrowth of plant fragments that floated into the cut plots from adjacent uncut areas (Caffrey and Acevedo 2008).

Based on the trial findings, a weed cutting boat that was purpose-built to operate V-blades was purchased and dedicated to *L. major* control in Lough Corrib. Since 2008 the strategic focus for weed cutting operations has been on the upper lake where all of the large founder populations of *L. major* are located. In the past three years some 22 heavily infested bays and shallow littoral areas, covering 50.4ha, have been treated using the V-blades. During these operations *c.* 6000 tonnes of *L. major* have been removed from the lake. As part of the *L. major* control programme for Lough Corrib, the efficacy of cutting operations is monitored at all treated sites. Results generally revealed that, one year after cutting, the percentage cover for *L. major* was at least 75% less than that present before cutting. The application of a second cut, where it is deemed necessary, reduces the level of regrowth even further (Millane *et al.* 2011).

Manual removal of *L. major* by scuba divers is conducted at sites where the plant has recently invaded and/or where the level of vegetative abundance is low. While this method is slow and labour intensive, it is acknowledged to be an effective long-term strategy for the control/eradication of *L. major* in such situations (Clayton 2003). Between 2007 and 2010 some 73 sites that supported small or isolated populations of *L. major* were identified and cleared by hand removal. Monitoring in the months following treatment revealed that little or no *L. major* regrowth was recorded at these sites.

In recent years only one approved herbicide (dichlobenil) has been available for use against submerged weed species in Ireland. Research in this country has demonstrated that this herbicide has minimal adverse impact on water quality, non-target plants, macroinvertebrates or fish (Caffrey 1993a; 1993b). The herbicide is used to best effect in discrete areas that are inaccessible to boats, such as in the vicinity of small marinas or harbours or to target localised plant stands that regrow following mechanical weed cutting operations. Trials using dichlobenil on *L. major* in Lough Corrib demonstrated the susceptibility of this weed to the activity of the herbicide and, in suitable habitats, a 100% weed kill was normally achieved. In the last three years 103 localised *L. major* beds, covering an area of 7.1ha, were treated with dichlobenil. Subsequent monitoring, up to twelve months following herbicide application, has revealed almost total weed control in all treated areas.

The exclusion of incident light from submerged vegetation will inhibit photosynthesis and result in the death of targeted plants. Trials using black plastic to exclude light from *L. major* in Lough Corrib were conducted in 2007. While a modest level of weed control was achieved where it was possible to secure the material to the lake bed (Caffrey and Acevedo 2008), it was considered that the method would prove too onerous and costly to implement in the longer term. In addition, the ballooning of the plastic towards the water surface as the weed decayed beneath presented a hazard to anglers and boaters.

Between August 2008 and October 2009, trials were conducted at seven *L. major*-dominated sites using a light-excluding material made of natural fibre (jute). The area of lake bed covered with the open-weave material varied between $100m^2$ and $5{,}000m^2$ and the length of time the matting was in place ranged from four to seventeen months. At all seven sites the *L. major* beneath the matting was killed, even where the matting was in place for only four months (Caffrey *et al.* 2010). At each site where seven or more months had elapsed from the time the jute matting was put in place, native macrophyte species grew through the weave of the material. The charophyte *Nitella flexilis* agg. was present at each of these sites. Three other charophyte species, namely *Chara globularis*, *C. rudis* and *C. virgata,* were also recorded growing through the jute matting. Percentage cover with charophyte species varied between 37% and 85% at these sites within seven months of jute placement (Caffrey *et al.* 2010). A number of indigenous or naturalised angiosperm species were also recorded growing through the weave of the jute matting. These included *Myriophyllum alterniflorum*, *M. spicatum* and *Elodea canadensis*.

Because of the success of these trials, the wide-scale use of jute matting for *L. major* control in Lough Corrib was adopted in 2009. To date, 116 discrete *L. major* infested areas in the lake, covering *c.* 1.6ha, have been covered. No *L. major*

has been observed growing through the matting at any site. The jute is normally placed over the weed during the summer months, when the vegetation is collapsed. The strategic focus of operations in 2009 and 2010 has been in the middle lake (see Fig. 1) in an effort to prevent the weed expanding into the shallow lower lake.

An investigation conducted in upper and middle Lough Corrib in 2008 revealed that, at that time, *L. major* occupied *c.* 92ha or 0.5% of the entire lake area. If the invasive weed was to successfully colonise all of the suitable habitat in the lake that is available (i.e. water between 1m and 4m deep in sheltered areas with soft mud or silt substrate), it could potentially occupy some 8550ha or 48% of the total area of the watercourse (Fig. 3). As a consequence of the weed control work to the end of 2010, the area of lake bed currently occupied by the invasive weed has decreased to 35.9ha or 0.2% of the total lake area.

DISCUSSION

The number of non-native and invasive freshwater species recorded in Irish watercourses has increased significantly in the late 1900s (Caffrey 1994; 2001; Wade *et al.* 1997; Stokes *et al.* 2006; Caffrey *et al.* 2007; 2008b; Hayden and Caffrey, in press). Northern Ireland and the Republic of Ireland have international obligations to address invasive species issues, principally under the Convention on Biological Diversity, International Plant Protection Convention, Bern Convention and the Habitats Directive. Lough Corrib is an SAC, as well as being an important water supply for Galway city, and every effort must be made to mitigate against factors or species that potentially impact on its high conservation status. *Lagarosiphon major* clearly is invasive in Lough Corrib and has adversely impacted on indigenous biotic communities in this expansive watercourse (Caffrey and Acevedo 2008; Baars *et al.* 2009). The current work programme on the lake is aimed at developing control procedures that will control or eradicate *L. major* before it spreads into the lower lake or to other lakes in Ireland.

In Lough Corrib *L. major* exhibits a life cycle that is at variance with that displayed in its native range or in other countries to which the weed has been introduced (J.-R. Baars, pers. comm.; Cook 2004; Caffrey *et al.* 2009; Millane *et al.* 2010). In Ireland *L. major* grows vigorously in winter and collapses during the summer months. Indeed, similar variations in lifecycle and in morphology have been reported for a few closely related aquatic invasive plant species, such as *Egeria densa* Planch. (Mazzeo *et al.* 2003; Yarrow *et al.* 2009) and *Elodea nuttallii* Planch. (Thiébaut and Di Nino 2009). It is considered that this growth cycle confers a competitive advantage on *L. major* over the indigenous macrophytes present in Lough Corrib by presenting tall, light-excluding stands during the spring season when most species emerge from the substrate to commence active growth. Results from studies conducted in the lake have revealed the success of this strategy and the virtual exclusion of native macrophyte communities in *L. major* dominated areas (Caffrey and Acevedo 2008; Caffrey *et al.* 2008; 2009).

The presence of tall and dense vegetation stands during the winter and early spring months provides a habitat type that was not present in the lake prior to the invasion by *L. major*. This new habitat is extensively utilised by pike and perch, both piscivorous species, as sites for shedding their adhesive egg masses. In fact, during April or May it is not uncommon to see hundreds of square metres of *L. major* carpeted with perch spawn in bays throughout the upper and middle lake. In addition to providing a suitable (and hitherto unavailable) spawning medium, these dense weed beds also provide sanctuary and a ready food supply for fry and fingerling perch, pike and for a number of cyprinid fishes, primarily roach (*Rutilus rutilus* L.). It is probable that the presence of this new habitat will ensure the survival of many fish through their first winter that would otherwise die at this vulnerable life cycle stage. These fishes will actively compete with native brown trout and young salmon for food and will increase the rate of predation on these valuable game fish. If the expansion of *L. major* was to continue unchecked, it is probable that the status of Lough Corrib as a game fishery of international repute would be seriously damaged.

Lagarosiphon major control measures undertaken to date have benefitted Lough Corrib in a number of ways. The removal of large canopy-forming weed stands has reduced the volume of potential fragments that are available to aid the further dispersal of this invasive species within or outside the lake. In addition, bays that were so clogged with weed that they were non-navigable and unfishable are now again open for recreational exploitation.

Between 2008 and 2010 the area of lake bed infested with *L. major* has decreased from 92ha to 35.9ha. The greater part of this decrease is accounted for by the removal of large and dense weed stands, many over 2ha in area, from relatively few bays or littoral areas in the upper lake. While this level of weed removal is significant, it is clear that *L. major* is continuing to spread within the upper and middle lakes. As a consequence, the focus of ongoing control programmes will aim to determine the detailed distribution of the weed in the lake on an annual basis (at least);

continue to develop new and upgrade existing weed control methods; remove the smaller infestations from a greater number of lake areas; and ensure that *L. major* does not spread into the lower lake or to waters outside Lough Corrib.

The increased frequency of aquatic invasive introductions to Ireland in recent times and the ongoing threat of new invasions has accentuated the risk not only to our native biodiversity but also to recreational exploitation and the overall functionality of impacted waters. With many invasions, eradication is practically impossible by the time the invader has been identified and control is the next best option. Research on a variety of control methods on *L. major* in Lough Corrib has been undertaken since 2006, which, although still ongoing, has resulted in the development of a suite of methods that, in combination, have significantly reduced the area of lake overgrown by this invader. In addition to the immediate benefit for anglers and boaters that the removal of dense and obstructive weed beds has had, there has also been a dramatic restoration in native plant communities, particularly where jute matting has been used to remove the *L. major* (Caffrey *et al.* 2010). A further benefit is the availability of effective, scientifically assessed weed control methods. These are transferrable to aquatic weed control projects worldwide and already some are being used for invasive species control as far afield as New Zealand (Hofstra *et al.* 2010).

While *L. major* is firmly established in upper and middle Lough Corrib, it has not yet been recorded in the lower lake or in any other natural watercourse in Ireland. It is imperative, therefore, that every effort is made to prevent this aggressive invasive species from being introduced to and establishing in any other waters. The ongoing weed control efforts in Lough Corrib will reduce the available source of plant material that can be spread either within or outside the lake, while also providing us with a suite of scientifically assessed control methods. However, the implementation of rigorous and informed biosecurity measures by all water users and stakeholders will be essential if the spread of *L. major* within the country is to be stopped. This will involve the proper disinfection of all angling equipment, boats, trailers, outboard motors and associated equipment after each fishing, shooting or boating trip. It may even be necessary to consider restricting the unauthorised movement of boats from one catchment to another.

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REFERENCES

Baars, J.-R., Keenan, E.A., O'Callaghan, P. and Caffrey, J.M. 2009 Changes to the invertebrate fauna of littoral habitats induced by the alien invasive species *Lagarosiphon major* (Hydrocharitaceae), Dublin. Central Fisheries Board.

Baars, J.-R., Coetzee, J.A., Martin, G., Hill, M.P. and Caffrey, J.M. 2010 Natural enemies from South Africa for biological control of *Lagarosiphon major* (Ridl.) Moss ex Wager (Hydrocharitaceae) in Europe. *Hydrobiologia* **656**, 149–58.

Baars, J.-M. 2011 Classical biological control for the management of alien invasive species in Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy* **111**B (3). DOI: 10.3318/BIOE.2011.17.

Caffrey, J.M. 1993a Plant management as an integrated part of Ireland's aquatic resources. *Hydroecologie Applique* **5** (1), 77–96.

Caffrey, J.M. 1993b Aquatic weed management practices using dichlobenil: an Irish experience. *Polskie Archiwum Hydrobiologii* **40** (3–4), 255–66.

Caffrey, J.M. 1994 Spread and management of *Heracleum mantegazzianum* (Giant hogweed) along Irish river corridors. In L.C. de Waal, L.E. Child, P.M. Wade and J.H. Brock (eds), *Ecology and management of invasive riverside plants*, Chichester. Wiley.

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. 2006 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. and Acevedo, S. 2007 *Status and management of Lagarosiphon major* in Lough Corrib —2007. Dublin. Central Fisheries Board, Dublin.

Caffrey, J.M. and Acevedo, S. 2008 *Lagarosiphon major* in Lough Corrib—management options. In C. Moriarty, R. Rosell and P. Gargan (eds), *Fish stocks and their environment*, 85–97. Westport. Institute of Fisheries Management.

Caffrey, J.M. and Evers, S. 2009 The use of life cycle traits in the management of the invasive species *Lagarosiphon major* in Lough Corrib, Ireland. *Proceedings of the 16th International Conference on Aquatic Invasive Species*, Montreal. Abstract.

Caffrey, J.M., Hayden, B. and Walsh, T. 2007 *Dace (Leuciscus leuciscus L.)—an invasive fish species in Ireland*. Irish Freshwater Fisheries, Ecology and Management no. 5. Dublin. Central Fisheries Board.

Caffrey, J.M., Acevedo, S., Gallagher, K. and Britton, R. 2008 Chub (*Leuciscus cephalus*): a potentially new invasive species in Ireland. *Aquatic Invasions* **3** (2), 197–205.

Caffrey, J.M., Evers, S. and Moran, H. 2009 Research and control programme for *Lagarosiphon major* in Lough Corrib 2008. Dublin Central Fisheries Board.

Caffrey, J.M., Millane, M., Evers, S., Moran, H. and Butler, M. 2010 A novel approach to aquatic weed control and habitat restoration using biodegradable jute matting. *Aquatic Invasions* **5** (2), 123–9.

Clayton, J. 2003 The history and principles of managing *Lagarosiphon major*, an invasive aquatic weed in Lake Wanaka. Internal report, National Institute of Water and Atmospheric Research, New Zealand.

Clayton, J.S. and Franklyn, G. 2005 Assessment of the December 2004 *Lagarosiphon major* control in Lake Wanaka. Internal report for the National Institute of Water and Atmospheric Research, New Zealand.

Cook, C.D.K. 1982 Pollination mechanisms in the Hydrocharitaceae. In J.J. Symoens, S.S. Hooper and P. Compere (eds), *Studies on aquatic vascular plants*, 1–15. Brussels. Royal Botanic Society of Belgium.

Cook, C.D.K. 2004 *Aquatic and wetland plants of southern africa*, Leiden. Backhuys Press.

Hayden, B. and Caffrey, J.M. in press First recording of the Asian clam (*Corbicula fluminea* (Müller, 1774)) from the River Shannon, with preliminary notes on population size and size class distribution. *Irish Naturalists' Journal*.

Hofstra, D., Clayton, J. and Caffrey, J.M. 2010 Weed matting. Options for control of submerged aquatic plants. Blenheim, New Zealand. New Zealand Biosecurity Institute, National Education and Training Seminar. Abstract.

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**, 149–61.

Liebhold, A.M., Macdonald, Q.L., Bergdahl, D. and Mastro. V.C. 1995 Invasion by exotic forest pests: a threat to forest ecosystems. *Forest Science Monographs* no. 30.

Liebman, M., Mohler, C.L. and Staver, C.P. 2001 *Ecological management of agricultural weeds*. Cambridge University Press.

Mazzeo, N., Rodríguez-Gallego, L., Kruk, C., Meerhoff, M., Gorga, J., Lacerot, G., Quintans, F., Loureiro, M., Larrea, D. and García-Rodríguez, F. 2003 Effects of *Egeria densa* Planch. beds on a shallow lake without piscivorous fish. *Hydrobiologia* **506**, 591–602.

Millane, M., Evers, S., Caffrey, J.M., Moran, H. and Sayed, S. 2010 Understanding the lifecycle and morphology of the invasive *Lagarosiphon major* in Lough Corrib, Ireland, in order to develop effective control practices. *Proceedings of the 17th International Conference on Aquatic Invasive Species*, San Diego, California. Abstract.

Millane, M., Evers, S., Moran, H., Caffrey, J.M. and Sayed, S. 2011 Control of *Lagarosiphon major* and Restoration of Natural Communities in Lough Corrib. In J.M. Caffrey (ed.), *Control of aquatic invasive species and restoration of natural communities in Ireland*, Annual report. Dublin. Inland Fisheries Ireland.

Newman, J. 2004 Centre for Ecology and Hydrology Information Sheet: *Lagarosiphon major*. Wallingford, England. Centre for Ecology and Hydrology.

Pimental, D., Zuniga, R. and Morrison, D. 2005 Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* **52** (3), 273–88.

Scalera, R. and Zaghi, D. 2004 *Alien species and nature conservation in the EU. The role of the LIFE program*. LIFE Focus Luxembourg. European Commission.

Stokes, K., O'Neill, K. and McDonald, R.A. 2006 Invasive species in Ireland. Unpublished report to Environment and Heritage Service and National Parks and Wildlife Service. Dublin. Quercus, Queens University. Environment and Heritage Service, Belfast and National Parks and Wildlife Service.

Thiébaut, G. and Di Nino, F. 2009 Morphological variations of natural populations of an aquatic macrophyte *Elodea nuttallii* in their native and in their introduced ranges. *Aquatic Invasions* **4** (2), 311–20.

Vitousek, P.M., D'Antonio, C.M., Loope, L.L. and Westbrooks, R. 1996 Biological invasions as global environmental change. *American Scientist* **84**, 468–78.

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 H. Brock, *et al.* (eds), *Plant invasions*, 139–52. Leiden. Backhuys Publishers.

Yarrow, M., Marin, I.H., Finlayson, M., Tironi, A., Delgado, L.E. and Fischer, F. 2009 The ecology of *Egeria densa* Planchón (Liliopsida: Alismatales): a wetland ecosystem engineer. *Revista Chilena de Historia Natural* **82**, 299–313.