EPA STRIVE Programme 2007-2013

Alien invasive species in Irish water bodies

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The EPA STRIVE Programme addresses the need for research in Ireland to inform policy makers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

EPA STRIVE PROGRAMME 2007–2013

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Executive Summary

While many non-native species have negligible negative effects, some cause significant economic and ecological impacts including reductions in biodiversity, decline of commercially important species and the alteration of ecosystems and ecosystem services. When these non-native species become established in existing ecosystems and threaten biodiversity and/or result in economic damage they are referred to as invasive alien species (IAS). IAS are regarded as the second most serious cause of biodiversity loss and environmental change worldwide, affecting freshwater ecosystems in particular due to their isolation and endemism. IAS have an impact on the ecosystem processes that are fundamental to human wellbeing including the wholesale loss or alteration of goods (e.g. fisheries) and services (e.g. clean and plentiful drinking water, culture and recreation).

Less diverse ecosystems, such as those that naturally occur on islands are particularly susceptible to invasion and damage following the introduction and establishment of IAS. Ireland, due to its glacial history and location on the western extreme of Europe is naturally depauperate in terms of its flora and fauna, and has repeatedly undergone invasion by a wide range of taxa, to the extent that many of its freshwater ecosystems are now dominated by IAS. The presence of these IAS in ecosystems can affect the ability of agencies or managers to maintain or improve ecological quality and halt degradation of ecosystem services. This has clear implications for the management of aquatic ecosystems and attainment of good ecological status under the Water Framework Directive (WFD).

As part of the STRIVE Programme 2007-2013, The EPA commissioned this project (Alien invasive species in Irish water bodies) with the aims of improving knowledge on the nature and extent of invasive alien species (IAS) and their impact on natural ecosystems; developing up to date national distribution maps showing the location of aquatic IAS in Ireland; and developing and trial control measures in the context of river basin management. This project has contributed to meeting these aims through a multidisciplinary, inter-institutional study, combining research, policy analysis and GIS database development.

A list of priority IAS of concern was compiled and distribution records collated to produce up to date distribution maps which can be viewed against a range of GIS layers in the National Invasive Species Database (NISD). Assessments of the coverage of the records for each species was made and for the majority of species, all known records are now included in the NISD. Opportunities to integrate IAS into WFD programmes were identified and a series of actions recommended including development of an alert list, inclusion of IAS in monitoring programmes and development of surveillance, recording and reporting protocols. A guidance note for contributors of IAS records was produced. The integration of the NISD with the Environmental Data Exchange Network (EDEN) will enable the delivery of distribution maps, identification of range expansions, species alerts and identification of waterbodies vulnerable to invasion on a River Basin District (RBD) level.

The impact of two IAS were investigated in two different RBD's namely, the ecological impacts of an invasive ecosystem engineer, *Lagarosiphon major* in Lough Corrib and the ecology of Ireland's most recent potential invasive fish, the chub (*Leuciscus cephalus*) in the River Inny. In Lough Corrib, macroinvertebrate community structure differed between invaded and native habitats with greater abundance and biomass in *Lagarosiphon* beds relative to that of the native *Chara* spp. The structure of the macroinvertebrate community also differed with increased abundance of invasive invertebrates, such as the zebra mussel in invaded habitats.

There were no such obvious effects of invasion on fish community structure or production, however, fish captured in invaded habitats differed in several key characteristics including size (roach), growth rate (perch), size at maturity (roach), instantaneous total mortality rates (roach and perch) and fish shape (roach and perch). Stable isotope analyses (SIA) revealed that *Lagarosiphon*, although representing the dominant primary producer in invaded habitats, made very little contribution to the food web of L. Corrib. Many consumers showed reduced isotopic variation in *Lagarosiphon*-dominated habitats, indicating that dietary variation may be reduced following invasion.

Chub were only present in very limited numbers during the study period and there was no evidence of any ecological impact of invasion. However, SIA revealed that the trophic ecology of chub in the River Inny overlaps with that of three important native fishes: eels, brown trout and Atlantic salmon and highlights the need for continued surveillance and control efforts for chub.

The efficacy of control measures was investigated and the use of jute matting to control *Lagarosiphon* and electrofishing to remove chub has delivered promising results. However, it is necessary to prevent and contain any new introductions or range expansions and the key pathways of introduction and vectors of spread for all the priority IAS were identified and include the horticulture, aquaculture, ornamental and aquaria trades and leisure activities such as boating, angling and water sports. A range of policy measures have been recommended including prevention and containment protocols for use at RBD level.

The research on the ecological impacts of *Lagarosiphon* and chub has increased our understanding of the impacts of these species and their interactions with native communities and other non-native species as well as demonstrating new means by which impacts can be measured. The development of the NISD, collation of records and mapping of the up-to-date distributions of aquatic IAS provides a valuable resource for researchers and managers. The demonstration of effective control measures for *Lagarosiphon* and chub will enable rapid reaction to further introductions and range expansions to new waterbodies. The development of proposals for surveillance, monitoring and reporting of IAS and policy measures for prevention and containment will inform the WFD programme of measures and river basin management.

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1 Introduction

1.1 Invasive alien species and aquatic ecosystems

While many non-native species have negligible negative effects (Bulleri *et al.*, 2008), some cause significant economic and ecological impacts including reductions in biodiversity, decline of commercially important species and the alteration of ecosystems and ecosystem services (Lodge & Shrader-Frechette, 2003). These non-native species that become established in existing ecosystems and subsequently threaten biodiversity and/or result in economic damage are referred to as invasive alien species (IAS) (Shine *et al.*, 2010). IAS are the second most serious cause of biodiversity loss and environmental change worldwide, affecting freshwater ecosystems in particular due to their isolation and endemism (Richter *et al.*, 1997; Dudgeon *et al.*, 2006). Aquatic ecosystems are susceptible to invasions, partly as a consequence of waterborne human activities such as shipping and boating, which represent a major vector for novel introductions (Darrigran, 2002). IAS have an impact on the ecosystem processes that are fundamental to human wellbeing including the wholesale loss or alteration of goods (*e.g.* fisheries) and services (*e.g.* clean and plentiful drinking water, culture and recreation) (Charles & Dukes, 2007; Pejchar & Mooney, 2009).

There are five pressures directly driving biodiversity loss namely, habitat change, overexploitation, pollution, climate change and IAS. Negative impacts of IAS on biodiversity can occur through a range of mechanisms such as competition, herbivory, predation, alteration of habitats and food webs, introduction of parasites and pathogens and through the dilution of native gene pools. In Ireland the most prominent of the negative impacts appears to be direct competition with native biota, whilst alteration to habitats and the influence of parasites and pathogens are also important (Stokes *et al.*, 2006). A pan-European analysis of presence of the 163 'worst' terrestrial and freshwater IAS threatening biodiversity in Europe showed that in 2006, the island of Ireland had 34 of these species (European Environment Agency, 2009) and since then a further 7 have been recorded. The cumulative number of high impact IAS recorded on the island of Ireland has also continued to grow and many species are expanding their distributions posing a threat to biodiversity and contributing to the degradation of ecosystem services.

1.2 Drivers for IAS management

Ireland as part of the European Union (EU) has recently committed to a target to halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, restore them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss. Therefore, in addition to the practical need to respond to the impacts of IAS directly there are also a range of policy drivers which require us to take action ranging from the international (e.g. Convention on Biological Diversity (CBD)), European (Habitats Directive) to National (Wildlife Amendment Act (2000); National Biodiversity Plan). The increasing impacts of IAS in the aquatic environment are of growing concern in the context of the Water Framework Directive (WFD) which requires Member States to achieve at least good status by 2015, aim at maintaining high status and prevent any deterioration in existing status of waterbodies. The species that were the focus of this project were ones that are currently impacting or have the potential to impact on meeting WFD objectives by affecting WFD biological parameters, including phytoplankton abundance and composition, macrophyte abundance and composition, benthic invertebrate communities and fish populations.

1.3 Aquatic invasive species in Ireland

In Ireland, practical management of introduced species is challenging because of the cross-border implications of controlling introductions and spread (Stokes *et al.*, 2006). Ireland, due to its glacial history and location on the western extreme of Europe is naturally depauperate in terms of its flora and fauna, and has repeatedly undergone invasion by a wide range of taxa, to the extent that many of its freshwater ecosystems are now dominated by IAS. The presence of these IAS in ecosystems can affect the ability of agencies or managers to maintain or improve ecological quality and halt degradation of ecosystem services. This has clear implications for the management of aquatic ecosystems under the WFD.

Over the last decade there has been a growing body of research on aquatic IAS and their impact on the Irish environment. Irish waterbodies are increasingly being invaded by more than one high impact invasive species and this may produce unpredictable effects. In some cases, native species or established invasive species appear to facilitate establishment of later-arriving non-indigenous species. Synergistic interactions among invaders may well lead to accelerated impacts on native ecosystems, in an 'invasional meltdown' process (Simberloff & Von Holle, 1999). Examples include Lough Corrib, which has been invaded by the zebra mussel and a range of non-native plants and fishes. This raises real challenges for policy makers on not only how they can deal with IAS under the WFD but in this time of limited resources, how they can identify and use opportunities that the WFD offers to address threats to biodiversity such as IAS. In this project we have sought to identify those opportunities and make practical recommendations to progress IAS management in tandem with wider WFD objectives.

1.4 Aims of the research

Tackling IAS is complex due to the range of environmental, social, economic, political and technological factors involved and the interactions between them. The 2004 characterisation and analysis of Ireland's River Basin Districts required under Article 5 of the WFD identified a number of significant knowledge gaps relating to IAS and the need for better information so that adequate management measures can be put in place and effective control measures developed for the WFD River Basin Management Plans. The EPA alien species risk assessment guidance stated that '*further work will be required to establish, more accurately, the range of each species and assess actual alien species pressures on waterbodies and to design the most appropriate programme of measures*' (EPA, 2005). A call for proposals was issued by the EPA with the main aims of:

- Improving our knowledge of the nature and extent of alien invasive species in Ireland and their impact on natural ecosystems.
- Developing up to date national distribution maps showing the location of alien invasive species in Ireland.
- Developing and trialling control measures in the context of river basin management.

This project was designed to fulfil all the elements of the EPA call, contribute to filling the knowledge gap under the WFD and to achieving commitments under the Convention on Biological Diversity (CBD), the Habitats Directive, the target to halt the loss of biodiversity and the degradation of ecosystem services by 2020 and the National Biodiversity Plan. The overall objectives of the project were to improve our knowledge of the nature and extent of IAS in Ireland and their impact on natural ecosystems and to develop and trial control measures for selected species. Three complementary work pages were undertaken by a multidisciplinary team focusing on policy development, IAS impacts and control and monitoring, mapping and recording.

Our policy development goals were to review impacts, vectors and management of high impact aquatic IAS in Ireland and internationally with a focus on a group of prioritised species, in order to inform policy development and management; and to develop strategies for monitoring and reporting and for preventing and containing IAS introductions (Work Package 1).

We aimed to describe the key consequences of invasion on the function and food-web dynamics, and on the community structure of, selected freshwater ecosystems in Ireland, thereby determining the impacts of IAS on community structure and function. Work Package 2a).

We undertook to determine the efficacy and consequences of measures aimed to control key invasive species including the invasive plant *Lagarosiphon major* in Lough Corrib, and an invasive fish, chub (*Leuciscus cephalus*), in one of the Shannon tributaries (Work Package 2b).

We aimed to determine the distribution of a range of priority IAS and put in place mapping and recording infrastructure. Specific objectives were to (a) identify the data requirements for monitoring and reporting strategies in line with national protocols and best practice, producing guidance note for data contributors; (b) prepare a GIS database of the location of all reported aquatic invasive species displayed by river system and lake catchments units; and (c) make this information publicly available via the National Biodiversity Data Centre web system and to provide an efficient mechanism for this information to be updated (Work Package 3).

The following chapters of this report summarise the approaches adopted in and the main findings from the project. The detailed results, analyses and discussion can be found in the End of Project Report available at http://erc.epa.ie/safer/reports.

2 IAS surveillance, monitoring and recording

2.1 Introduction

As measures to prevent the introduction of invasive species will not always be successful, it is important that species are detected early before they can become widely established. Surveillance, monitoring and recording programmes are vital components of the tool-kit of IAS prevention and management. They consist of a range of activities focused at different pathways, taxonomic groups and habitats operating at different spatial scales. An effective programme of early detection leading to rapid response is totally dependent on information being collected, communicated and acted upon. The overall aim of these programmes is to develop and implement effective mechanisms for detection, surveillance, monitoring and recording of new and established invasive species and disseminate the information in a timely way to enable appropriate action to be taken.

Risk assessment is a key mechanism to enable the allocation of limited resources to those species which pose the greatest threat to Irish biodiversity and ecosystem services. The Invasive Species Ireland (ISI) project developed a risk assessment and prioritisation methodology and carried out nearly 600 risk assessments for established and potential IAS which classified a number of species as high risk (see www.invasivespeciesireland.com for details). The risk assessments were carried out in a transparent manner with input from a wide range of IAS experts. The ISI list of high risk freshwater species, the DAISIE (Delivering Alien Invasive Species Inventories for Europe) inventory for Ireland and the Ecoregion 17 list for the Water Framework Directive were used to compile a list of priority species which were the focus of this project. The priority list comprised 17 established species and 14 species considered high risk potential invaders to Ireland (see Table 1). These species were the focus of the mapping and recording, the surveillance, monitoring and recording strategy and the best practice guide to prevention and containment (Chapters 3, 4 and 9 of the End of Project Report respectively).

Table 1: Priority species list

Established high impact	**Species**	**Common name**
Aquatic plant	*Lagarosiphon major*	Curly waterweed
	Elodea nuttallii	Nuttall's waterweed
	Myriophyllum aquaticum	Parrots Feather
	Crassula helmsii	New Zealand pigmyweed
	Azolla filiculoides	Water fern
	Lemna minuta	Least duckweed
	Nymphoides peltata	Fringed waterlily
	Hydrocotyle ranunculoides	Floating pennywort
Invertebrate	*Dreissena polymorpha*	Zebra mussel
	Gammarus pulex and G. tigrinus	Crustacean
	Eriocheir sinensis	Chinese Mitten Crab
Fish	*Leuciscus cephalus*	Chub
	Leuciscus leuciscus	Dace
Riparian plant	*Fallopia japonica*	Japanese knotweed
	Impatiens glandulifera	Himalayan balsam
	Heracleum mantegazzianum	Giant hogweed
Potential high impact	**Species**	**Common name**
Aquatic plant	*Ludwigia peploides* and *L. grandiflora*	Water primrose
Invertebrate	*Astacus astacus*	Noble crayfish
	Astacus leptodactylus	Turkish crayfish
	Pacificastacus leniusculus	Signal crayfish
	Orconectes limosus	Spiny-cheeked/striped crayfish
	Procambarus clarkii	Red swamp crayfish
	Hemimysis anomala	Bloody red shrimp
	Gyrodactylus salaris	Parasite
	Dreissena bugensis	Quagga mussel
	Corbicula fluminea	Asian clam
Fish	*Gymnocephalus cernuus*	Ruffe
	Sander lucioperca	Zander
	Pseudasbora parva	Top mouth gudgeon

2.2 The National Invasive Species Database

Accurately tracking the movement of invasive species is particularly important as this information can feed directly into effective early warning, rapid response and monitoring and control programmes. The National Invasive Species Database (NISD) has been developed by the National Biodiversity Data Centre and this project has made a major contribution to this important initiative. This element of the project focused on developing the mapping and recording infrastructure necessary to support surveillance and monitoring and provide up to date information on species distributions to support the implementation of programmes to manage IAS as part of achieving favourable conservation status of species and habitats and good ecological status of waterbodies. This involved developing a

GIS based database of aquatic invasive species which enables records to be displayed against the backdrop of additional GIS layers, the provision of a mechanism for online submission of verified records and the production of guidance for data contributors that meets requirements for monitoring and reporting strategies in line with national protocols and best practice. The combination of a mechanism for online submission of records and a mapping system has moved the NISD from a static resource into a dynamic database that has the potential to become a vital tool in the identification, monitoring and control of aquatic IAS in Ireland. It also provides the infrastructure for an early warning system which has been deployed four times in 2010. Work undertaken in the National Invasive Species Database project has also contributed to the wider development of IAS information exchange and horizon scanning at the European level largely through NOBANIS – the European Network on Invasive Alien Species (www.nobanis.org).

Records were collated for the 17 established species (see Table 1) and entered into the National Invasive Species Database and as of September 2010 this amounted to 5077 records. Three of the potential high impact species that were not known to occur in Ireland when this project began have since been recorded in Ireland namely, the Asian clam (*Corbicula fluminea*), bloody red shrimp (*Hemimysis anamola*) and water primrose (*Ludwigia grandiflora*) and 62 records are in the database for these species. Species distributions have been mapped and made publicly available on the National Biodiversity Data Centre's interactive GIS Biodiversity Maps website: http://maps.biodiversityireland.ie. Not all species have a complete dataset of records i.e. there are records in existence that are not in the database. However, the National Invasive Species Database is a full time project of the Data Centre and so records for these species will be continually updated. The distribution maps for the established aquatic plant species are shown in Figure 1 and the records shown are those available in the NISD at the time of writing. An assessment of the coverage of the data has been used to indicate whether the distribution mapped is an accurate reflection of the species actual distribution based on a traffic light system:

All known records displayed	Missing majority of records
Missing some records	Unable to assess

The distribution maps shown can be viewed against a range of GIS layers which are currently available on the Biodiversity Maps site including geographic (border, counties, localities, townlands), ecological (Special Protection Areas, Natural Heritage Areas, Special Areas of Conservation, Nature Reserves, lakes and rivers) and physical (Corine landcover (2000), bedrock geology, soils, subsoils). In addition, GIS layers for transport, aerial photography, base map and various layers for Northern Ireland are also available. The mapping system will be continually up-dated and developed to optimise its use as a tool for the geographic presentation of observational data on Ireland's biodiversity. Additional GIS layers due to be added to the mapping system which will contribute to the management of aquatic IAS include detailed rivers and lakes layers with WFD water body codes and the EPA water quality indicator layer. There are a multitude of benefits from displaying IAS distributional data against GIS layers on an interactive mapping system. The NISD can provide additional contextual information to inform risk assessment and management plans such as natural distribution corridors, soil suitability for establishment conditions and proximity to or presence in designated areas.

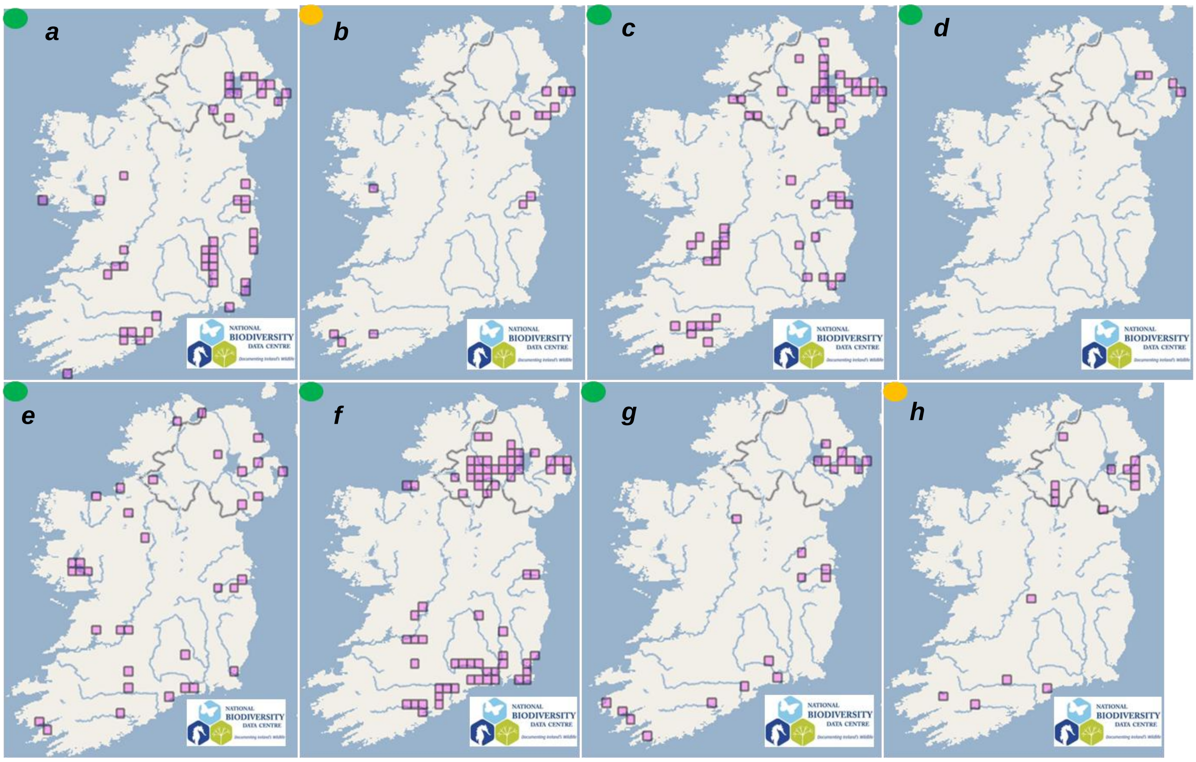

Figure 1: Distribution maps of the aquatic plant species (a) Water fern (*Azolla filiculoides)*, (b) New Zealand pigmyweed (*Crassula helmsii)*, (c) Nuttall's pondweed (*Elodea nuttallii)*, (d) Floating pennywort (*Hydrocotyle ranunculoides)*, (e) Curly leaved waterweed (*Lagarosiphon major)*, (f) Least duckweed (*Lemna minuta)*, (g) Parrot's feather (*Myriophyllum aquaticum)* and (h) Fringed waterlily (*Nymphoides peltata)*.

The provision of an online record submission facility is provided through the Data Centre's invasive species website: http://invasives.biodiversityireland.ie in the form of a customised excel file. This excel file provides a template for inserting invasive species records and highlights the mandatory fields that constitute a valid biological record as well as some desirable data that would enhance the value of the record. Example entries are provided for guidance.

The Invasive Species Ireland website also includes an Alien Watch page where invasive species records can be submitted (www.invasivespeciesireland.com/sighting/). Periodically, the records are then forwarded on to the National Biodiversity Data Centre for inclusion in the National Invasive Species Database. A Guidance Note for Data Contributors with specific reference to invasive species has been produced and is available for download on the Data Centre website. It provides guidance on meeting standards for data capture and reporting in order to provide high quality information and is based on the Data Centre's current Guidance Note for Data Contributors.

This project initially proposed to display aquatic IAS records by river and lake segments with Water Framework Directive (WFD)/EU coding. The preliminary results of undertaking this mapping process showed that this was not the most effective way to display this information and records of aquatic IAS will continue to be displayed by point location on the mapping system but once the WFD/EU coded detailed river and lake layers are added, it will be possible to view the coding of the river/lake segment and use this information for management and reporting purposes. Static GIS maps for the zebra mussel (*Dreissena polymorpha)* by lake segment will also be displayed on the NISD website once all of the historic records available have been entered into the database. The collation and updating of aquatic IAS records will continue beyond the life of this project as the National Biodiversity Data Centre will continue to hold and manage the species distribution data as part of its National Invasive Species Database project. The importance of continuing the management of this data cannot be overstated. The ability to publicly display the current distribution of IAS, track their spread and detect early introductions into new areas is vital to effective invasive species management. However, this requires intensive management of the database with ongoing support and collaboration from a wide range of individuals, organisations and state bodies.

2.3 Surveillance, monitoring and reporting strategy

2.3.1 Introduction

Monitoring programmes are usually undertaken for IAS once they are already established and are having economic and/or ecological impacts. However, non-native species may be present in an ecosystem for many years before they become invasive and start causing problems, known as a lag phase. Usually it is only when they become a problem that control or eradication attempts are made, often when it is too late. Regular surveillance for IAS is needed so that new invasions or range expansions are detected and control or eradication attempts may be made at an early stage. A recent report for Great Britain estimating that IAS cost the British economy at least £1.7 billion each year (Williams *et al.*, 2010) demonstrated that investment in surveillance and monitoring can reduce the economic impact of IAS by enabling management to be carried out at an early stage.

A series of species accounts were produced that are available from the ISI and NISD websites for use by stakeholders and a surveillance, monitoring and reporting strategy has been proposed that focuses on the priority aquatic species and can be used at River Basin District level and incorporated into the WFD programme of activities.

2.3.2 The Water Framework Directive and IAS

While the text of the WFD does not explicitly mention IAS, it has been considered that what is listed in Annex II (1.4) under identification of pressures as '*estimation and identification of other significant anthropogenic impacts on the status of surface waters*' includes IAS. At the present time there is no common approach to dealing with invasive species under the WFD with only the UK and Ireland issuing guidance on the assessment of alien species pressures. The European Commission's ECOSTAT group is examining the use of IAS in ecological status classification and how the WFD programmes of measures might be used to address IAS. As part of the WFD characterisation and analysis of waterbodies in Ireland, risk assessments were carried out and these included IAS as a shadow assessment as they were reliant on expert opinion. There are five River Basin Districts (RBDs) and three International River Basin Districts (IRBDs) on the island of Ireland and draft River Basin Management Plans (RBMPs) have now been prepared for all of them. The North Eastern RBMP identified IAS as a main pressure and a programme of measures has been proposed. The other seven RBMPs identified IAS as a 'local focus and future issue' and proposed that supplementary measures to address IAS should be undertaken at district level on a 2009-2015 timeframe. Therefore IAS have been identified as a pressure that should be included in the programme of measures for every RBD. This provides an opportunity to integrate IAS into WFD programmes across Ireland.

The WFD monitoring programme comprises three types of monitoring; surveillance, operational and investigative and each has different objectives. Timely reporting of monitoring results is seen as a key element in the achievement of the aims of the WFD. The EPA, in conjunction with the Local Government Computer Services Board and the River Basin Districts have developed an Environmental Data Exchange Network (EDEN) which will enable the exchange of data, including WFD monitoring data between environmental agencies in Ireland. While not all the species which were the focus of the project are included in the WFD biological parameters, they all have the potential to impact on the assessment of the biological quality of the waterbody and would be included in surveillance and operational monitoring. Given that the sampling frequency of the WFD monitoring programme is once every three years, for many IAS more frequent monitoring will be needed to detect range expansions especially for species which are in the early stages of establishment.

2.3.3 Proposals for Ireland

Ideally, the surveillance, monitoring and reporting programme would cover all established and potential IAS identified through risk assessment as a threat to biodiversity, ecosystem service and the economy. The proposals presented here contain recommendations on surveillance, monitoring, recording and reporting protocols and identify synergies with the ISI work programme. This offers the opportunity to move beyond making recommendations to implementation over the next few years.

Priority species alert list: It will not be possible to include all aquatic IAS in the programme given the need to prioritise resources and also the practical difficulties in intercepting and identifying IAS. Therefore a prioritised alert list should be developed. The ISI risk assessment framework has been reviewed and a new set of risk assessments are currently in preparation and due for publication early in 2011. This should be used to develop and agree an updated priority species list, and as national and local priorities may differ, specific alert lists can also be developed for each RBD which will help identify the risk of invasion to previously unaffected waterbodies.

Monitoring: The WFD river and lake surveillance and operational monitoring programmes consists of a number of subnets focused on different elements. All the subnets in the river and lake surveillance monitoring programmes should incorporate the priority species into the monitoring protocols with quantitative data collected on species as part of the monitoring of biological quality elements. Priority IAS should also be included in subnet 4 (monitoring of the effectiveness of measures aimed at retaining high and good status) and subnet 5 (species and habitat protected areas) of the rivers and lakes operational monitoring programmes. Monitoring programmes can be amended during the period of the RBMP and between RBMP cycles so priority IAS could be incorporated before 2015.

Surveillance: The WFD monitoring programme offers the opportunity for surveillance for new IAS. Once the priority species list has been revised and agreed, ISI will produce materials including identification guides that can be used in the field and if these were supplied to all those involved in the WFD monitoring programme, that would greatly enhance surveillance capacity from current levels right across the island of Ireland.

Recording: Recording of IAS should be carried out according to the guidance note for contributors of IAS data and this guidance note should be used as the data standard and supplied to all staff involved in the monitoring programme.

Reporting: All IAS records should be submitted to the National Invasive Species Database. Integrating the NISD into EDEN would provide a mechanism to integrate IAS data with WFD data. This would require linking EDEN and the River Basin Management Systems to the NISD and integration of the RBD and catchment GIS layers into the NISD. This will enable IAS records to be displayed in the form of up to date distribution maps on a RBD and catchment basis as well as for individual waterbodies which will provide a useful resource. Outputs would include distribution maps, identification of range expansions, species alerts and identification of vulnerable waterbodies on a RBD level.

The proposals presented here demonstrate the added value of integrating IAS into the WFD monitoring programme and could be progressed over the next few years with supporting measures can be provided by the ISI project. This could include information on the distribution of established IAS, recording guidance, identification of potential IAS, best practice management guidance, IAS action plans (which include management, exclusion and contingency plans) and education and awareness materials.

3 The ecological impacts of IAS on freshwater ecosystems

3.1 Introduction

Invasion is typically one of a series of factors effecting biotic and abiotic disturbance of natural ecosystems (Didham *et al.*, 2005; Dudgeon *et al.*, 2006; Strayer, 2010) that need to be considered by ecosystem managers. Like similar habitats elsewhere (Dudgeon *et al.*, 2006), Irish freshwaters face the combined effects of habitat degradation, human regulation of water levels, water extraction, nutrient enrichment, overexploitation as well as the introduction of IAS, both accidental and intentional. These factors can interact to modify abiotic and biotic conditions, and may facilitate the successful invasion of non-native species into already stressed ecosystems (Didham *et al.*, 2005; Didham *et al.*, 2007). This further complicates the management of natural ecosystems, where managers have a statutory requirement to maintain, or improve ecological quality (EU, 2000), whilst also reflecting the needs and wishes of stakeholders, including recreational and commercial use and exploitation of aquatic resources (Wilson & Carpenter, 1999).

Ireland has undergone a series of historical introductions of non-native species (Thompson, 1856; Went, 1950; Stokes *et al.*, 2006), including 12 species of fish, although the origin and timing of introduction of some species remain unclear (Went, 1950; Wilson, 1986; Griffiths, 1997). The numbers of freshwater IAS in Ireland have increased drastically in recent years (Griffiths, 1997; Caffrey *et al.*, 2008), with most high-impact invaders being introduced during the last 25 years. Although invaded, freshwater ecosystems in Ireland continue to support internationally important habitats (EEC, 1992) and species such as Arctic charr (*Salvelinus alpinus*) (Maitland, 1987; Igoe *et al.*, 2001; Igoe *et al.*, 2003) and pollan (*Coregonus autumnalis*) (Harrod *et al*., 2002). Furthermore, Ireland's freshwaters represent an important tourism resource, and annually attract large numbers of anglers, who contribute substantially to the Irish economy (Solon & Brunt, 2006), but may represent a vector for the spread of IAS (Caffrey *et al.*, 2008). The simplicity of Irish freshwater ecosystems may not only increase their susceptibility to invasion, but may also represent a stage for the generation of novel biological diversity, e.g. Hybridisation between non-native bream and roach occurs at an unprecedented frequency in Ireland (Hayden *et al.*, 2010) and the abundance of hybrid progeny can often exceed that of both parental species.

Although invasive species have the potential to impact receiving ecosystems (Crooks, 2002; Ward & Ricciardi, 2007), it can be difficult to actually quantify the direction and intensity of any subsequent ecological change e.g. in ecosystem structure and function (Parker *et al.*, 1999; Strayer *et al.*, 2006). A means of assessing the consequences of IAS that has recently gained wide use in ecology is the use of stable isotope analysis (SIA) (Vander Zanden *et al.*, 1999; Kelly & Hawes, 2005; Britton *et al.*, 2010a). For example, by examining the carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope values of consumers and putative food sources, ecologists are able to examine variation in energy utilisation and trophic level within a population (Harrod *et al.*, 2005) or community (Harrod & Grey, 2006). SIA has proved particularly useful in studies examining the consequences of invasion by alien species on the structure and function of aquatic foodwebs (Vander Zanden *et al.*, 1999; Kelly & Hawes, 2005; Maguire & Grey, 2006). This project used SIA to aid our understanding of the ecology of IAS and their impacts (Parker *et al.*, 1999) on receiving Irish freshwater ecosystems as part of a multidisciplinary approach including measures of community structure, trophic ecology and life history responses. We examine the impact of two contrasting IAS on two different river basin districts in Ireland. The first case study examines the ecological impacts of an invasive ecosystem engineer, *Lagarosiphon major* on Lough Corrib, Ireland's second largest lake. The second case study examines the ecology of Ireland's most recent potential invasive alien fish, the chub (*Leuciscus cephalus*) in the River Inny. Detailed descriptions of the study sites, their physical and biological characteristics and potential drivers of aquatic ecosystem change can be found in the End of Project Report along with detailed descriptions of the field and laboratory methods and statistical analyses used in the project (available at http://erc.epa.ie/safer/reports).

3.2 Rationale for site and species selection

The rationale for the approach followed during WP2 was to focus research efforts on high impact species in waterbodies of high ecological value. This reflects the fact that these systems will require management actions in the context of WFD-required programmes of measures. Given the relatively short term nature of this project, in order to quantify the impact on structure and function of ecosystems, it was necessary to conduct research in waterbodies where the project team held baseline data on the biological parameters of interest. Two species of concern were selected from sites in two separate River Basin Districts in order to quantify the impact on invasive species on ecosystem structure and function and to also trial control measures.

Lagarosiphon major, a submerged macrophyte native to southern Africa was first recorded from a single bay in Lough Corrib (Western RBD) in 2005. This fast-growing, stand-forming invasive plant has proven to be a problem e.g. in New Zealand where it has been shown to depress native flora, alter species interactions and preclude angling and recreational use of water bodies (Clayton, 1982; Howard-Williams & Davies, 1988; James *et al.*, 1999; Clayton, 2003), Following its initial appearance in L. Corrib, *L. major* rapidly spread through the upper basin of the lough (Caffrey & Acevedo, 2008), markedly changing the structure of the water column and apparently resulting in the loss of native charophytes. We examined the ecological impacts of the *L. major* invasion of L. Corrib, and the potential control of this macrophyte due its well-reported ecological effects and potential to spread and impact other waters across Ireland.

In the Shannon IRBD, chub (*Leuciscus cephalus*) were reported to invaded the River Inny in 2005 (Caffrey *et al.*, 2008) and were highlighted as a species of concern due to their potential to act as competitors or predators of native fishes that are ubiquitous to many Irish rivers e.g. *Salmo* spp. Chub are not naturally present in Ireland due to biogeographical reasons, however, if introduced they could be expected to thrive due to the large amounts of suitable riverine habitat. This, combined with the potential opportunity to control an invasion in its initial stages, led to the inclusion of chub within the project as an understanding of the ecological impact of chub and the development of control measures would be of interest to managers across Ireland.

3.3 Ecological impact of *Lagarosiphon major* in Lough Corrib

3.3.1 Introduction

Although larger than many Irish lakes, L. Corrib can be considered as a good model to examine the response of Irish lakes to invasion by non-native species. The lough is internationally significant for conservation purposes, supports economically-important activities and provides ecosystem goods and services (Costanza *et al.*, 1997) to the third largest city in the Republic of Ireland and surrounding areas. Lough Corrib's responses to invasion may therefore extend beyond simple changes in community structure, or ecosystem function, following invasion by IAS through to a loss of conservation value, tourist revenue or key ecosystem services. The study aimed to examine the potential impact of *Lagarosiphon* on the L. Corrib ecosystem through the examination of a series of questions:

1. Did areas of the lough dominated by native charaphytes (Native) and those invaded by *Lagarosiphon* (Invaded) support different biological communities, i.e. fish and benthic macroinvertebrates?;
2. Was there any measurable impacts of invasion by *Lagarosiphon* on the population structure (age, size), and life history characteristics (e.g. growth, mortality rate) of the keystone fish species, roach and perch?;
3. Was invasion by Lagarosiphon associated with a shift in the diet and trophic niche of macroinvertebrates or fish?; and
4. Did *Lagarosiphon* make any measurable contribution of carbon or nitrogen to the food web of L. Corrib?

At a broad level, comparisons were made of overall macroinvertebrate and fish community structure in areas that are either dominated by native charophytes or invasive *Lagarosiphon.* Due to their dominance of the L. Corrib fish community and the habitat-mediated competitive asymmetry that exists between the two species, a particular focus was made on the ecology of roach and perch, and possible interactions between the two species. Comparisons were made of various population characteristics (size and age structure) and life-history traits (condition, growth, age at maturity and mortality) from both species from native and invaded habitats. Spatiotemporal comparisons were made of the trophic ecology of both invertebrate and fish consumers including the use of stable isotope mixing models to examine the relative contribution of different primary producers to consumer diet and to examine trophic overlap between roach and perch.

3.3.2 Summary of key findings

Macroinvertebrate community structure: Both total abundance and biomass (Fig. 2) of vegetation-associated macroinvertebrates per unit area of lough bed were greater in *Lagarosiphon* than in *Chara* dominated habitats. Multivariate comparisons of macroinvertebrate community structure differed between sites dominated by invasive *Lagarosiphon* and those dominated by native charophytes.

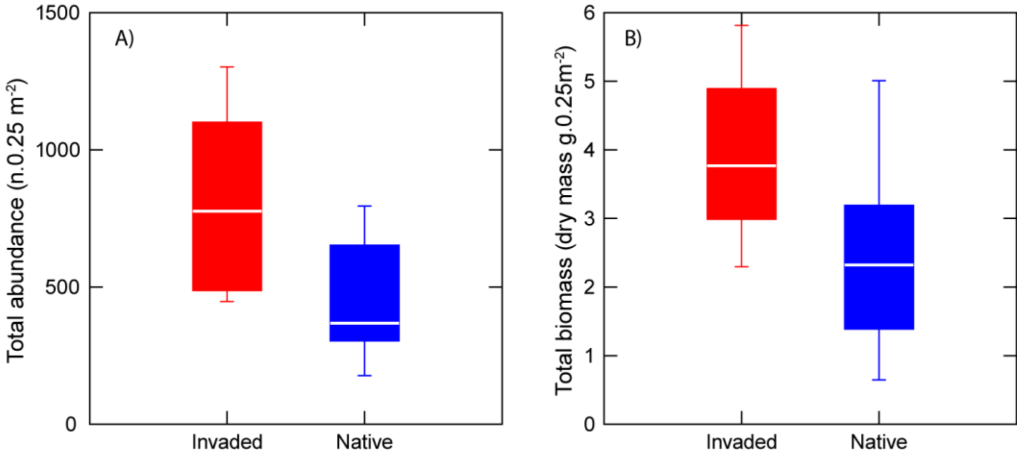

Figure 2: Comparison of total macroinvertebrate A) abundance and B) biomass in 0.25 m^2 *Lagarosiphon* (invaded) and *Chara* stands during August 2008.

Fish life history characteristics: A range of life history characteristics were investigated including fish size, age, growth, condition, size at maturation and adult mortality rates. Detailed findings are presented in Chapter 6 of the End of Project Report. Fish growth is commonly used as a means of assessing spatial or temporal variation in the performance of fish stocks (Francis, 1990; Britton, 2007). Growth of both roach and perch in Lough Corrib was slightly above the mean calculated for a series of European lakes (Jamet & Desmolles, 1994). Differences in back-calculated length at age extended to years prior to the invasion of *Lagarosiphon*, suggesting that perch with different growth trajectories were associated with the different habitats (Hjelm *et al.*, 2001; Svanbäck & Eklöv, 2002; Svanback & Eklov, 2003), rather than differences in growth being driven by *Lagarosiphon* itself. This is further supported by a breakdown in the clear habitat-associated differences in the length at age in perch from cohorts that recruited subsequent to the invasion by *Lagarosiphon* (Fig.3).

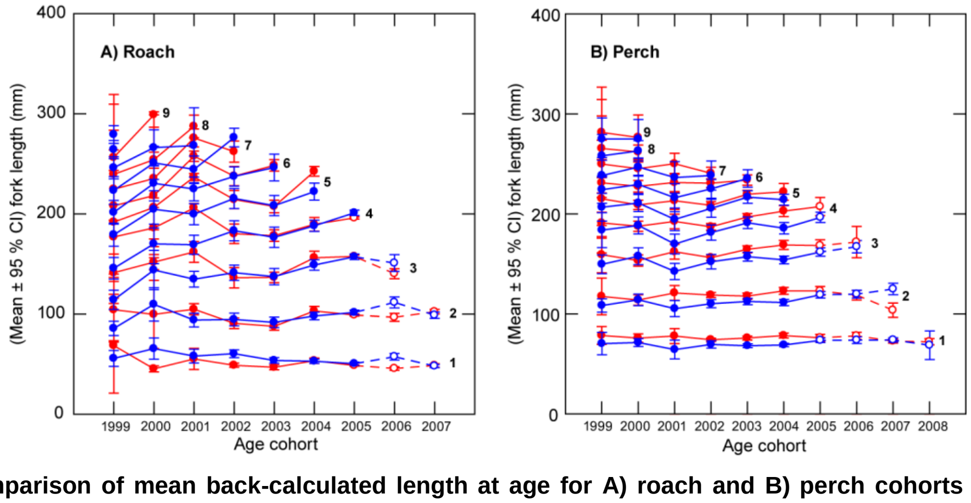

Figure 3: Comparison of mean back-calculated length at age for A) roach and B) perch cohorts captured from native (blue) or invaded (red) habitats during the current study. Filled markers relate to cohorts hatched prior to the *Lagarosiphon* invasion, open markers to those subsequent to the invasion. Numbers to the right of markers reflect different age classes.

Observations of maturation status of roach and perch captured in the two vegetation types showed that in both species, individuals associated with *Lagarosiphon*-dominated habitats matured at a larger individual size than conspecifics from *Chara*-dominated habitats (Fig.4). Interestingly, our estimates of adult mortality rates in both roach and perch were both higher in *Lagarosiphon* than *Chara*-dominated habitats, possibly reflecting increased foraging success by piscivorous fishes in invaded habitats (Eklöv, 1997)

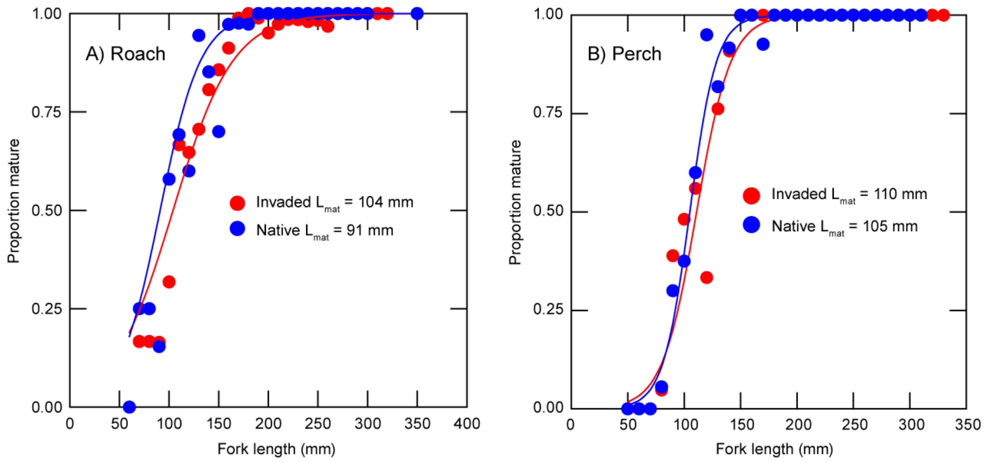

Figure 4: Comparison of the length at which 50% maturity was reached by A) roach and B) perch from native and invaded habitats during the current study. Logistic curves are fitted to observed data (markers).

Fish ecologists have recently increased their use of geometric analysis of shape to examine population structuring in fishes (Elmer *et al.*, 2010; Harrod *et al.*, 2010) including perch (Svanbäck & Eklöv, 2002; Svanback & Eklov, 2003). Here, we showed significant shape differences in both roach and perch captured from *Lagarosiphon* and *Chara*-dominated habitats. Differences were more substantial in perch than roach, but in both species, individuals collected from native habitats were more fusiform, with large eyes, whilst individuals from *Lagarosiphon*-dominated, invaded habitats had the deep bodied form typical of benthivorous fish (Svanbäck & Eklöv, 2002; Svanback & Eklov, 2003) (Fig.5).

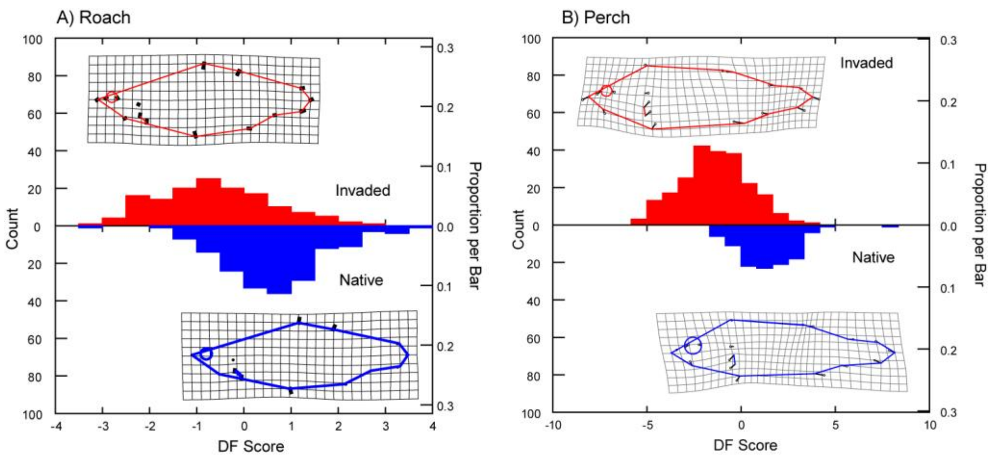

Figure 5: Variation in A) roach and B) perch shape associated with capture in habitats dominated by invasive or native vegetation (deformation plots = mean value x 4 to highlight differences).

Stable isotope analysis: The distribution of $\delta^{13}C$ and $\delta^{15}N$ values for primary producers and consumers sampled from Lough Corrib was typical of that from temperate freshwater lakes (Fig. 6). Isotopic variance (as estimated from isotope convex hulls, Layman et al., 2007a) exhibited by macroinvertebrates from the two habitats was identical. A strong temporal effect was noted between sampling periods. The strength of the interaction between sampling habitat and period indicated that macroinvertebrates in the two different habitats displayed different temporal isotopic shift.

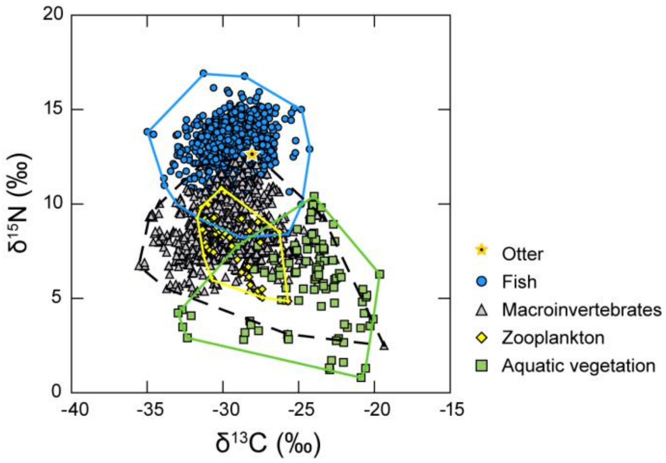

Figure 6: Variation in carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) values for primary producers and consumers sampled from Lough Corrib during the current study. Convex hulls encompass individuals belonging to different taxonomic groups. The value for the otter reflects a young road kill individual sampled from the West shore of the Lough in June 2008.

The fish isotope values considered variably between species and sampling dates. There was reduced isotopic variance in fish species between the invaded and uninvaded habitats (Fig. 7A). There was also no difference in trophic position of fish species between the habitats.

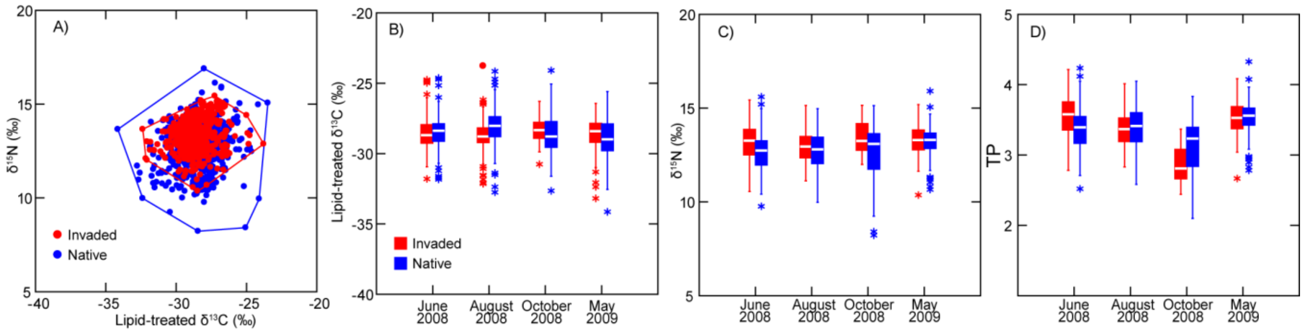

Figure 7: A) Isotopic biplot comparing variation in $\delta^{13}C$ and $\delta^{15}N$ in fish collected from *Lagarosiphon*–dominated (invaded) and *Chara*-dominated (native) habitats during the current study. Temporal variation in B) $\delta^{13}C$, C) $\delta^{15}N$ and D) trophic position is also shown.

3.3.3 Discussion

The effects of invasion by *Lagarosiphon* include marked changes in the form of the littoral habitats of the Lough Corrib ecosystem, with a shift from *Chara* meadows that include both structured benthic habitats, and an overlaying unstructured pelagic zone to a state where, depending on the time of year, the whole water column can consist of monospecific stands of the invasive macrophyte (Caffrey *et al.*, 2009), forming structured habitat and limiting light penetration to the lake bottom. Bickel & Closs (2008) suggested that *Lagarosiphon* may have been directly subsidising the food web of invaded lakes in New Zealand. At the start of the current study, we estimated that between 8-15 % of the C and N assimilated by macroinvertebrates was *Lagarosiphon*-derived. However, over the entire study, this fell to a mean of 5 %, suggesting that at a community level, little of the macroinvertebrates biomass was derived from *Lagarosiphon* (Bickel & Closs, 2008). In the case of Lough Corrib, it also suggests that native consumers have a limited capacity to act as natural biological control of this invasive plant, and that other non-native taxa would be required to fulfil this role, if required by lake managers (Baars *et al.*, 2010).

At the time of sampling, the Lough Corrib fish community was dominated by non-native fishes (*e.g.* roach, perch, pike, roach x bream hybrids, bream), while the capture rate of brown trout was very low in all habitats, which given the status of the lake as a noted salmonid fishery (Solon & Brunt, 2006) is of concern. Roach, which were first recorded in the Lough Corrib system in the 1980s have rapidly become the dominant fish in the system, which, when considering their capacity to effect water quality (Brabrand *et al.*, 1986; Bergstrand, 1990) and to regulate populations of other fishes (Persson, 1990; Persson, 1991) is of concern. This invasive species now dominates the fish community of most of the large lakes in Ireland, including Loughs Corrib, Neagh, Erne, Derg and Ree (Harrod *et al.*, 2002; Inger *et al.*, 2010).

In terms of the wider Lough Corrib ecosystem, it is clear that the impacts of the *Lagarosiphon* invasion varied considerably. There was no obvious effect of *Lagarosiphon* on the overall abundance, biomass or structure of the fish community. However, during this study, we have revealed marked, habitat-associated differences for a number of ecological measures between native *Chara*-dominated habitats compared to *Lagarosiphon*-invaded sites (e.g. invertebrate biomass, abundance, and community structure; perch growth rates; size at maturity in both roach and perch; adult mortality rates; fish trophic ecology). There were ecosystem-level differences between native and invaded habitats, ranging from different macroinvertebrate communities, to a reduction in the length of the food chain in *Lagarosiphon*-dominated habitats. Of the fishes examined here, perch appeared to be most sensitive to the invasion of Lough Corrib by *Lagarosiphon*. Comparison of fish captured in native and invaded habits revealed differences in several key life history characteristics including maturation patterns, growth and mortality rates. Perch from the two capture habitats also had distinct shapes, diets and were isotopically distinct. There is an increasing interest in phenotypic plasticity and adaptive responses to change (Agrawal, 2001), and ecosystems invaded by ecosystem engineers such as *Lagarosiphon* may provide novel habitats that generate biological variation through phenotypic plasticity, that may also lead to increased population differentiation.

3.3.4 Conclusions

Assuming that *Lagarosiphon* remains in the system, and is not fully managed through the control methods recommended in Section 4.2, the effects of invasion detailed here are likely to have implications for the lake's status in the light of several WFD quality elements, e.g. macrophytes, macroinvertebrates and fish. The most obvious effect is the loss of native *Chara* species associated with the invasion by *Lagarosiphon*. The increased abundance/biomass of invasive macroinvertebrates in invaded habitats e.g. *C. pseudogracilis*, *D.polymorpha*) indicates the potential for 'invasional meltdown' in Lough Corrib.

The experimental approach used here was aimed to provide an understanding of the effects of invasion by *Lagarosiphon* (and by extension, other invasive taxa) on receiving ecosystems. It performed well, and could be extended to studies of invasion at other sites: we recommend that it should be continued in future as a means of quantifying the potential long-term effects of invasion or responses to the successful control of *Lagarosiphon* in Lough Corrib.

3.4 Ecological implications and control of chub (*Leuciscus cephalus*) in the River Inny.

3.4.1 Introduction

In recent years, a number of non-native fish species have become invasive in Ireland (Griffiths, 1997) and are now present in rivers across the island. Currently, roach are present in most river catchments in Ireland and their introduction has had significant consequences. Dace (*Leuciscus leuciscus*) another non-native cyprinid that is very closely related to chub is also expanding its range and has established large, sustainable populations and like roach, threatens to compete directly with resident fish species (e.g. brown trout and salmon) for food, habitat and spawning substrates (Caffrey et al., 2007). Chub, are larger than both roach and dace, and are a highly sought after angling species in Britain and Europe. The absence of chub from the rivers of Ireland, many of which may provide suitable putative habitat for the species (Maitland & Campbell, 1992) and excellent conditions for the angler, have provoked considerable controversy among the visiting angling fraternity. In 2005, a number of chub were caught in the River Inny by anglers and officially identified by fisheries scientists from Inland Fisheries Ireland. This species had most likely been illegally introduced to the river by anglers with a view to establishing a population of this popular angling species (Maitland & Campbell, 1992) in Ireland (Caffrey *et al*., 2008). In 2006 and 2007 IFI conducted baseline surveys to establish the distribution of chub in the river Inny. Chub were positively identified at two sites. This project aims to build on the findings of these previous surveys and to understand the ecology of invasive chub in Ireland through the examination of a series of research questions:

1. What was the current status of the chub population in the River Inny?;
2. Did sections of the River Inny inhabited by chub support different biological communities, i.e. fish and benthic macroinvertebrates, compared to non-invaded areas?;
3. Did the population structure (age, size), and life history characteristics (growth) of different fish species shift in areas of the River Inny invaded by chub?;
4. Was invasion by chub associated with a shift in the diet and trophic niche of macroinvertebrates or fish and did chub diet overlap with native and established fishes?; and
5. Did chub make large scale-movements in the River Inny that may impact the efficacy of control measures?

3.4.2 Summary of key findings

Macroinvertebrate community structure: Macroinvertebrate community structure was similar across three different survey stretches (Fig. 8), but differed considerably across the different survey dates.

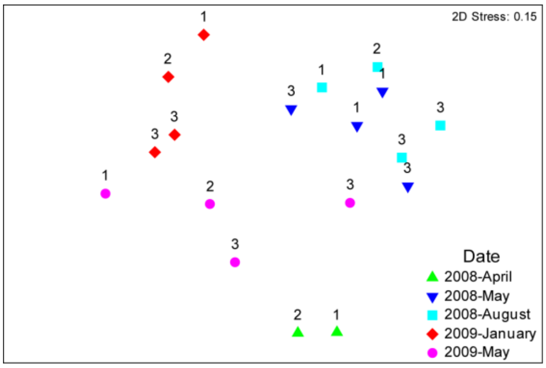

Figure 8: Nonmetric multidimensional scaling ordination of macroinvertebrate community structure. Each point represents the results of an individual kick sample, with markers reflecting different sampling date, and numbers reflecting the location of the sample on the three different survey stretches. The proximity of individual markers reflects the relative similarity of different samples (close together = increased similarity).

Stable isotope analysis: Macroinvertebrate and fish consumers collected from the River Inny during the April 2008 survey displayed considerable variation in both $\delta^{13}C$ and $\delta^{15}N$ (Fig. 9). River Inny consumer $\delta^{15}N$ values suggested the existence of ca. three different trophic levels within the macroinvertebrate and fish community. The $\delta^{13}C$-$\delta^{15}N$ isotope space occupied by chub was similar to that of salmonids, rather than to other cyprinid fishes (note overlap with brown trout (Fig. 9A and C) and salmon (Fig. 9C).

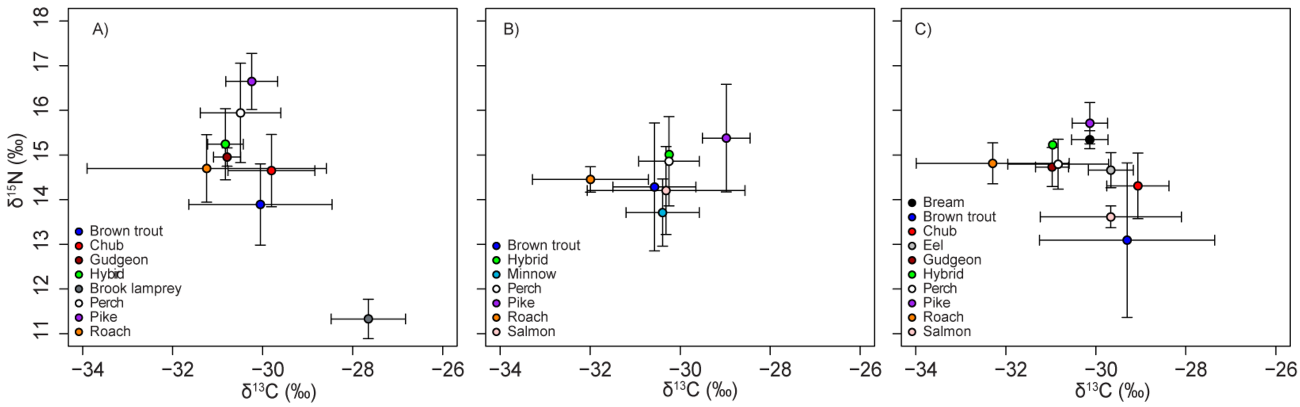

Figure 9: Stable isotope biplots comparing variation in mean (±SD) $\delta^{13}C$ and $\delta^{15}N$ in fishes collected from each of the three survey stretches of the River Inny, A) = Stretch 1, B) = Stretch 2 and C) = Stretch 3.

In order to gather a general impression of isotopic differences between species encountered during the study, and to understand the ecology of chub relative to native (eel, brown trout, salmon, brook lamprey), and other non-native fishes (roach, perch, pike, minnow, gudgeon, bream, roach-bream hybrids), data were pooled for all stretches and compared. There was a strong species effect on $\delta^{13}C$-$\delta^{15}N$ location, indicating that at a larger geographical scale, the fish species examined here differed isotopically. Invasive chub were statistically indistinguishable from three native and conservationally-important species: brown trout, salmon and eels.

Movement and behaviour of invasive chub: In April and August 2008 two mature male chub were captured and fitted with VHF radio transmitters and returned to the same section of river. Regular monitoring over the next 9 months provided no evidence of any long-distance movements. The chub remained reasonably proximal to each other and occupied a normal range of about 600 m. However, following a period of intense rainfall and a shift in water levels, both fish made a relatively long-range upstream movement. Movements by chub between individual tracking surveys were typically small but included several large (>900 m) movements, as chub responded to increased water levels following floods. Although based on only two individuals, taken together, these data indicate that chub in the River Inny showed considerable fidelity to a small area of river, and even considering movements in response to flood, the bulk of their activities were located in a stretch of < 200 m in length.

Control of invasive chub: Inland Fisheries Ireland conducted chub control electrofishing operations on the River Inny on eight separate occasions between 2006 and 2010. During these control operations a total of 28 chub were removed from the river. Using these data, an estimate of the mean ± 95% abundance of chub in the River Inny was made following Carle & Strub (1978). The estimated population size was 28 ± 0 individuals, indicating that the population of chub in the River Inny was very small. The overlap between the population estimate with the number of chub removed to date indicates the likelihood that chub have been extirpated in the River Inny.

3.4.3 Discussion

This study aimed to examine the key impacts of the introduction of chub a potential IAS on the community and function of the River Inny. As such, this study aims to present methods in which to examine the adverse impacts of invasive species on riverine ecosystems in Ireland (Richter *et al.,* 1997). Williamson (1996) suggested that approximately 1% of freshwater fish introductions are likely to result in serious adverse ecological effects. There is always an inherent risk that potentially catastrophic and irreversible ecological consequences will result after the introduction of a non-native fish (Reinthal & Kling, 1994; Vander Zanden *et al.*, 1999; Baxter *et al.*, 2004; Britton *et al.*, 2010a; Britton *et al.*, 2010b).

Our results showed no obvious ecological effects of the chub invasion although our analysis of macroinvertebrate abundance was limited by an inability to routinely sample each survey stretch due to hazardous water conditions, no obvious response to chub predation pressure was detected. The fish assemblage of the River Inny consisted of 13 species and was heavily dominated primarily by roach, itself a non-native fish – with contrasting habitat requirements to those of chub. However native brown trout were also abundant. The stable isotope analysis of chub raised concerns as it indicated that the long term assimilated diet of chub was generally similar to that of the native and conservationally important brown trout, eel and salmon. Potential overlap between chub and these species has also been noted in other studies (Hellawell, 1971; Mann, 1976; Caffrey *et al.*, 2008).

The link between the River Inny and the River Shannon catchment through Lough Ree and ultimately the River Erne system was of serious concern to fisheries biologists in terms of possible migration of invasive chub. However the rapid assessment made by IFI allowed infested sites to be located, and control was promptly applied, rapidly minimising an already limited chub population size. The population estimation was equal to the number of chub removed by IFI and QUB to date, providing evidence that all chub have been removed from the river and this potentially high impact invasive species is now considered eradicated by IFI.

3.4.4 Conclusions

Chub were only present in very limited numbers during the survey period and there was no evidence of any ecological impact of invasion. However, using stable isotope analysis, we demonstrated that the trophic ecology of chub in the River Inny to overlap with that of three important native fishes: eels, brown trout and Atlantic salmon.

This combined with the suitability of many Irish rivers for chub and the known overlap in habitat preferences (Maitland & Campbell, 1992; Caffrey *et al.*, 2008) highlights the considerable potential for chub to become an IAS in Ireland if not controlled, with implications for the ecology, management (e.g. WFD) and conservation (e.g. Habitats Directive) status of Irish freshwaters.

Given the potential for chub to impact Irish waters, thought needs to be directed at the provision of surveillance for the introduction and establishment of chub (see Chapter 4) both in the River Inny and other waters across Ireland. As the potential for reintroduction remains, annual electrofishing monitoring and control surveys following the methods used in the current study are recommended, and should limit the capacity of chub to become established in the River Inny.

4 Preventing and containing IAS introductions

4.1 Introduction

Preventing new introductions of IAS is particularly important in the aquatic environment given the difficulty in eradicating or managing introductions once species have become established. There are a range of key prevention measures that can be put in place such as legislative provisions banning import, sale and spread of species; risk assessment and the development of priority/alert lists; identification and management of key vectors and pathways; voluntary measures such as Codes of Practice and industry standards; and an early warning system linked to interactive information portals that also shares information with neighbouring countries or at a regional level. All of these measures have been developed to different extents in Ireland to date including legislative provisions, risk assessment, alert lists, exclusion and contingency plans for species, Codes of Practice and the National Invasive Species Database. However there are still significant knowledge gaps about the relative importance of the pathways which facilitate spread of invasive species and what the key prevention actions are that will reduce the risk of IAS introductions. This project has sought to address this for the priority aquatic IAS and to build on developments to date by identifying the key pathways and vectors and measures and prevention measures for each. Containment and control measures have been evaluated for the priority species and management actions are recommended. Control measures for chub and *Lagarosiphon* have also been evaluated in the field. Together these outputs will provide an important resource to inform the design and implementation of programmes of measures to reduce IAS pressures on Irish waterbodies.

4.2 Control of *Lagarosiphon major* in Lough Corrib

The project had intended to examine the efficacy and consequences of control measures for *Lagarosiphon major* in Lough Corrib. The resources provided by this project contributed to on-going control work being undertaken by Inland Fisheries Ireland (IFI). The *Lagarosiphon* control programme consists of manual removal of plants by divers, mechanical removal and harvesting, herbicide treatment and light exclusion. Manual removal has been successful at recently invaded sites where abundance is low. Mechanical cutting provides a fast method for removing *Lagarosiphon* however the weed commonly grows back rapidly and can again present obstructive stands within weeks of the initial cut. A weed cutting boat equipped with blunt paired V-blades or trailing knives which rips the vegetation from the substrate rather than cleanly cutting has resulted in regrowth of less than 10% in trial areas, much of this resulted from the regrowth of plant fragments that floated into the plots (Caffrey & Acevedo, 2008).

Herbicide treatment (dichlobenil) was used to treat a number of localised sites and the results indicated that *Lagarosiphon* is susceptible to the activity of dichlobenil but that treatment will only be effective when the weed bed is sufficiently open to allow the granules to reach the substrate. Excluding light to inhibit photosynthesis using natural fibre (jute matting) has been the most successful method (Caffrey *et al.*, 2010). Excellent results have been achieved and *Lagarosiphon* has never been observed to grow through the matting while the native *Chara* is recolonising the treated areas.

4.3 National Best Practice Guide on Preventing and Containment of aquatic IAS

4.3.1 Introduction

In order to prevent and contain aquatic invasions it is important to focus on pathways and vectors as well as species and include measures to address intentional and unintentional introductions and have exclusion plans coupled with containment protocols. In order to successfully formulate and implement an effective toolkit to prevent and contain IAS introductions, these key elements need to be in place. While the focus of this guide is on measures that can be put in place to address aquatic IAS at a national level, there is added value in identifying actions that can be taken at a RBD level to inform the development of any supplementary actions or programmes of measures. Therefore the proposals presented here have aimed to maximise synergies with ongoing projects such as Invasive Species Ireland which will be delivering outputs that can be used to help implement these proposals over the coming years.

4.3.2 Pathway and vector analysis

The vectors and pathways by which IAS are transported are numerous and result from the diverse array of human activities which operate over a range of scales. There is no standardised classification of pathways or vectors for use in risk assessment or this type of analysis as the field of pathway risk assessment is at an early stage in development. There is some confusion with the terminology in the literature with the terms pathways and vectors often used interchangeably. As the aim of this analysis was to identify both pathways of introduction and vectors of spread and some processes are both a pathway of initial introduction and a vector of secondary spread e.g. shipping, an integrated approach was taken and a classification developed that can be used for both.

The pathways of introduction and the main vectors of secondary spread for the priority species were identified from the literature for Ireland (Minchin, 2007 and references therein), Great Britain (Keller *et al.*, 2009) and the project team's own unpublished records and field studies (see Table 10.2 in the End of Project Report). The pathways and vectors for potential IAS have also been identified for Britain as usually these species appear in Britain before occurring in Ireland (Minchin & Eno, 2002).

In many cases it is not possible to definitively state what the pathway of introduction was due to a lack of documented evidence. This particularly applies to identifying the vectors of secondary spread which can be multiple. The key pathways of introduction of those species which are already established in Ireland are the ornamental and aquaria trades, vessels (either commercial or leisure) and intentional release for fisheries. These are also the key pathways by which the potential high risk IAS would be introduced with the addition of aquaculture. Therefore any policy measures to prevent aquatic IAS introductions must address the risks associated with these industry sectors, vessels and intentional releases to enhance fisheries. They key vectors of secondary spread for all the priority species are also the ornamental and aquaria trades; leisure activities such as boating, water sports and angling; intentional releases; escapes from captivity and natural dispersal. Therefore any policy measures to contain IAS introductions must address the risk associated with these vectors and identify the contingency and management actions required.

4.3.3 Prevention measures for key pathways and vectors

The risks associated with the key pathways and vectors are not always fully understood. Reducing the risks will require the use of a combination of policy instruments, a regulatory and voluntary approach and will be more successful if developed in partnership with stakeholders. The majority of the priority species will be introduced and spread unintentionally therefore completely preventing their introductions and spread will be impossible, but risk can be managed and reduced. There are a range of measures needed to prevent IAS introductions which are listed below. These address both intentional and unintentional pathways and many of these measures will reduce the risk of all IAS introductions not just aquatic:

- **Legislation banning the import and sale of listed IAS:** The implementation of legislation banning the import and sale of known IAS will be one of the most important measures to prevent new introductions via industry sectors.
- **Ratification of the IMO Ballast Water Convention:** Shipping and releases of untreated ballast water and hull fouling are important pathways and vectors for IAS therefore Ireland should ratify the IMO Ballast Water Convention to reduce the risk of IAS introductions from this pathway.
- **Pre-import risk screening for new species:** There are many IAS which could be introduced by industry sectors and potentially become established in Ireland. A system of pre-import risk screening would reduce the risk from industry pathways as once species are kept in Ireland; the risk of secondary spread is always present.
- **Licensing and permitting:** The introduction of a system of licensing and permitting for possession of high impact IAS is an important way of reducing the risk from pathways and vectors such as escape from captivity and intentional release. A license should only be granted where the introduction of the species is deemed to be unlikely to cause harm to ecosystems, habitats or species on the island of Ireland or indeed pose a risk to neighbouring countries. The burden of proof should be with the applicant and the anticipated benefits of introduction should strongly outweigh potential adverse effects and related costs.
- **Codes of practice and industry standards:** As it is currently legal to possess or sell the priority plant IAS, voluntary measures such as Codes of Practice and industry standards can be used to reduce the risk of further spread by educating and encouraging sectors not to trade in these species.
- **Public procurement:** The adoption of Codes of Practice by public bodies for use in procurement will enable Government to target their purchasing at species which are not IAS and act as an incentive for industry to adopt the standards.
- **Integration of IAS into border inspection control:** There is limited capacity for the integration of IAS into current border control as many of the species arrive in Ireland from intra-EU trade. However customs and border control can be involved in surveillance and reporting for potential IAS if they are provided with training and the resources they need to do this. These would include focusing on those IAS that are contaminants of imports with identification guides for staff and clear reporting protocols.
- **Stakeholder partnerships with key industry sectors:** Having an effective policy mix that reduces risk also requires building partnerships with key industry sectors. Strong legislative provisions will not be

effective without enforcement and awareness of those provisions by stakeholders and industry support for voluntary measures.

- **Awareness raising and communications:** Awareness of the impacts of IAS, control measures and where to report sightings and get advice can help address vectors and pathways such as intentional release and accidental spread through leisure activities. Awareness programmes can encourage the uptake of targeted guidance and should also include raising awareness of legislation and penalties.

4.3.4 Control and containment measures for priority species

Prevention will not always be successful so at a national level measures to effectively control and contain IAS must be in place. These should include targeted monitoring for new introductions and range expansions of IAS into vulnerable waterbodies coupled with an early warning and information system and a rapid response mechanism. For the majority of aquatic IAS once they have become established, eradication i.e. the elimination of the entire population including any resting stages is not feasible. Before a decision is made on whether eradication is feasible an analysis of the costs (including indirect costs) and likelihood of success must be made and eradication should only be pursued when both funding and commitment of all stakeholders is secured.

When eradication is not feasible, the aim should be to control and contain the species to prevent further spread. Containment plans should have clearly defined goals e.g. to protect particular waterbodies from invasion and identify the area beyond which the species should not spread. Containment measures are most likely to be successful for those species which spread slowly over short distances and in the absence of effective natural dispersal mechanisms. Ireland's main river basins are connected by canals so containment of species in these systems is unlikely to be successful. However it may be possible to contain some species in isolated waterbodies, but only in the absence of effective natural dispersal mechanisms. Whether new introductions or range expansions of the priority species can be contained will depend on the location. For many of these species, particularly the invertebrates, effective control measures in the natural environment are not available. In addition, increasing restrictions on the use of herbicides and concerns over the impact on non-target species may make the relative impact of control measures unacceptable to managers.

The species accounts detail the key prevention, control and management actions for each species and are available from the ISI and NISD websites. An integrated approach should be taken to IAS control incorporating physical, chemical and biological. Protocols for use at RBD level were also proposed.

4.3.5 Conclusions

The proposals presented here are best practice for preventing and contain IAS at a national level and set out simple protocols for use at RBD level. For many aquatic IAS prevention and containment will be challenging if not impossible due to the nature of the pathways and vectors of spread and lack of effective control methods. There is also an opportunity to further develop the prevention actions in the coming years as the ISI project is carrying out pathway risk assessment and developing management strategies for the highest risk pathways. This work can support the actions being taken at RBD level and it is recommended that the EPA facilitate dissemination of the project outputs to those involved with the WFD programme supported by the project partners.

5 Conclusions and Recommendations

5.1 Introduction

The EPA commissioned this project with the aims of improving knowledge on the nature and extent of IAS and their impact on natural ecosystems; developing up to date national distribution maps showing the location of aquatic IAS in Ireland; and developing and trial control measures in the context of river basin management. This project has contributed to meeting these aims through a multidisciplinary project combining research, policy analysis and GIS database development.

The research on the ecological impacts of *Lagarosiphon* in Lough Corrib and chub in the River Inny has increased our understanding of the impacts of these species and their interactions with native communities and other non-native species as well as demonstrating new means by which impacts can be measured. The development of the National Invasive Species Database, collation of records and mapping of the up-to-date distributions of aquatic IAS provides a valuable resource for researchers and managers. The demonstration of effective control measures for *Lagarosiphon* and chub will enable rapid reaction to further introductions and range expansions to new waterbodies. The development of proposals for surveillance, monitoring and reporting of IAS and policy measures for prevention and containment will inform the WFD programme of measures and river basin management.

5.2 Nature and distribution of IAS in Ireland

Determining the distribution and tracking range expansions of IAS is fundamental to effective management. Given the large number of non-native species present in Irish waterbodies, it was important to focus efforts at those species which have the greatest impact. The development of a prioritised list of species based on, amongst other factors, their potential to affect the ecological status of Irish waterbodies has enabled efforts to be targeted. The development of a GIS database of aquatic IAS as part of the National Invasive Species Database enables up-to-date distribution maps for 21 priority species to be produced. Although it was not possible to display aquatic IAS records by lake and river segment with WFD coding, the distribution maps are displayed against a backdrop of GIS layers that provide important contextual information which assists risk assessment and the identification of waterbodies vulnerable to invasion. The addition of the detailed rivers and lakes layer with WFD waterbody codes and the EPA water quality indicator layer will enhance the functionality of the database as a tool for management of aquatic IAS.

The provision of a mechanism for online submission of verified records and the production of guidance for data contributors also ensures that this output can be used in any monitoring and reporting programme and has moved the NISD from a static resource into a dynamic database that has the potential to become a vital tool in the identification, monitoring and control of aquatic IAS in Ireland. A number of areas for future work have been identified that can build on these outputs including the development of an information exchange network; surveys for the priority species to improve the coverage and quality assessment of the distribution maps; and further development of the NISD as the information infrastructure for an early detection and rapid response mechanism.

Ensuring that information on the distribution of IAS is up-to-date and that new invasions are detected early requires surveillance, monitoring, recording and reporting programmes. The assessment of current developments and how IAS can be integrated into the WFD monitoring programmes has enabled the development of proposals for these programmes in Ireland. All of the priority species will either be included in the biological parameters of the WFD, or have the potential to impact on the assessment of biological quality and so will be included in WFD surveillance and operational monitoring. While the WFD monitoring programme does not cover all aquatic IAS, it does provide a useful framework for a monitoring programme and in addition, it offers the opportunity to greatly enhance surveillance capacity across the island of Ireland.

The EPA has highlighted the importance of data information and management so that the data generated by the monitoring programme is collected, managed, analysed and reported in a systematic, efficient and timely manner. The integration of the NISD into the Environmental Data Exchange Network (EDEN) will enable a range of outputs to be delivered that can inform river basin management. These include IAS distribution maps, identification of range expansions, species alerts and identification of waterbodies vulnerable to invasion at a RBD level.

5.3 Analysis of IAS pressures

Developing effective programmes of measures for RBDs will require greater understanding and analysis of IAS pressures. The species accounts produced for the priority species highlight their potential impacts on WFD objectives. However, IAS are just one pressure and many waterbodies are subject to the combined effects of habitat degradation, human regulation of water levels, physical modification, water extraction and nutrient enrichment. It can be challenging to actually quantify the direction and intensity of ecological change as a result of a species invasion and for the wide range of IAS that are currently established in Irish waterbodies. As such, the project aimed to present ways in which to examine the impact of invasion on ecosystems rather than categorically define the impacts of IAS on receiving ecosystems.

The introduction of two relatively recent IAS, *Lagarosiphon* and chub, and the lack of knowledge about their potential ecological and economic impacts raised concerns, particularly as they have the potential to become widely established in Ireland. The study of the ecological effects of the invasion of Lough Corrib by *Lagarosiphon* investigated several different levels of biological organisation. The effects of invasion by *Lagarosiphon* include marked changes in the form of the littoral habitats of the Lough Corrib ecosystem, with a shift from *Chara* meadows that include both structured benthic habitats, and an overlaying unstructured pelagic zone to a state where, depending on the time of year, the whole water column can consist of monospecific stands of the invasive macrophyte (Caffrey *et al.*, 2009), forming structured habitat and limiting light penetration to the lake bottom. The research showed a series of ecological impacts of invasion that include changes in macroinvertebrate community structure and production, differences in key life history traits of the two dominant fishes of Lough Corrib and marked differences in some measures of consumer trophic ecology.

Lagarosiphon invasion was associated with increased macroinvertebrate biomass and changes in community structure which may reflect increased habitat availability; however other IAS including zebra mussels were also associated with *Lagarosiphon* beds. In terms of the wider Lough Corrib ecosystem, it is clear that the impacts of the *Lagarosiphon* invasion varied considerably. There was no obvious effect of *Lagarosiphon* on the abundance, biomass or structure of the fish community. However we have demonstrated marked, habitat-associated differences for a number of ecological measures between native *Chara*-dominated habitats compared to *Lagarosiphon*-invaded sites (e.g. invertebrate biomass, abundance, and community structure; perch shape and growth; size at maturity in both roach and perch; adult mortality rates; fish trophic ecology). However, many effects of the invasion were relatively subtle; suggesting that some effects of invasive species are indeed less marked, and furthermore vary over time. There were ecosystem-level differences between native and invaded habitats, ranging from different macroinvertebrate communities, to a reduction in the length of the food chain in *Lagarosiphon*-dominated habitats.

As the study of the ecological implications of the introduction of chub in the River Inny was also combined with a control programme aimed at eradicating the population, the focus of the research was on understanding the ecology of chub to improve our understanding of the implications of further introductions of this species. No obvious ecological effects of the chub introduction were detected although the stable isotope analysis results raised concerns as they indicated that the long term diet of chub was similar to that of the native and conservationally important brown trout, eel and salmon. The analysis of IAS pressures on waterbodies of these two species was hindered by logistical and financial restraints. However the results clearly show that *Lagarosiphon* is impacting on the biological quality elements in Lough Corrib, in particular, macrophyte and benthic invertebrate abundance and community composition.

5.4 Prevention and control measures

Preventing new introductions is particularly important in the aquatic environment given the difficulty in eradicating or managing IAS once they have become established. The analysis of the vectors and pathways for the priority species identified the ornamental and aquaria trades, vessels (either commercial or leisure) and intentional release for fisheries as the key pathways of introduction. The key vectors of secondary spread were also the ornamental and aquaria trades; leisure activities such as boating, water sports and angling; intentional releases; escapes from captivity and natural dispersal. A range of policy measures were proposed that addressed the risk associated with these pathways and vectors, and identified the contingency and management actions required to reduce risk. Simple protocols for use at RBD level with the aim of reducing IAS pressures and ensuring that available resources are supplied to local managers are recommended.

Control measures for *Lagarosiphon* and chub were evaluated in the field and showed that effective control measures could be identified for use with new introductions and range expansions even if *Lagarosiphon* is too widely established in Lough Corrib for eradication to be successful. Tracking the movement of chub showed that their movement was limited; allowing control, assuming the response is suitably rapid. It appears that such rapid control activities *i.e.* electrofishing, combined with a low propagule pressure and a limited population size enabled the removal and putative eradication of this new IAS to Ireland.

5.5 Implications for the WFD programme of measures

The outputs from this project will contribute to how IAS are managed in the context of the WFD programme of measures and the RBMPs. While the agreement of a common European position on how IAS should be dealt with in ecological status classification and how WFD programmes of measures might be used to address IAS is important, this project clearly shows that aquatic IAS are a growing problem in Ireland. We now know that most of the major Irish lakes have established IAS populations: therefore actions will need to be progressed without European consensus on these issues.

All the RBMPs have identified IAS as either a main pressure or an issue for which programmes of measures need to be developed. Here we have proposed how the outputs from this project and follow on actions can assist in this process, namely:

- Further development of the NISD with the addition of detailed lakes and rivers layers with WFD coding to provide up-to-date distribution maps of IAS at an RBD level which will enable the identification of range expansions and waterbodies vulnerable to invasion.
- Integration of the NISD into EDEN so that IAS information is supplied in a timely way and the adoption of the guidance note as the IAS data standard.
- Integration of IAS surveillance and monitoring into WFD monitoring programmes.
- Development of alert lists at a national and RBD level and provision of ID guides for use in the field.
- Provision of Invasive Species Action Plans and template management plans for use at local level.
- Analysis of IAS pressures for a range of species and provision of this information online in this report and in the species accounts.
- Identification of control measures that can be used for new introductions or range expansions of *Lagarosiphon* and chub (and similar taxa).
- Development of protocols for use at RBD level to enable rapid reaction and containment of IAS.

5.6 Recommendations

This project has produced research and policy analysis that provides an evidence base for policy development and decision making on aquatic IAS management in Ireland. We have attempted to present the research findings in a way which will facilitate their uptake and use. As such, the outputs of this project can provide an evidence base for decision making for a range of stakeholders, examples of which are set out below:

- Policy makers to underpin the development of the WFD programme of measures and target resources to address aquatic IAS impacts.
- Industry sectors whose activities are the key pathways of introduction of IAS to demonstrate the need to change practises to reduce the risk of IAS introductions and spread.
- Local Authorities to provide information on what IAS are present in their areas and to encourage their participation in surveillance.
- Development and support of a research community to further our understanding of the ecological impacts of aquatic IAS in Ireland.

A range of recommendations have been developed for further work, divided into three main areas, policy, research and education and capacity building.

Policy:

- The EPA should routinely liaise with Invasive Species Ireland and other relevant organisations to update the list of species that need to be considered in the WFD risk assessments and programmes of measures.

- A programme of surveillance and monitoring should be developed and implemented by integrating aquatic IAS into the WFD monitoring programme supported by guidance on surveillance, monitoring, recording and reporting for use by programme staff.
- The proposals in the best practice guide on preventing and containing aquatic IAS should be implemented to reduce the risk of new introductions of IAS.

Research:

- Further research on the impact of multiple IAS in Irish freshwater systems is required to further understanding of IAS pressures, *e.g.* interactions between invasive species and the potential for invasional meltdown.
- The ecological effects of control measures should be investigated further to inform their refinement and proposals for ecological restoration, e.g. through the monitoring of ecological responses to control, such as the removal of *Lagarosiphon* from Lough Corrib.
- The efficacy of jute matting as a control method should be evaluated for other aquatic plant IAS.

Education and capacity building:

- The EPA should convene a workshop with the RBD co-ordinators, technical and stakeholder councils, project partners and Invasive Species Ireland to enable targeted dissemination of the project outputs and further development of resources for use at RBD level.
- The NISD should be further developed as the information infrastructure which underpins an early warning and rapid response mechanism for Ireland.
- The NISD should be promoted to and used by those involved in the WFD programme.
- Targeted education and awareness initiatives should be developed that increase awareness of IAS amongst those involved in activities which act as pathways and vectors of introductions and spread.
- Education and training materials should be produced targeted at those involved in recording to improve knowledge of IAS distributions.

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7 Acronyms and Annotations

BSBI	Botanical Society of the British Isles
CBD	Convention on Biological Diversity
CeDAR	Centre for Environmental Data and Recording
DAISIE	Delivering Alien Invasive Species Inventories for Europe
ECOSTAT	European Commission intercallibaration process for the WFD
EDEN	Environmental Data Exchange Network
GIS	Geographical Information Systems
IAS	Invasive Alien Species
IRBD	International River Basin District
IFI	Inland Fisheries Ireland
ISI	Invasive Species Ireland
NBDC	National Biodiversity Data Centre
NISD	National Invasive Species Database
NOBANIS	European Network on Invasive Alien Species
PERMANOVA	Permutation-based Analysis of Variance
PRIMER	Plymouth Routines in Multivariate Ecological Research
QUB	Queen's University Belfast
RBD	River Basin District
RBMP	River Basin Management Plan
SIA	Stable Isotope Analysis
SIMPER	Similarity Percentage Analysis
WFD	Water Framework Directive