ZEBRA MUSSEL MANAGEMENT STRATEGY

FOR NORTHERN IRELAND

2004 - 2010

Queen's University Belfast

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ENVIRONMENT AND HERITAGE SERVICE

Foreword

I am pleased to see this positive effort for the control of Zebra Mussels in Northern Ireland. Invasive alien species are the biggest threat to native biodiversity, after habitat destruction. All habitats can be threatened, resulting in grave damage to conservation and economic interests such as agriculture, fisheries, forestry, tourism and civil infrastructure. In some cases, public, animal and plant health may also be threatened.

The need to address the issue of invasive introduced species is recognised in the Convention on Biological Diversity (CDB), to which both the UK and Irish Governments are signatories. It requires contracting parties, as far as is appropriate "to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species". Last year, Environment and Heritage Service (EHS), in conjunction with National Parks and Wildlife Service (NPW), Dublin, commissioned The Queen's University of Belfast (QUB) to carry out a review of introduced species in Ireland and make recommendations for future action. The report made 10 key recommendations to address both the urgent and longer-term issues. This will provide the framework in which this management strategy will be implemented.

The need for a co-ordinated approach between jurisdictions to tackle the zebra mussel invasion was recognised and acted upon from the outset. Although the Zebra Mussel Management Strategy has focused on Northern Ireland, it is both welcome and essential that strong links have been made with the rest of Ireland.

The overall aim of the management strategy is to minimise the spread of zebra mussels in Northern Ireland through raising awareness, developing policy and legislation, monitoring and research and developing contingency plans for immediate action in the event of further zebra mussel spread.

I am confident that this strategy provides a sound basis for all those involved to work together to ensure that all possible measures are taken to protect our natural habitats and biodiversity from the threat of further Zebra Mussel invasions.

Dr Bob Brown
Chairman of the Northern Ireland Biodiversity Group

Executive Summary

1. The recent review of invasive species in Ireland made recommendations to both Governments. These recommendations are currently under review and will provide the future legislative framework and structures in which this management strategy will be implemented.

2. The Zebra Mussel Management Strategy for Northern Ireland (2004-2010) aims to minimise the spread of zebra mussels in Northern Ireland through raising awareness, developing policy and legislation, monitoring and research and developing contingency plans for immediate action in the event of further zebra mussel spread.

3. The Strategy is based on an understanding of the invasion history, general biology and ecology of the zebra mussel, economic and ecological impacts and control methods. The Strategy aims to build on the co-ordinated approach that has been taken in both jurisdictions to tackle the zebra mussel invasion to date.

4. The zebra mussel was first documented in Ireland in 1997 and has continued to expand its range. Although zebra mussels are established in Northern Ireland their spread to date has been confined to the Erne system and the majority of waterbodies remain uncolonised. Many of these waterbodies support important recreational and commercial fisheries and it is desirable that they remain uncolonised for both ecological and economic reasons.

5. The zebra mussel has had a detrimental impact on native biodiversity in those lakes where it has become established. Lough Erne has undergone rapid and extensive ecological change. This includes an increase in water clarity; a decrease in both phytoplankton and zooplankton abundance; near extirpation of native unionid mussels and changes in the fish population. Although the economic impacts have not been severe to date, there remains the potential for greater impacts with further spread. These include the costs associated with excluding the zebra mussel from municipal and industrial water intakes; impacts on important commercial fisheries and impacts on recreational fisheries and related tourist income.

6. The Strategy examines the potential vectors of the zebra mussel in Northern Ireland. Seven high and medium risk zebra mussel vectors are identified. The high-risk vectors are recreational boating, intentional introductions and the re-opening of the Ulster Canal. Medium-risk vectors include angling activities, fisheries and aquaculture activities, illegal eel fishing and scientific research and conservation work. Each vectors' potential to spread zebra mussels is outlined and mitigation measures are recommended.

7. There are limited resources available to tackle the zebra mussel invasion. The most vulnerable lakes were prioritised to enable focused use of resources. However, those waterbodies most at risk of invasion might not be those that are the most important ecologically or economically. Therefore, the assessment of vulnerability was a combination of an objective assessment of the risk of invasion from both natural and human-related dispersal mechanisms and an assessment of the value of the waterbody based on conservation designations. Parameters used to prioritise lakes included water chemistry, physical characteristics, recreational use and conservation designations. Data was available for 624 lakes, of which 361 were suitable for zebra mussel establishment. These lakes were then scored and the most vulnerable lakes prioritised. The most vulnerable lakes were the Lough Neagh - Lower Bann system, Lough Melvin catchment and the MacNean lakes.

8. Measures to be employed around vulnerable lakes were recommended. These include erection of slipway signs advising boaters on how to prevent the spread of the zebra mussel at the main launching points and codes of practise for marina managers.

9. The implications of zebra mussel spread to Lough Melvin and Lough Neagh; on features and species that are used to designate lakes; and the classification of Northern Ireland's lakes under the Water Framework Directive are outlined.

10. Six management objectives are presented which together aim to minimise the spread of zebra mussels in Northern Ireland.

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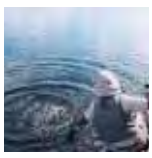

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1 Introduction

1.1 The invasive species problem

Invasive species are the biggest threat to native biological diversity after habitat destruction. An invasive species (alien, non-indigenous, non-native) is a species or sub species that has moved beyond its normal or past distribution. Globalisation and growth in the volume of trade and international travel have greatly accelerated biological invasions in the last few centuries (Ruesink *et al*., 1995; Mooney & Hofgaard, 1999). When species are moved beyond their native ranges the outcome is extremely unpredictable. Many non-native species have no major impacts while others have had catastrophic impacts on ecosystems and native species and economic interests such as agriculture, forestry, infrastructure and public health (DEFRA, 2003). Invasive species can have severe economic consequences, in the US, invasive plant and animal species are estimated to cost the economy $137 billion annually (Library of Congress, 2003).

Ireland has a depauperate fauna compared with continental Europe. This isolation has given rise to some unique species and gene pools. Species invasions may therefore be particularly damaging if the few native species are adversely affected. Conversely, vacant habitats or niches may allow integration of species with minimal community disturbance and/or rapid recovery (Dick, 1996). 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, an 'invasional meltdown' process (Simberloff & Von Holle, 1999). Often invasive species are already locally established before they are recognised, making their eradication unfeasible. The challenge is to establish management priorities based on the scientific assessment of current impact and prediction of future impact of the species (Lodge *et al*., 1998). The most effective management techniques for tackling invasive species will often be educational, legislative and ameliorative (Boon, 2002).

1.2 Invasive species policy in Ireland

Over the last few years invasive species in Ireland have increasingly come to the attention of policy makers. Both the Republic of Ireland and the United Kingdom are contracting parties to the Convention on Biological Diversity (CBD). The CBD is the only global and legally binding instrument to address the issue of invasive species and it requires contracting parties, as far as is appropriate, "to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species". There is currently no comprehensive national strategy for prevention and mitigation of invasive species in either jurisdiction although proposals for addressing the impact of alien species on native biodiversity have been published in the biodiversity action plans produced in both Northern Ireland (Biodiversity in Northern Ireland) and the Republic of Ireland (The National Biodiversity Plan for Ireland).

A review of invasive species in Ireland has recently been completed (Stokes *et al*., 2004). This project was jointly commissioned by Environment and Heritage Service and the National Parks and Wildlife Service. The project reviewed the impact of existing and potential future alien species on native biodiversity in Ireland; addressed the requirements of the CBD decisions on alien species; improved measures to avoid or limit the ecological impact of alien species and recommended actions to government (in both Northern Ireland and the Republic of Ireland). The recommendations are currently under consideration by both Governments. This will provide the future legislative framework and structures in which this management strategy will be implemented.

1.3 Summary of zebra mussels management to date

The need for a co-ordinated approach between jurisdictions to tackle the zebra mussel invasion was recognised and acted upon from the outset. Shortly after zebra mussels were first documented in Ireland, an international workshop took place in February 1998. The workshop brought experts from North America and Europe to Ireland to share their research and experiences, and to collectively consider the economic and ecological impact of zebra mussels and their control. The Zebra Mussel Control Group (ZMCG) was set up following this and comprises of representatives from all the relevant Government agencies and incorporating researchers working on aquatic invasive species, as appropriate. The ZMCG is a forum for sharing information, co-ordinating joint education and awareness campaigns and identifying research needs. The zebra mussel education and awareness programme was initiated in Northern Ireland during 1998 and is still ongoing. This has been multifaceted and involved the production of fact sheets and leaflets, exhibitions, generating media coverage of the issues and it has mainly focused on recreational water users such as anglers and boaters.

Research into the zebra mussel invasion and subsequent impacts has been carried out in both jurisdictions with good information sharing and networking between researchers. In Northern Ireland, research has been funded by Environment and Heritage Service (EHS), the Department of Agriculture and Rural Development (DARD) and the Department of Culture, Arts and Leisure (DCAL). Since 1998, this has included investigations into the invading population dynamics of the zebra mussel; vectors; documenting spread; effects on aquatic food webs and native species and development of strategies to limit the spread of zebra mussels in Northern Ireland (Rosell *et al.*, 1999; Maguire, 2002; Minchin, 2003;

Figure 1. Castlewellan Lake

Minchin *et al*., 2003; Maguire *et al*., 2003; Sykes, 2003). The production of the Zebra Mussel Management Strategy is one element of the current research programme.

1.4 The need for a management strategy

Prevention is generally more cost-effective and ecologically desirable than measures taken after the establishment of non-native species. Although zebra mussels are already established in Northern Ireland, their spread to date has been confined to the Erne system and the majority of waterbodies remain uncolonised. There are legislative, economic and ecological drivers for the production and implementation of a management strategy for zebra mussels in Northern Ireland.

The European Council (EC) Directive on the conservation of natural habitats and of wild fauna and flora (the "Habitats Directive") and the European Council (EC) Directive on the conservation of wild Birds (the "Birds Directive"), together form the main legislative framework for the prevention of the introduction of non-native species because of the potential threat they pose to protected areas. Member states must take measures to maintain in 'a favourable condition', the habitats and species for which the sites have been selected, or where necessary take action to restore them. The recent review of invasive species in Ireland makes recommendations on control and management of established invasive species including production of management plans for single species.

Habitats listed on the Habitats Directive are protected as Special Areas of Conservation

(SACs), while sites that are important for birds are protected as Special Protection Areas (SPAs), collectively these areas are known as Natura 2000 sites. As well as sites designated at a European level, Areas of Special Scientific Interest (ASSIs) are nationally important sites designated under the Nature conservation and amenity lands (NI) Order 1985. In addition, the Northern Ireland Biodiversity Strategy has identified 3 lake types which are "priority habitats", i.e. eutrophic standing waters, mesotrophic lakes and marl lakes. Many of Northern Ireland's lakes fall into one of the above categories, therefore it is necessary to address the risk posed by further zebra mussel spread.

Many water bodies that support important recreational and commercial fisheries remain uncolonised by zebra mussels and it is desirable that they remain uncolonised for both ecological and economic reasons. The zebra mussel has had a detrimental impact on native biodiversity in Ireland in those lakes where it has already become established (Maguire *et al.*, 2003). Although economic impacts have not been severe to date, there remains the potential for greater impacts with further spread. These include the costs associated with excluding the zebra mussel from municipal and industrial water intakes; impacts on important commercial fisheries and impacts on recreational fisheries and related tourist income.

1.5 Aims of the management strategy

The overall aim of the management strategy is to minimise the spread of zebra mussels in Northern Ireland through raising awareness, developing policy and legislation, monitoring and research and developing contingency plans for immediate action in the event of further zebra mussel spread.

Research into the effectiveness of the zebra mussel education and awareness programme has indicated that knowledge about zebra mussels does not necessarily lead to appropriate behaviour for limiting the spread of zebra mussels (Sykes, 2003). The management strategy will identify the strategies and partnerships that are necessary to prevent further zebra mussel spread.

Given the limited resources available for preventing further zebra mussel spread, a strategic approach is needed to allow effective targeting of resources so they are used most effectively. Several Government departments and agencies have responsibilities and interests in managing some aspect of the problems caused by zebra mussels and the management strategy will bring together those interests in a co-ordinated approach.

The management strategy is based on an understanding of the invasion history, general biology and ecology of the zebra mussel, economic and ecological impacts and control methods. It will:

* Identify the most important dispersal vectors in Northern Ireland and mitigating measures
* Prioritise the most vulnerable lakes and preventative measures that are needed
* Outline possible consequences of invasion in the most important lakes
* Recommend a surveillance programme for further spread
* Make management recommendations to minimise the spread of zebra mussels
* Outline an implementation table.

2 Invasion History of the Zebra Mussel

It is only in the last 200 years that the zebra mussel (*Dreissena polymorpha*) has expanded its range from the Black Sea and Aral-Caspian Sea basins where it mainly inhabited inflowing rivers. Its post-glacial recolonisation of Europe has been greatly accelerated by the development of a canal network interconnecting the major European river systems and the increased shipping trade resulting from the Industrial Revolution (Morton, 1993). The zebra mussel has been present in Hungary since 1794, Germany since 1838 and Denmark since 1840 (Morton, 1969). Zebra mussels are now present in Sweden, Finland, France, the former USSR, Germany, The Netherlands, Italy, Switzerland, Britain, Ireland and Spain (Jenner *et al*., 1998; Minchin *et al*., 2002b).

Zebra mussels were first recorded in Britain in Surrey docks (London) and at Wisbech, Cambridgeshire in 1824; both ports were handling unsawn logs from the Baltic (Coughlan, 1998). By 1834, zebra mussels were recorded in lowlands of Scotland and by 1850 they were widespread in England but the distribution largely corresponded with the extent to which interconnected canals and rivers formed a linked network of navigable waterways (Coughlan, 1998).

Zebra mussels were first recorded in North America by Hebert *et al*. (1989) and appear to have been accidentally introduced in ballast water to Lake St Clair some time in the mid 1980's. They spread with dramatic rapidity and by 1992 had reached the Mississippi basin. Their current distribution corresponds largely with the navigable waters of the Great Lakes and Mississippi basins (Johnson & Carlton, 1996). Models suggest that they will ultimately colonise most of the United States and southern Canada (Strayer, 1991). However, as is the case in Europe, overland dispersal to isolated lake basins has been slow (Johnson & Carlton, 1996).

After establishment in Britain, the zebra mussel did not arrive in Ireland for another 170 years. It was first recorded in 1997 in Lough Derg on the Shannon (McCarthy *et al.*, 1997). The zebra mussel is thought to have spread to Ireland in 1994 and several events in 1993 may have created an 'invasion window' facilitating the spread of the zebra mussel. The introduction of the European Free Trade Agreement permitted the tax-free importation of used watercraft to Ireland from January onwards. In England, it became necessary to have a certificate of competence for second-hand boats. Combined with a favourable exchange rate these events resulted in increased sales of second-hand boats from England to Ireland, some of which had zebra mussel fouled hulls (Minchin & Moriarty, 1998; Minchin *et al.*, 2003). It is known that boats with fouled hulls travelled via the Shannon-Erne canal to Lough Erne and the first reports received of zebra mussels in Northern Ireland were in Lower Lough Erne in late 1996. The first comprehensive survey was carried out in June 1998 and within three years zebra mussels had colonised the entire Erne system and some inflowing rivers.

Zebra mussels have continued to expand their range in Ireland and are established in the Shannon, Boyle and Erne navigations. However, dispersal to waterbodies outside these connected navigable waterways has been slower, and zebra mussels were only recorded outside these waterways for the first time in Lough Derravaragh, Co. Westmeath in 2002. Research funded by the Marine Institute has documented further spread in the Republic of Ireland (Appendix 1).

3 Biology and Ecology of the Zebra Mussel

Dreissena polymorpha was first described by the Russian zoologist Pallas in 1771 and is commonly known as the zebra mussel due to the striped appearance of its shell, the pattern can be variable as indicated by the name 'polymorpha' or 'many forms'.

Figure 2. Zebra mussel (*Dreissena polymorpha*)

3.1 Zebra mussel life cycle

The life cycle of the zebra mussel consists of a planktonic free swimming larval stage, a settling juvenile stage and a relatively sessile adult stage. Zebra mussels reproduce by releasing eggs and sperm into the water column, producing microscopic larvae called veligers. Spawning usually occurs when water temperatures exceed 12^{o}C, which is from May to September in Ireland (Sprung, 1987). However, zebra mussels have a highly variable reproductive cycle and larval production can take place over a time period ranging from 6 to 52 weeks. The time veligers remain in the plankton also varies widely with reports ranging from 8 to 240 days. Veligers then settle on hard surfaces, mainly during the summer and autumn, where they metamorphose into juveniles and develop the adult form (Hopkins & Leach, 1993; Nichols, 1996). The success of zebra mussels as invaders is aided by their ability to adapt to a wide range of habitats and flexibility of their reproductive cycle.

Zebra mussels will settle on a wide range of substrata. They can attach to almost any firm substratum including rocks, anchors, boat hulls, intake pipes, unionid mussels and fragments of vegetation. Recent research has shown that successful colonisation can also occur in areas with soft, muddy substrate (Berkman *et al*., 1998). They secrete byssal threads for attachment and an individual mussel can have as many as 600 threads holding it in place (Claudi & Mackie, 1994). Densities of zebra mussels can be extremely high and in the western basin of Lake Erie there have been reports of densities between 112,000 to 342,000 mussels m^{-2} (Leach, 1993). However, densities in Irish waters are lower ranging from 2,500 m^{-2} in Lough Erne to 36,990m^{-2} in Lough Key (Lucy & Sullivan, 1999; Maguire, 2002).

3.2 Age and growth

The growth rate of zebra mussels is dependent on water temperature, quality and quantity of food and body size. Two patterns of growth have been described for European populations, slow: less than 1cm yr^{-1} with a maximum shell length of 3.5 cm, and fast: exceeding 1.5 cm yr^{-1} with a maximum shell length of >4 cm. The zebra mussel in Lough Erne shows a fast pattern of growth but with a maximum size of 3 cm and a life span of 2-3 years or cessation of growth in older mussels (Maguire, 2002).

3.3 Food sources and feeding

Zebra mussels feed by filtering water through their gills and removing phytoplankton, seston, bacteria, small zooplankton and bacterio-plankton (Ten Winkel & Davids, 1982; Neumann *et al*., 1993; Claudi & Mackie, 1994). Each mussel can filter as much as 1 litre of water a day and it is estimated that the population of zebra mussels in Lough Erne can filter the entire lake every 2 weeks.

3.4 General Ecology

An enormous number of publications deal directly or indirectly with aspects of the ecology of *D. polymorpha*. Comprehensive reviews have been compiled by Mackie *et al*. (1989) and Schlosser *et al*. (1994). However, there should be a clear appreciation of differences in the zoogeographical and ecological community contexts in which North American research is conducted, as opposed to the situation in Europe. The zebra mussel in Europe is recolonising some northern areas from which the Pleistocene glaciations eliminated it. In North America, zebra mussels are a truly exotic species, which has been transplanted to an environment that is very new to it in a zoogeographical sense (Mc Carthy *et al*., 1997).

Zebra mussel ecology has been studied over a 30-year period in the lakes of north-eastern Poland (see review by Stanczykowska & Lewandoski, 1993). The ecology of zebra mussels have also been researched in other European waterbodies: Morton (1969), Bij de Vaate (1991), Neumann *et al*. (1993), and Smit *et al*. (1993).

Numerous species interactions between zebra mussels and their natural enemies have been documented in Europe and North America. Molloy *et al*. (1997) reviewed literature dealing with 176 species of predators, 34 species of parasites and 10 species that are ecological competitors and can potentially exclude zebra mussels. Most of these are native to Europe although ecologically similar forms are present in North America. The absence of these natural enemies in North America is thought to have contributed to the rapid population growth of zebra mussels, though the extent that they have been involved is disputed (Molloy *et al*., 1997).

Zebra mussels are ecosystem engineers: a species that directly or indirectly controls the availability of resources to other organisms by causing physical state changes in biotic or abiotic materials. Most of the ecological impacts of a zebra mussel invasion are a direct result of zebra mussels functioning as ecosystem engineers (see section 4.2).

3.5 Climate change and zebra mussels

Human induced climate change is now accepted as the world's greatest environmental problem. Predicted annual mean temperature increases may enable further species to become established in Britain and Ireland from continental Europe without direct human assistance due to natural range expansion (McLean, 2001; Minchin & Eno, 2002).

Climate change must be considered when developing a strategy to manage zebra mussel spread. In Northern Ireland annual temperatures are predicted to increase by 1.2^{O}C by 2020 and 2.8^{O}C by 2080 (Harrison *et al*., 2001). It is possible with increased temperatures, the threshold that initiates spawning (above 12^{O}C) will occur earlier in the year, thus promoting earlier spawning events of the zebra mussel. Water availability is likely to increase by up to 60 mm in winter (December to February) throughout Britain and Ireland (UK Climate Impacts Programme, 2003). This may also benefit the zebra mussel as some can die in years of low rainfall where zebra mussels present in shallow areas of lakes are exposed either to frost in winter or desiccation in summer.

4 Impacts of a Zebra Mussel Invasion

After zebra mussels become established in a water body, a number of signature impacts occur in most. These include increased water clarity, decrease in phytoplankton abundance, colonisation of native unionid mussels and infestation in water intake pipes of industrial and municipal plants.

4.1 Economic Impacts

The greatest economic impacts of zebra mussels are those associated with biofouling. Water intake structures for municipal, industrial and hydroelectric plants are highly vulnerable to fouling if they draw intake water from an infested waterbody. The intensity of fouling can depend on substrate type and current velocity (Kilgour & Mackie, 1993).

The most significant economic losses as a result of zebra mussel fouling have occurred in North America. Numerous municipal and industrial facilities have experienced severe zebra mussel fouling. Facilities that have been severely affected include Ontario Hydro station facility, Detroit Edison facility, Perry Nuclear power plant and Monroe waterworks, Michigan (Harrington *et al*., 1997). At Monroe waterworks zebra mussel fouling reduced water flow by 20% and the cost of controlling the infestation from 1989 to 1991 was $300,950 (LePage, 1993). The US Fish and Wildlife Service (1999) estimated that large water users in the Great Lakes, including municipalities and industry, pay at least $30 million a year to prevent zebra mussels infesting water intake pipes and causing blockages of water flow.

Figure 3. Zebra mussels covering a pot

Few economic impacts resulting from zebra mussel infestations have been documented in Britain, apart from some problems with drinking water supplies and an infestation of the Kingston Power Station on the River Thames in the 1960's. Since establishment in the Republic of Ireland, zebra mussels have caused problems in screens and water intake pipes for Cathleen's Falls power station, Ballyshannon and Lanesborough station and Ardnacrusha and Parteen hydroelectric stations on the Shannon. In 1997, a salmon hatchery at Parteen, Lough Derg encountered problems; 8,000 salmon fry died because of low water levels due to blockage of water inlet pipes by zebra mussels (Kirwan, 1999). In Northern Ireland, zebra mussels have blocked water intake pipes at Killyhevlin water works in Enniskillen and modifications were needed at a cost of over £100,000 to date.

Fouling can also occur on recreational and commercial watercraft. Fouling of boat hulls increases fuel consumption because of increased drag (Minchin *et al*., 2002b). Zebra mussels have blocked the water intake slots on boat engines which leads to engine damage from overheating. There can be increased maintenance costs with the need for regular hull cleaning or application of antifouling treatments.

Many of Northern Ireland's waterbodies support important recreational tourist fisheries that make a significant contribution to the local economy. Competition fishing is an important draw for tourists and many continental visitors also use and support the local cruiser and day boat hire businesses. The potential impact of zebra mussels on fish populations may have an economic impact if there is a change in the quality or perceived quality of fishing in Northern Irish lakes.

4.2 Ecological Impacts

Some European and North American freshwater communities have experienced profound ecological changes subsequent to invasion by zebra mussels (Karatayev *et al*., 1997; Heath *et al*., 1995; MacIssac, 1996).

Zebra mussels may alter nutrient cycling in a waterbody and their filtering activities often result in reduced concentrations of suspended solids and phytoplankton, alteration of phytoplankton community structure, increases in water clarity and increased macrophyte growth (Johengen *et al*., 1995; Fahnensteil *et al*., 1995; Baker *et al*., 1998). Zooplankton may be suppressed owing to food limitation and smaller taxa may be ingested directly by zebra mussels (Bridgeman *et al*., 1995; Jack & Thorpe, 2000). Habitat structure associated with, and waste products generated by, colonies of zebra mussels enhance production of many benthic invertebrates (Gonzalez & Downing, 1998; Haynes *et al*., 1999). Fouling of unionid mussels can dramatically reduce unionid populations (Ricciardi *et al*., 1996; Strayer, 1999). Changes in fish populations can occur, through colonisation of spawning grounds and the ability of a species to shift feeding behaviour to prey on zebra mussels (Karatayev *et al*., 1997; Mayer *et al*., 2001). It is possible that well-mixed or shallow systems invaded by zebra mussels may experience a shift in energy and biomass from pelagic to benthic food webs (Strayer *et al*., 1999).

4.2.1 Impacts in the Erne system

Lough Erne has undergone rapid and extensive ecological change since the establishment of zebra mussels. There has been a significant increase in water clarity and a dramatic reduction in phytoplankton abundance to 10% of peak summer maximum. Although zebra mussels do not appear to have altered phytoplankton community composition, a monospecific bloom of *Microcystis* sp occurred in Lower Lough Erne during summer 2003. This was a new occurrence and if such blooms become regular they will have economic and ecological consequences. The total zooplankton density has also declined in both Erne lakes.

The most visible impact has been the near extirpation of the native unionid Swan and Duck mussels (*Anodonta* sp.). Zebra mussels will attach themselves to unionid shells because they provide a hard surface for attachment in soft sediment. Unionids can die from starvation and suffocation because attached zebra mussels can prevent normal valve opening and closing.

Figure 4. Zebra mussels colonising a native *Anodonta*.

Live native mussels have not been found in Lough Derg in recent years and in Lough Erne the native mussel population is heavily colonised by zebra mussels. Mortality of native mussels has increased dramatically. The percentage of live mussels collected in dredge samples has decreased from 78% of specimens in 1998 to less than 1% in 2003. The reduction in the native mussel population may affect eels because *Anodonta* represent an important component of the diet of the eel in the Erne (Matthews *et al*., 2001).

The local extinction of native mussels in the Shannon and Erne systems can be expected

in the near future, however some small populations may survive in the mouths of some inflowing rivers.

Changes in the fish populations in Lough Erne have also been documented. Three years after the first major effects, the initial response of the fish community has been a decline in roach recruitment and an increase in perch recruitment. If this effect continues, the roach/perch biomass ratios will shift from roach dominance to parity or even to perch dominance. Before the establishment of zebra mussels, Lower Lough Erne was effectively a eutrophic lake with low water clarity and a mid water energy pathway, favouring roach. The zebra mussel invasion has dramatically reduced phytoplankton abundance and increased water clarity. Lower Lough Erne is now effectively a lake with a benthic energy pathway that apparently favours perch. The fish populations would therefore appear to be responding to the zebra mussel invasion as if to an effective reduction of trophic status. An international workshop was held in October 2003 which examined ecological change in Lough Erne and the influence of catchment changes and invasive species (Maguire & Gibson, in press).

Research into the ecological impacts of the zebra mussel invasion is ongoing. Research in other Irish lakes indicates similar impacts on water clarity, phytoplankton and unionid populations.

4.3 Zebra mussel control

Numerous strategies exist for the control of zebra mussels in industrial systems. Control strategies can be divided into two main categories, chemical and non-chemical. Chemical controls are the most popular and widely used methods of zebra mussel control. Chemical methods include the use of chlorine, ozone, bromine, potassium permanganate, molluscicides, flocculation processes, salinity, oxygen deprivation and antifouling coatings.

Figure 5. Upper Lough Erne

Non-chemical methods include proactive techniques to prevent infestation such as filtration, application of UV light, the use of electric and magnetic fields, acoustic energy and increasing water velocity. Reactive techniques to treat infestations include thermal shock treatments, desiccation, freezing, mechanical cleaning and biological control. Although most chemical treatments treat and protect almost the entire facility, they can have damaging effects on other species and on the aquatic environment.

Research into control of zebra mussels has focused on control in an industrial context. Once zebra mussels have become established in a waterbody there is little that can be done to control or eradicate the population while preserving the ecosystem. Control efforts in an ecological context tend to focus on preventing zebra mussels becoming established in the first place. As such they are primarily education and awareness initiatives.

5 Zebra Mussel Vectors

The route by which invasive species enter new areas are known as pathways; while the way they travel to new destinations are known as vectors (UNEP, 2001). Pathways and vectors are numerous. Carlton (1993) outlines the dispersal vectors of the zebra mussel. Dispersal is mediated by three natural mechanisms (currents, birds and other animals) and twenty human-related mechanisms. Human-related mechanisms include those related to waterways, vessels, navigation and fishery activities.

A management strategy needs to focus on those activities that are most likely to further spread the zebra mussel in Northern Ireland. When assessing the importance of different vectors, it is also important to consider the life stage of the zebra mussel that is likely to be transferred and the frequency of transfers. The single transfer of a few zebra mussel adults or juveniles to an environmentally suitable lake will not guarantee the development of a new colony, it is more probable that multiple deliveries of zebra mussels are necessary for the successful colonisation of a water body (Bossenbroek *et al*., 2001). Transfer of veligers between lakes may be less likely to create a founder population than transfer of adults, as the number of veligers transferred and their subsequent survival is likely to be low, as it is for the veligers of most bivalves. Following settlement, they would need to be sufficiently aggregated to allow successful reproduction when mature.

Seven major vectors that may transfer zebra mussels to new lakes in Northern Ireland were identified (Sykes, 2003). Of these vectors however, some are likely to have a larger and more important role to play in zebra mussel spread than others. The importance of a particular vector is also time related. While the reopening of a disused canal link between the Erne system and Lough Neagh would almost certainly result in the spread of zebra mussels to Lough Neagh, this is a long term project, and zebra mussels may become established in Lough Neagh before the canal development is complete due to overland inoculations from boat hulls. Therefore vectors were qualitatively ranked into high risk and medium risk categories based on their likelihood of introducing zebra mussels to new lakes in Northern Ireland (Table 1). The role of each vector in spreading zebra mussels is discussed and mitigating measures proposed.

Table 1. Vectors with the potential to introduce zebra mussels to new lakes in Northern Ireland.

High risk	Medium risk
1. Recreational boating	4. Angling activities
2. Intentional introductions	5. Fisheries and aquaculture operations
3. Re-opening of the Ulster canal	6. Illegal movements of eels and nets
	7. Accidental introduction from scientific/ conservation work

5.1 Recreational Boating

5.1.1 Potential to spread zebra mussels

Recreational boating was identified as a vector that was likely to facilitate rapid intra-national spread of the zebra mussel in Ireland (Minchin *et al*., 2003). Barges on canals and navigable rivers have probably been the main dispersal vector of zebra mussels in Britain and Northern Europe and movements of vessels in the rivers of North America have been implicated in its dispersal.

Movement between water bodies of boats that have zebra mussels attached is the primary means by which zebra mussels are spread between unconnected waterbodies (Johnson & Padilla, 1996; Bossenbrook *et al*., 2001). Zebra mussels can be attached to the boat hull, inboard motor systems, pumping systems, rudders, propellers and anchors (Padilla *et al*., 1996). Zebra mussels are also often found attached to macrophytes that are entangled on boats and trailers, such as the Eurasian watermilfoil (*Mynophyllum spicatum*), the club rush (*Shoenoplectus lacustis*) and the common reed (*Phragmites australis*) (Johnson & Padilla, 1996; Maguire, 2002). Heavy clusters of mussels can break off under their own weight if a fouled boat remains in one place for a long time. Zebra mussel larvae can be carried in bilge water, engine-cooling water, live wells and bait buckets.

In summer conditions in North America, zebra mussels can survive for more than five days attached to a boat hull or trailer (Ricciardi *et al*., 1995). In Ireland, zebra mussels will be likely to survive for longer periods because of the lower temperatures. Larval stages of zebra mussels can survive at least 8 days in water collected from live wells in recreational fishing boats (Johnson & Padilla, 1996). Zebra mussels will survive transport between waterbodies in Ireland.

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Figure 6. Barge on Barrow navigation

A survey of the incidence of hull fouling on the Shannon navigation, Erne Loughs and Grand Canal in Ireland found variation in the levels of colonisation of different vessel types (Minchin *et al*., 2003). Privately owned boats had a higher incidence of fouling than hired cruisers, probably due to frequency of maintenance. Large boats, such as barges, that are heavily fouled pose a great risk but these are moved relatively infrequently. Angling boats had the highest incidence of fouling and anglers will move boats following the emergence of insects in different lakes when fishing for brown trout (*Salmo trutta*) and other species. This vector has the potential to transport larvae and mussels to a wide range of lakes.

5.1.2 Recommended mitigation measures

Groups involved in recreational boating, such as angling and yachting clubs, have been targeted in the past by the zebra mussel awareness programme implemented by the Zebra Mussel Control Group (ZMCG). Leaflets have been distributed to clubs based around Lough Neagh, Lough Erne and Lough Melvin. However levels of awareness among the general public is low and some boaters who reported that they had knowledge about zebra

mussels and the methods that can be used to prevent their spread, still did not inspect their boats (Sykes, 2003). There is a need not only for more educational initiatives, but also for a code of practice for ensuring appropriate behaviour by boaters and anglers (Action 3.3).

Boating festivals and angling competitions will attract hundreds of boats from a variety of regions to one location, thus greatly increasing the likelihood of introducing zebra mussels to an uninvaded lake (Minchin *et al*., 2003). Lakes that are vulnerable to zebra mussel invasion should either have a ban on competitive and festival events, or a requirement for boats not normally berthed or launched in the lake to be steam-cleaned and inspected before they are launched (Action 3.3).

5.2 Intentional introductions

5.2.1 Potential to spread zebra mussels

Although most human-mediated dispersal of zebra mussel is unintentional, this is not always the case. The potential for the spread of zebra mussels to new lakes by intentional introductions is of concern. In North America, there have been cases where zebra mussels have been introduced to ponds to improve the water quality, from where further spread of mussels has occurred with economic and ecological impacts. There are concerns that anglers may intentionally introduce the zebra mussel to lakes and water bodies that are eutrophic and have low water clarity.

Many anglers favour the introduction of the zebra mussel because it increases water clarity and as a result improves catches of fish species that hunt for prey in the water column, such as trout. It is thought that zebra mussels were intentionally introduced to Lough Sheelin, Co. Westmeath, in the Republic of Ireland. Recent articles in the angling press have emphasised the benefits of the zebra mussel to the angler and condoned the deliberate introduction of zebra mussels to lakes.

The perception that zebra mussels 'clean up the water' is widespread and inaccurate as they just mask the problem of excess nutrient inputs. As the ecological consequences of a zebra mussel introduction on fish populations cannot be accurately predicted, its encouragement is irresponsible and this practice should be deterred.

5.2.2 Recommended mitigation measures

Zebra mussel education and awareness campaigns need to highlight the consequences of intentionally spreading zebra mussels. Surveys suggest that boaters and anglers mostly gain their information about zebra mussels from other boaters, anglers or club members (Sykes, 2003). Consequently there is the potential for misinformed beliefs to spread widely throughout the angling community, particularly encouragement to spread mussels deliberately.

Messages such as 'clearer water is not cleaner water' need to be emphasised because zebra mussels may be masking the effects of increases in nutrient inputs. Also, improved catches of trout, are not a result of an increase in stocks, but simply increased catchability due to increased water clarity, need to be communicated to the angling community. Indeed, increased catchability would put greater pressure on target species. A more specific education programme needs to be targeted solely at anglers and the angling press emphasising that intentional introductions are not beneficial, however these messages need to be delivered in a sensitive manner as not all anglers condone deliberate spread of zebra mussels.

Information should be disseminated to the angling community through their clubs in the form of leaflets and/or oral presentations. This

should be co-ordinated with current activities such as inclusion of leaflets with competition notices and angling permits to ensure the majority of local anglers have been targeted (Action 1.1).

The Wildlife (NI) Order (1985), Article 15, must be amended, to enable prosecution of intentional introductions of species that are non-native but that are already present in Northern Ireland (Action 2.1).

5.3 Ulster canal

5.3.1 Potential to spread zebra mussels

The restoration of canals creates corridors that allow the spread of non-native species by both natural dispersal and recreational boating. The re-opening of the Ulster Canal will contribute to further spread of zebra mussels in Northern Ireland.

The construction of canals in the late 18th and 19th century facilitated the spread of the zebra mussel throughout much of Europe and North America (Mills *et al*., 1999). The Ulster Canal was originally opened in 1841, fell into decline and was abandoned in 1931 (Ulster Canal Organisation, 2002). Serious consideration is now being given to re-watering the 45-mile canal network, of which half is in Northern Ireland and half in the Republic of Ireland. This will connect the Erne navigation with Lough Neagh so that pleasure cruisers and other boats can travel from the Shannon-Erne system to Lough Neagh. Some boats will have zebra mussel fouling on their hulls.

The linking of the Erne and Neagh catchments may facilitate transfer of other aquatic species apart from zebra mussels. Currently, the proposal for the re-opening of the canal is in its infancy and a feasibility assessment has been submitted to Governments in both jurisdictions. The estimated cost to re-open the canal is £88.8m (Waterways Ireland, 2001; Lough Neagh Management Strategy, 2002).

5.3.2 Recommended mitigation measures

The re-opening of the canal has many potential positive and negative implications and zebra mussels are one species that would most certainly expand their distribution into Lough Neagh. Lough Neagh has been designated under the Birds Directive and is a Natura 2000 site. It will be necessary to assess the impacts that a proposed project may have on a conservation site and a test of 'likely significance' will be required under the Habitats Regulations. This predicts any effect of the project that may affect conservation objectives or features, which enabled the site to be designated. If likely effects are found an Appropriate Assessment must be undertaken. This is different from the normal Environmental Impact Assessment process because it only focuses on the impacts on the conservation objectives of the site (EHS, pers. comm).

A full Environmental Impact Assessment (EIA) will also be required before any decision is made about the re-opening of the canal. The EIA will take into account the ecological problems associated with the spread of zebra mussels into Lough Neagh and the impacts they may have on the eel and sand extraction industries. Economic appraisals, of both potential tourist revenue returns from the estimated £88 million investment and of the ecological value of this area, should also be carried out to ensure that the economic benefits of re-opening the canal are balanced against the ecological value of the area and present economic interests.

Figure 7. Angler at Lough Navar

5.4 Angling activities

5.4.1 Potential to spread zebra mussels

Angling is a popular pastime in Northern Ireland and an important part of the tourism sector. A total of 9,659 angling permits were sold in Northern Ireland in 2003 (DCAL, 2003)

Table 2. Breakdown of angling permit data (DCAL, 2003).

Permit	Numbers
14 day	51
3 day	1749
Coarse	1090
General	1533
Juvenile	2799
Senior	1330
Local	1107

Angling activities are considered as a medium risk vector. Nonetheless, anglers possess a variety of equipment that has the potential to transport larval and adult zebra mussels. For example, bait buckets can contain water with larval stages, while wet landing and keep nets can have attached mussels. The zebra mussel is used by a number of fishermen as bait for perch fishing and unused bait may be discarded in an uncolonised lake.

5.4.2 Recommended mitigation measures

Neither the ZMCG zebra mussel fact-sheet nor leaflet give direct instructions on how to ensure that angling equipment does not spread zebra mussels to new lakes. This has been recognised and the following advice will be included in the future EHS web-site;

* Anglers should ensure that all angling equipment is fully dried out or immersed in hot water before use in a different lake.
* Anglers should not place bait bucket water in an uninvaded lake.
* Anglers should not re-use bait if it has been exposed to infested waters.
* Anglers should not use zebra mussels as bait in uninfested waters.

This advice should be included with annual renewals of angling licences, emphasising the importance of keeping angling equipment clean in order to prevent the spread of a number of invasive species and fish diseases. These include the zebra mussel, the salmon parasite *Gyrodactilis salaris* (Peeler *et al*., 2003), spores of the fungus of the crayfish plague *Aphanomyces astaci* (Wildlife Trust, 2000) and the Spring Viraemia of Carp virus (DEFRA, 2002). The Department of Culture, Arts and Leisure (DCAL) should consider developing a code of good practice for anglers to ensure that their activities do not spread invasive species and damaging fish diseases (Action 3.3).

5.5 Fisheries and aquaculture activities

5.5.1 Potential to spread zebra mussels

Aquaculture is the fastest growing sector within fisheries due to increasing demand for aquatic products (Minchin & Rosenthal, 2002). Commercial fisheries and aquaculture companies have the potential to transport zebra mussels through fishing equipment, cages and stocking water (Carlton, 1993). As a result, zebra mussels may be inadvertently introduced into stocked streams, lakes and ponds and may be transported to other fish hatcheries (Waller *et al*., 1996). When live fish or fish for stocking purposes are transported, lake water is pumped into holding tanks aboard lorries; this water may contain large numbers of zebra mussel larvae that will be released in a new location. At present in Northern Ireland there are over 20 fish farms and aquaculture operations and a number of angling club hatcheries, of which a small number may have the potential to spread zebra mussels as a result of their activities.

However the potential for fisheries and aquaculture operations to transport zebra mussels to new lakes may not be great. Waller *et al*. (1996) found that zebra mussel veligers and recent settlers are susceptible to treatment with sodium chloride (10,000mg/l for 24 hours) and that it was the only treatment that was safe for all fish species. This chemical is commonly added to transport tanks to reduce handling stress in fish because it acts as an osmoregulatory aid. Therefore it is likely that even if stocking water used by fisheries and aquaculture operations is transporting veligers, the veligers are most probably destroyed by the chemicals used in the transportation process. It has also been discovered that if transport tanks are treated with 100 mg/l of formalin for 2 hours 100% mortality of zebra mussel veligers occurs without considerable effect on salmonids (Edwards *et al*., 2000). However, methods such as ultrafiltration are more environmentally friendly than the use of chemicals.

Eel stocking activities in Northern Ireland have the potential to spread zebra mussels. In the past the Erne Eel Enhancement Programme stocked elvers and glass eels caught at Cathleen Falls on the River Erne near Ballyshannon, Donegal in the Upper and Lower Lough Erne and the Cavan-Monaghan lakes (Matthews *et al*., 2001). Currently elvers are distributed evenly between Upper and Lower Lough Erne and the Cavan lakes (J. Kerrigan, pers. comm.). Elvers are caught and placed in large tanks of water. This water is then released to the margins of the lake that is being stocked. Zebra mussels are present in the River Erne at Cathleen Falls so this activity has the potential to spread the zebra mussel to Cavan lakes, although most stocking takes place at a time of year when there are few zebra mussel larvae in the water.

The Lough Neagh Eel Fishermens Co-operative Society Ltd also import glass eels for stocking from the Severn. However, these have veterinary certification, are transported in borehole water and are unlikely to spread invasive species.

5.5.2 Recommended mitigation measures

The ZMCG needs to include all fisheries operations on their mailing list and disseminate information to these organisations. All parties involved in eel stocking activities need to be targeted to ensure they are aware of the potential to transfer larvae through elver releases. These organisations should adhere to a strict protocol that ensures that stocking water is not taken from zebra mussel infested lakes and if it is, it is left back to the same water body or discarded safely (Action 3.3).

5.6 Illegal eel fishing

5.6.1 Potential to spread zebra mussels

Fishing for the European eel (*Anguilla anguilla*) is licensed in Ireland, however unlicensed captures of eels using fyke nets take place at night. Transmission of zebra mussels to other water bodies by illegal eel fishing is possible because fouled water-logged branches and fragments of weed are regularly snagged in these nets (Minchin *et al*., 2002b). Also eel fishermen often leave fyke nets out for 3 to 5 nights before lifting them, which means that nets remain in the water for a long period potentially enabling zebra mussels to become attached (Matthews *et al*., 2001).

5.6.2 Recommended mitigation measures

Mitigation measures to be employed against this activity are limited because of the fact that this activity is being carried out illegally. The only measure that can be taken is for FCB staff to undertake regular inspections and enforce regulations where possible.

5.7 Scientific research and conservation work

5.7.1 Potential to spread zebra mussels

Extensive scientific and conservation work by governmental and non-governmental organisations occurs on a variety of freshwater bodies in Northern Ireland. These activities have the potential to accidentally transfer zebra mussels; however, the risk is likely to be small. A survey of organisations involved in work in the freshwater environment revealed that, of the participants who used a boat in their work 38% have found zebra mussels attached to the boat. Also of the 54% that use the same boat in Lough Erne and other water bodies, and only 71% inspect their boats for zebra mussels before launching on an uninvaded lake (Sykes, 2003). The use of weedcutting equipment has the potential to spread zebra mussels attached to macrophytes between waterbodies. The survey also revealed that 30% of the organisations had not received the ZMCG information. In addition, only half of the organisations involved in freshwater work inform their employees about the zebra mussel and how to prevent its spread through their own work activities.

5.7.2 Recommended mitigation measures

Zebra mussel information needs to be disseminated more widely, particularly to Non Governmental Organisations. A code of practice to encourage appropriate behaviour should be developed, because some organisations do not inspect their boats, even after receiving the ZMCG information on zebra mussels. Finally employees involved in work on fresh water bodies need to be informed how to minimise the risk of transferring zebra mussels to uncolonised waters. For example a simple checklist, listing steps to be taken to prevent mussel spread, could be distributed by organisations to relevant employees. This could be made available for download from the zebra mussel website (Action 1.5 and Action 3.3).

Figure 8. Zebra Mussels (*Dreissena polymorpha*)

6 Prioritisation of Vulnerable Lakes

6.1 Introduction

Northern Ireland has 1100 freshwater lakes including some of the largest lakes in the British Isles; Lough Neagh, Lower Lough Erne and Upper Lough Erne. Not all freshwater lakes will support populations of zebra mussels. There was a high probability of zebra mussels being introduced to lakes of the English Lake District and the Scottish highlands because these lakes are heavily used for recreational activities that could spread the mussel. However, zebra mussels have not become established in these waterbodies, most likely because of their water chemistry (Ramcharan *et al*., 1992).

The pattern of geographic spread of an invading species will depend on the overlap between the movement of dispersal vectors (i.e. boats with infested hulls) and suitable habitat (Padilla *et al*., 1996). It is possible to identify which lakes in Northern Ireland are suitable for zebra mussels based on physical and chemical parameters.

The aim of the prioritisation exercise was not to provide a definitive list of which lakes are likely to be invaded in a particular order; rather it is a tool to enable focused use of limited resources. In order to focus resources when planning to contain the spread of an invasive species, it is necessary to predict which habitats are at most risk from invasion and therefore the most vulnerable (Schneider *et al*., 1998).

However, those waterbodies most at risk might not necessarily be those that are the most important ecologically or economically. Therefore the assessment of vulnerability was a combination of an objective assessment of risk of invasion from both natural and human mediated dispersal mechanisms and an assessment of value of the waterbody based on conservation designations.

6.2 Parameters used to prioritise lakes

6.2.1 Water chemistry

Suitable water chemistry seems to primarily set the threshold for the presence of zebra mussels, rather than determine their abundance (Mellina & Rasmussen, 1994). The density or biomass of zebra mussels in Lough Erne was not significantly related to any physical or chemical parameter (Maguire, 2002).

6.2.1.1 pH

The pH of a water body is one of the most important factors influencing the distribution of zebra mussels. This is because water acidification causes disturbances in sodium, calcium and potassium exchange between mussels and the water. Assessment of the lower pH limit below which zebra mussels will not survive ranges from 6.5 to 7.3 in lakes over a wide geographical area and type (Ramcharan *et al*., 1992b; Sprung, 1993; Vinogradov *et al*., 1993; Claudi & Mackie, 1994;). In the prioritisation exercise, the lower pH limit of 6.5 was used.

6.2.1.2 Calcium concentration

The reported calcium concentrations that limit zebra mussel distribution range from 15 mg/l in the St. Lawrence River to 28.3 mg/l in the Great Lakes (Sprung, 1987; Ramcharan *et al*., 1992; Claudi & Mackie, 1994; Mellina & Rasmussen, 1994). In the prioritisation exercise the lower limit of 15mg/l was used.

6.2.2 Physical parameters

Consideration of the physical characteristics of a water body that are required for successful establishment of zebra mussels is also necessary. Water depth, lake size, proximity to invaded water bodies and whether a lake is upstream from other waterbodies are important physical parameters.

6.2.2.1 Lake depth

For the successful settlement and establishment of zebra mussels, the mean depth of a water body should be 2 metres or greater and the maximum depth should be greater than 4 metres (Strayer, 1991; Bossenbroek *et al*., 2001). In depths from 0.5 to 2 metres there is high turbidity and abrasion levels from waves breaking in shallower water. This makes it difficult for veligers to settle and adults to effectively filter feed and increases the possibility of exposure to freezing or desiccation if water levels are low (Yankovich & Haffner, 1993). However in Ireland lakes do not tend to freeze over in the winter to the same extent as in North America. A 2 m depth limit was used in the prioritisation exercise. Depth data was not available for all lakes and if a lake was designated/high quality and no depth data was available it was retained in the analysis.

6.2.2.2 Lake area

In North America, estimates of the relationship between lake area and suitability for colonisation have ranged from lakes 50 hectares in size being the most vulnerable (Strayer, 1991) to lakes that are greater than 100 hectares being the most vulnerable to zebra mussel colonisation (Kraft & Johnson, 2000). Lake area influences susceptibility of a lake to invasion, but the lake's size also influences the likely volume of boater activity and large lakes generally contain more boats (Johnson & Padilla, 1996; Reed-Andersen *et al*., 2000). Indeed the attractiveness of a lake to boaters is correlated to its area, with larger lakes being more attractive (Bossenbroek *et al*., 2001). The smallest known lake invaded by zebra mussels in North America is 15 hectares (Kraft *et al*., 2002). However, many small lakes in Northern Ireland are used for angling and are of conservation value so lake area was not used as a parameter to exclude lakes from the analysis.

6.2.2.3 Proximity to colonised waterbodies

The overland spread of zebra mussels has not occurred as rapidly as it has through connected waterways (Johnson & Padilla, 1996). Waterway connections between colonised and uncolonised lakes greatly increase the likelihood of mussel spread (Kraft *et al*., 2002). This was taken into consideration in the prioritisation exercise.

6.2.2.4 Connectivity of waterbodies

It is important not only to consider lakes on an individual basis but on a catchment basis. Lakes such as Lough Neagh and Lough Melvin are valued not only because of their conservation status but their economic importance. Therefore not only is it important to try and prevent zebra mussel spread to these lakes but also those lakes situated upstream. If zebra mussels colonise a lake situated upstream from Lough Neagh this would ultimately lead to the colonisation of Lough Neagh. Natural dispersal of zebra mussels within a catchment will occur as veligers are passively transported from colonised lakes through outflowing streams and rivers allowing colonisation of downstream lakes. Whether a lake is upstream from a lake of high conservation value was taken into consideration in the prioritisation exercise, as its colonisation would lead to colonisation of downstream lakes.

6.2.3 Recreational use

In Ireland, recreational boating has been identified as the most important vector for intra-national spread (Minchin *et al*., 2003). This is a three-step process; firstly boats must travel to a colonised lake and pick up juvenile or adult zebra mussels. These infested boats must then travel to an uncolonised lake, where mussels are released to the water body. Thirdly these transported mussels must survive the abiotic and biotic characteristics of the water

body to enable the recruitment of a new colony (Bossenbroek *et al*., 2001). Thus the first lakes predicted to be colonised by zebra mussels are high boater usage lakes that are relatively close to infested waters and in areas of high population density (Schneider *et al*., 1998). Whether a lake was used for recreational activities was taken into consideration in the prioritisation exercise.

6.2.3.1 Competitions

If any boating or angling competitions occur on a lake, there will be a high level of boating traffic from a wide variety of areas travelling to the lake for the competition, thus increasing the potential for the introduction of zebra mussels into the lake.

6.2.3.2 Boat clubs

In addition, the presence of boat clubs on a lake will mean a greater number of boats using and travelling to it, thus increasing the chances of zebra mussels being transported to the lake.

6.2.3.3 Licensed fishing

A large number of Northern Ireland's lakes are important for recreational fishing. Some waters are controlled by the Department of Culture, Arts and Leisure and some waters by angling clubs. Information on fishing in these waters is readily available along with facilities such as fishing stands and visiting anglers are encouraged. Therefore waters with licensed fishing are more likely to be at risk from invasion than those with no licensed fishing. In some lakes visiting anglers are allowed to launch their own boats.

6.2.3.4 Number of access points

The number of access points, such as marinas and public slipways that are present on a lake is also an important criterion in the prioritisation of vulnerable lakes. If there are few access points to a lake, limited numbers of potentially infested boats can be launched. Research in North America found that there were more boats per lake in lakes with more public access and that the number of public access points was strongly correlated with lake size (Reed-Andersen *et al*., 2000).

6.2.4 Conservation designations

A final criterion that was used to prioritise those lakes that are most vulnerable to zebra mussel invasion was the conservation value of individual lakes. This obviously does not facilitate zebra mussel colonisation of a lake, but helps to assign resources more wisely to protect areas that are at a high risk of invasion and have important conservation designations. Conservation designations included Areas of Special Scientific Interest (ASSI), Special Protection Areas (SPA) and Special Areas of Conservation (SAC). There are also a number of lakes that have been identified by EHS as High Quality, but have not yet been designated. Northern Ireland Lake Survey (NILS) data were examined to determine which lakes are chemically and physically suitable for zebra mussel colonisation. Data was available for 624 lakes (170 designated or of high quality).

6.3 Methodology

Step 1:
Those lakes with a pH below 6.5, calcium concentration below 15mg/l and depth below 2m were excluded. There were 367 lakes suitable for zebra mussel establishment. (see Appendix 2 for the list of designated/high quality lakes that were not suitable). However 6 of these lakes which drain into Lough Foyle are known to be brackish and above the salinity tolerance of the zebra mussel and so were excluded.

Step 2:
These 361 lakes were then individually scored according to the variables below (Table 3).

Table 3. Scoring system to prioritise lakes

Variable	Category	Score
Proximity of lakes to colonised waterbody	Lake in any way connected to colonised waterbody	15
	Lake within 5 miles of colonised lake	10
	Lake further than 5 miles from colonised lake	5
Connectivity of lakes	Upstream from an uncolonised designated / high quality lake	10
	Upstream from a colonised designated / high quality lake	5
Lakes with competitions (angling / boating)	Competitions	10
	No competitions	0
Boat clubs on lake	Yes	10
	No	0
Licensed fishing	Yes	10
	No	0
Access to lakes (includes marinas and slipways)	5 or more access points	15
	2-4 access points	10
	1 access point	5
	No access points	0

Step 3:
The score for each individual lake was totalled and then multiplied by the appropriate factor according to conservation designation. If a lake was designated (SAC, SPA or ASSI) the total score was multiplied by 3; if a lake was defined as high quality the total score was multiplied by 2; if the lake had no conservation designations and was not defined as high quality the total score was used.

Step 4:
Although the scoring was carried out on an individual basis many of these lakes are connected or can be grouped on a catchment and sub-catchment basis. This was carried out

where it made ecological sense. For example, Lough Neagh was grouped with Lough Beg, Portmore Lough and the Lower Bann as they form a connected system. The average score was calculated for each group (see Appendix 3 for the groups of lakes). The lakes were then ranked and prioritised according to their vulnerability.

6.3.1 Evaluation of the prioritisation method

There is no definitive method for prioritising lakes and the method used is constrained by the availability of data. Adopting the most stringent criteria published in the literature ensured that all lakes suitable for zebra mussel invasion were included in the vulnerable lakes list, although this increased the number of lakes in the list. Not all lakes in Northern Ireland were surveyed in the Northern Ireland Lakes Survey (NILS) therefore there may be suitable lakes which were not included in the analysis. However this method provides a straightforward template which will allow assessment of additional lakes as data becomes available

Figure 9. Monitoring on Lough Beg

6.4 Prioritised Vulnerable Lakes

The ten most vulnerable lakes or groups of lakes are listed in Table 4 and mapped in Figure 4 (see Appendix 4 for the full list).

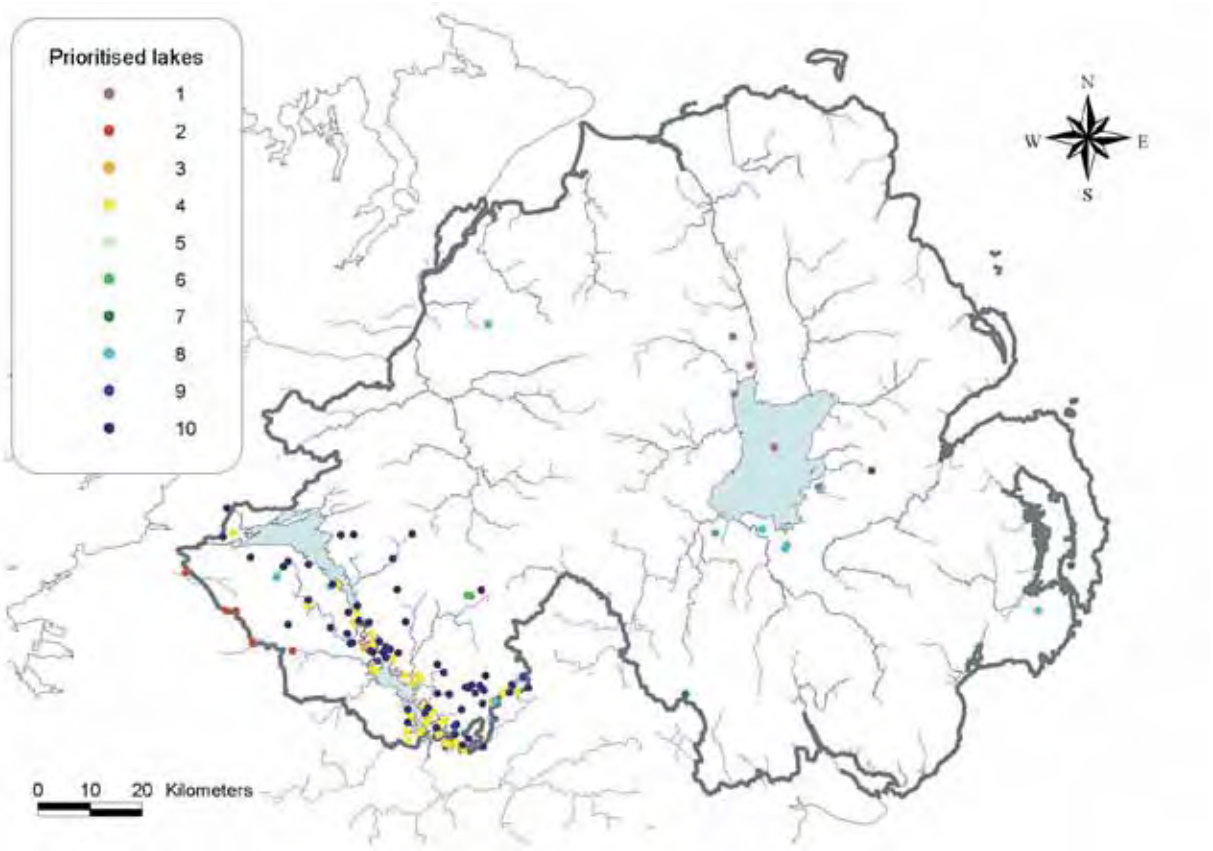
Table 4. Ten most vulnerable lakes or groups of lakes

Rank	Name	Grid Reference	County	Total Score
1	Lough Neagh - Bann system	J030770	ANT	115
2	Lough Melvin catchment	G905530	FER	80
2	MacNean lakes	H040395	FER	80
3	Mill Lough	H246385	FER	60
4	Erne catchment (designated/high quality lakes)		FER	56
5	Clea lakes	J505554	DOW	50
6	Blackwater - Neagh catchment (designated/high quality)		TYR	45
6	Monawilkin SAC/SPA	H082529	FER	45
6	Derryadd Lough	H917605	ARM	45
7	Tullynawood Lake	H860295	ARM	40
7	Lough Cowey	J596543	DOW	40
7	Breandrum Lough	H249431	FER	40
8	Lough Money	J534456	DOW	30
8	Lough Gullion	J006612	ARM	30
8	Lough Ash	C483004	TYR	30
8	Fardrum Lough	H181501	FER	30
8	Doagh Lough	H078521	FER	30
8	Craigavon Park Lakes	J053582	ARM	30
8	Burdautien Lough	H495283	FER	30
9	Lough Barry	H272360	FER	25
9	Leathemstown Reservoir	J215725	ANT	25
9	Drumnacritten and Black Loughs	H549331	FER	25
10	Erne catchment lakes		FER	22

These lakes can be specifically targeted with appropriate management measures to minimise the risk of water users introducing zebra mussels into the lake.

Although Lough Neagh and Lough Melvin could be considered equally valuable, the Lough Neagh - Lower Bann system score higher as it comprises of four waterbodies all of which have conservation designations and are used recreationally.

Figure 10. Map showing the location of the top ten vulnerable lakes or groups of lakes (see Appendix 3 for lake groups).



6.5 Measures to be employed around vulnerable lakes

6.5.1 Slipway signs

At Garrison slipway, Lough Melvin, the Lough Melvin Anglers Association erected a slipway sign advising boaters how to prevent the spread of the zebra mussel to the lake. However, there are no other signs on any of the other prioritised lakes. Slipway signs need to be placed at the main launching points on all vulnerable lakes (Action 1.3).

6.5.2 Code of practice for marina managers

Marina and slipway managers of the most vulnerable lakes require basic training about the zebra mussel and how to inspect boats being launched. A specific code of practice for marina and slipway managers should be developed (Action 3.3).

6.5.3 Steam cleaning

The Lough Melvin Anglers Association have taken a proactive stance against invasion by the zebra mussel. There is a requirement for all boats that are launched on the lake to

have been steam-cleaned at a certified garage, otherwise people can hire boats from the Garrison angling club. However, problems with this voluntary initiative are the lack of resources and staff to regularly inspect launching watercraft to ensure they have been steam-cleaned. Information should be made available on slipway signs on the nearest steam cleaning facilities (Action 1.3).

6.5.4 Visual inspections

Stakeholders should be encouraged to carry out random visual inspections of boats being launched on the most vulnerable lakes. This would contribute to continued monitoring of the problem and allow specific practical advice to be provided to boaters (Objective1).

Inspections of boats being launched at fishing and boating competitions on the vulnerable lakes identified is a necessity. This may be impractical due to the time constraints of such an event however necessary and worthwhile. If visual inspections are impractical in terms of staffing resources and time constraints, a requirement might be included in the competition entry forms for all boats that will be used in the lake to be steam-cleaned. Steam-cleaning receipts could be produced by all competitors when they are registering, thus getting around the time constraint problem on competition days (Action 3.3).

6.5.5 Early warning systems

Early warning systems are an essential tool in the task of detecting the spread of zebra mussels. Effective early warning systems include the use of equipment that is inexpensive, readily obtainable and simple to build and deploy (Marsden, 1998). This includes sampling lakes for veligers from the shore and using spat collectors. Spat collectors are composed of a rope with a weight on the bottom and a buoy or an empty plastic milk carton at the top. On the rope simple domestic pan scourer pads are attached at various points. These pads will collect the larval forms (veligers) of the zebra mussel if they are present. These pads are then detached every two weeks and cut into 10 random $1cm^2$ sections, placed in a petri dish with water and pulled apart with tweezers. Pads are examined with a binocular microscope for mussels.

Early warning systems will detect the presence of zebra mussel veligers or adults at an early stage and while the common belief is that once zebra mussels have invaded a lake nothing can be done about it, eradication may be attempted if the zebra mussel is present in small numbers. Early warning systems should be part of a structured surveillance programme (see section 8).

6.5.6 Stakeholder involvement

Stakeholder groups will be interested and committed to the protection of the lake resources for their benefit. Promoting environmental stewardship among local lake user groups may be an effective initiative. Help from grant aid programmes would encourage local user groups to participate in ensuring the zebra mussel and other invasive species are prevented from spreading to their lake, by producing leaflets and making public presentations. EHS should inform stakeholders that grant aid is available (Objective 1).

6.5.7 Competitions restrictions

The Lough Melvin Anglers Association banned all fly-fishing competitions on the lake from March 2000 because of the high potential of competitors to introduce the zebra mussel to the lake by launching of fouled boats. The first angling competition held on the lake since this ban was in June 2003. There was a requirement for boats to be steam-cleaned at an approved garage before being launched on the lake. Consultation is needed with the angling community to incorporate such restrictions into competition practises (Action 3.3).

7 Possible Consequences of Further Spread

There are widespread concerns about the ecological and economic consequences of zebra mussel spread to lakes such as Lough Neagh and Lough Melvin. While it is difficult to predict what the exact impacts will be in any particular waterbody, the research in the Erne system and other Irish lakes can inform thinking about the possible consequences of zebra mussel invasion of those lakes. Experiences in other waterbodies can also inform an assessment of what the potential impacts of zebra mussels would be on those features that are used to designate waterbodies. Zebra mussels also have implications for assessing waterbodies under the Water Framework Directive (WFD).

7.1 Lough Neagh

Lough Neagh is the largest freshwater lake in the United Kingdom covering an area of 383 km^2 (Lough Neagh Management Strategy, 2002). Lough Neagh and its satellite lakes (Portmore Lough and Lough Beg) have been designated as a National Nature Reserve (NNR), an Area of Special Scientific Interest (ASSI) and a Special Protection Area (SPA). Lough Neagh has had long-term problems with excess nutrients entering the lake from both point (sewage) and diffuse (agricultural) sources. The zebra mussel may mask increased nutrient input to the lake.

Lough Neagh provides habitat for numerous species of wintering wildfowl. The site qualifies under Article 4.2 of the Birds Directive as a wetland of international importance by regularly supporting over 20,000 waterfowl in winter (EHS, 2003b). Zebra mussels may have an impact on a number of bird species present in Lough Neagh that are internationally important, such as Whooper Swans (*Cygnus cygnus*), Pochard (*Aythya ferina*), Tufted Duck (*Aythya fuligula*), Scaup (*Aythya marila*) and Goldeneye (*Bucephala clangula*). This is because the zebra mussel may become a novel food source for some species. The increase in water clarity that results from the presence of a large population of mussels will increase the photic depth and thus encourage increased growth of aquatic vegetation on which some species feed. Some species of wildfowl may be adversely affected because of the potential effect that zebra mussels exclude chironomids from the littoral zone.

Loughs Neagh, Portmore and Beg and the rivers flowing into the Lough offer chances to fish salmon, pollan, perch, bream, roach and dollaghan (the Lough Neagh brown trout). Lough Neagh also represents the last remaining viable population of pollan (*Corregonus autumalis*) in Ireland (Harrod *et al*., 2001). Pollan are now rare and endangered and the subject of a UK and Northern Ireland Species Action Plan.

This species could be greatly affected by the invasion of zebra mussels through colonisation of spawning grounds and modifying zooplankton resources available to pollan. Pollan require clean gravel to spawn and zebra mussels may colonise these areas. However pollan recruitment has been documented in Lough Erne after zebra mussel invasion (R. Rosell, pers. comm.). Pollan are largely zooplanktivorous and the abundance of zooplankton has decreased in other Irish lakes after the establishment of zebra mussels.

Lough Neagh supports a highly productive European eel (*Anguilla anguilla*) industry, and is the largest and most commercially important fisheries for this species in Europe (Kennedy & Vickers, 1993; Woodman & Mitchel, 1993). Approximately 95% of the Northern Ireland eel catch is taken in Lough Neagh (DARD, 1999). At the height of the eel season some 6 to 9 tonnes may be dispatched daily throughout the European Union, specifically to Germany and the Netherlands (R. Rosell, pers. comm.). In 1999, the industry had a total yield of 669 tonnes and a net profit of £2,089,264 (DARD, 1999). However to date the total yield has decreased by 20 - 25% (R. Rosell, pers. comm.).

Zebra mussel invasion of Lough Neagh could have potential impacts on this industry. For example, zebra mussels have been found in eel stomachs and can cause lacerations of the gut (D. Evans, pers. comm.) and zebra mussels may cause problems with hauling of draft nets.

In addition, the sand extraction industry of Lough Neagh could also suffer adverse impacts if zebra mussels spread to the Lough. Zebra mussel shells could result in a deterioration of the quality of sand being sold, with a consequent requirement for all sand to be filtered to remove shells. Zebra mussels could also cause problems for this industry in terms of hull fouling of sand barges, which if severe, would cause increases in fuel costs and a requirement for barges to be dry-docked and cleaned more regularly.

Zebra mussels may also have impacts on the Water Service pumping station at Dunore Point (Department of Regional Development). This plant filters water with the slow sand filtration process and does not use chlorine in the water filtration process. To implement a chemical control strategy (e.g. chlorine application) for the control of zebra mussels, if they infested water intake pipes and sample lines, would be problematic and costly (R. Taylor (Killyhevlin WTW), pers. comm.).

7.2 Lough Melvin

The majority of the 2125 hectares of Lough Melvin lie in Leitrim in the Republic of Ireland. It is designated as an Area of Special Scientific Interest (ASSI) and has been proposed as a candidate Special Area of Conservation (SAC).

Lough Melvin is the best example of a relatively unpolluted (mesotrophic) and undisturbed large lough in Northern Ireland (EHS, 2003c) but increases in nutrient input to the Lough have been recorded recently (J. Girvan (QUB), pers. comm.). In comparison, Lough Erne and Lough Neagh have undergone eutrophication and been altered hydrographically. Increased nutrient loading to a lake normally results in increased algal blooms. The zebra mussel de-couples the nutrient-chlorophyll relationship so this normal response does not occur.

Eutrophication models that link nutrient loadings and pelagic measures of water quality may not be valid in water bodies that have large zebra mussel populations (Maguire, 2002). In zebra mussel invaded water bodies, changes in nutrient loadings are better reflected in changes in benthic algae. If the zebra mussel spreads to Lough Melvin, normal indicators of increased nutrient input to the lake will be masked. It is probable that the establishment of zebra mussels in Lough Melvin will lead to an increase in water clarity, decrease in phytoplankton and zooplankton abundance and an increase in macrophyte growth.

Lough Melvin may be one of the few remaining examples in the whole of north-western Europe of a natural post-glacial salmonid lake which is typically very fragile and susceptible to disruption. The Lough supports a unique salmonid community with three genetically distinct populations of trout, the Sonaghen (*Salmo trutta nigripannis*), Gillaroo (*Salmo trutta stomachius*) and Ferox (*Salmo trutta ferox*) (Ferguson, 1986). As a result Lough Melvin is regarded as the best game fishery in Northern Ireland (Northern Ireland Tourist Board, 2002). Sonaghen spawn in the sandy bays in the middle region of the northern shore again which could be affected by zebra mussel colonisation of these areas.

There are also stocks of Atlantic Salmon (*Salmo salar*) which is listed in Annex II of the EC Habitats and Species Directive and the Arctic Charr (*Salvelinus alpinus*), an Irish Red Data species which spawns on shallow rocky areas of Lough Melvin (EHS, 2003c). Zebra mussel colonisation of these areas may have an

adverse impact on these species. Any changes or perceived changes to the quality of fishing in Lough Melvin will have an economic impact on the tourist industry in the area.

Response to a zebra mussel invasion of Lough Melvin needs a co-ordinated approach between agencies in both jurisdictions. Any legal or management barriers that could delay a response should be identified as soon as possible and a contingency plan and protocol agreed.

7.3 Conservation designations

Lakes in Northern Ireland possess a number of conservation designations including Special Areas of Conservation (SACs), Special Protection Areas (SPAs), Areas of Special Scientific Interest (ASSIs). These designations are based upon a number of features and species and zebra mussels have the potential to affect a number of these (see appendix 5 for a full consideration of the potential impacts of zebra mussels on features and species selected for conservation designation).

7.4 Classification of lakes under the Water Framework Directive

The EC Water Framework Directive (WFD) (2000/60/EC) came into effect in December 2000. The purpose of the WFD is to establish an overall framework for the protection of surface and ground water throughout Europe. This will be delivered through the development of River Basin Management Plans (RBMPs). Under the WFD, water bodies will be classified according to biological, hydromorphological and chemical status. The biological status of lakes will be determined by invertebrate, plant, phytoplankton and fish communities.

The WFD requires that water bodies that are already of high quality be maintained to "high status" level. It also requires the prevention of deterioration of current water bodies and aims to achieve a classification of at least "good status" for all water bodies by 2015 (Joint North / South Consultation Paper, 2003).

The WFD does not make explicit reference to non-indigenous species and the subject of the impact that invasive species may have on the definition of the status of water bodies has yet to receive full consideration (UK TAG Guidance, 2004). However, Annex II of the Directive refers to anthropogenic pressures to which water bodies may be subjected. As zebra mussels have been introduced via human activities, they can be considered an anthropogenic impact.

The WFD classification of water bodies that have high ecological significance is based on the concept of naturalness. However, the presence of non-indigenous species will detract from this classification in numerous water bodies.

Zebra mussels in particular may have an extensive impact on the biological parameters that have been selected to determine the status of water bodies (Table 5). For example, to achieve "good status" with regard to biological quality only slight changes from reference conditions in the composition and abundance of phytoplankton, macrophytes, phytobenthos and benthic invertebrates can occur. Zebra mussels can potentially impact on all these parameters.

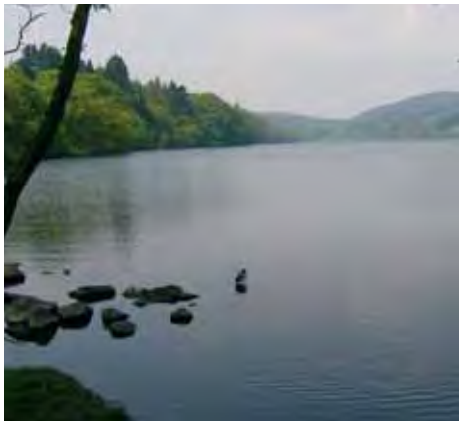


Figure 11. Castlewellan Lake

Table 5. Elements of the WFD classification of good status for lakes that may be affected by zebra mussels.

Parameter / (Status)	Definition	Effect of zebra mussel
General conditions (Good status)	"Temperature, oxygen balance, pH, acid neutralising capacity, transparency and salinity do not reach levels outside the range established so as to ensure the functioning of the ecosystem and the achievement of the values specified for the biological quality elements."	Transparency or water clarity can increase significantly Phytoplankton
Phytoplankton (Good status)	"Slight changes in the composition and abundance of planktonic taxa compared to the type-specific communities."	Decrease in phytoplankton abundance and alteration of community composition
Macrophytes and phytobenthos (Good status)	"Slight changes in the composition and abundance of macrophytic and phytobenthic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of phytobenthos or higher forms of plant life."	Increased abundance of macrophytes and phytobenthos
Benthic invertebrate fauna (Good status)	"Slight changes in the composition and abundance of invertebrate taxa compared to the type-specific communities."	Alteration in the abundance of particular taxa and change in community composition.

For the purpose of a risk assessment of alien species under the WFD, UK TAG Guidance (2004) classified a number of alien species as having a 'high impact'. These are defined as species that are known to be invasive and have caused documented harm. The guidance recommends that their impacts are considered in future risk assessments for the WFD. Zebra mussels are included on this list.

UK TAG guidance also recommends a set of guidelines to ensure alien species are taken into account in the classification of water bodies. For example, a water body should only receive a 'high status' classification if no alien species on the 'high impact' list are present. The guidance also states that if a water body is provisionally classified as of 'good status' but is suffering significant impacts from species on the 'high impact' list, it then is liable to fail achieving a classification of 'good status'.

If the risk assessment guidance is applied, Ireland and numerous other countries will be at risk of failing to achieve at least 'good status' of all water bodies by 2015, due to the presence of zebra mussels and other alien species.

8 Surveillance for Zebra Mussel Spread

Figure 12. Lough na Blaney Bane

Surveillance is the act of undertaking repeated surveys and monitoring is surveying against a standard to determine subsequent changes (DEFRA, 2003). To successfully manage the impacts of further zebra mussel invasions in the prioritised lakes, it is necessary to draw up a structured surveillance programme.

A lake surveillance programme needs to monitor for the presence of zebra mussels or their veligers during the summer months and collate and co-ordinate records. Such a programme would include 5-10 yearly surveys of the prioritised lakes, combined with focused opportunistic surveys and focused site surveys around areas of high levels of human activity such as boating. Surveillance for zebra mussel must involve all water users and should be incorporated into current research and monitoring programmes to avoid duplication of effort.

There has been limited surveillance for zebra mussels in Northern Ireland. Spat collectors have been deployed in Lough Neagh and Lough Melvin and combined with opportunistic shore sampling. No zebra mussels have been detected in these lakes to date.

Government agencies have generally relied on sightings of zebra mussels in new lakes being reported by the public. A structured surveillance programme would increase understanding of the spread of zebra mussels in Northern Ireland and allow timely and more effective management (Action 4.2).

9 Management Recommendations

Overall Aim

To minimise the spread of zebra mussels in Northern Ireland through raising awareness, developing policy and legislation, monitoring and research and developing contingency plans for immediate action in the event of further zebra mussel spread.

Objective 1:

To raise awareness among the public and target groups in order to encourage them to take action to minimise the spread of the zebra mussel.

Action 1.1: Prepare a single, updated leaflet for water users containing advice on preventing the spread of the mussel, a key contact if the zebra mussel is sighted in a new lake and reference to the web-site for further information.

Action 1.2: Prepare lake specific posters for Lough Neagh and Lough Melvin.

Action 1.3: Slipway signs should be placed at the main launching points on vulnerable lakes.

Action 1.4: Develop an annual electronic newsletter and compile an email list for its distribution.

Action 1.5: Develop a zebra mussel web-site, which should include facilities for reporting new sightings and subscribing to the annual newsletter.

Action 1.6: Carry out an annual press release campaign at the start of the main boating and angling season.

Action 1.7: The chair of the Zebra Mussel Control Group (ZMCG) or their nominee to respond to press enquiries.

Action 1.8: Education on invasive species and their implications should be retained and improved within school curricula and higher education centres.

Objective 2:

Amend and co-ordinate appropriate policy and legislation.

Action 2.1: Amend the Wildlife (NI) Order (1985), Article 15, to enable prosecution of intentional introductions of species that are non-native but that are already present in Northern Ireland.

Objective 3:

Identify sectors involved in the spread of zebra mussels and characterise the necessary requirements for each sector to ensure their activities are not responsible for the further spread of zebra mussels in Northern Ireland.

Action 3.1: Identify sectors that have the potential to spread zebra mussels (marina / slipway managers, boaters, anglers, fisheries managers, environmental agencies and researchers, the tourism sector, boat importers and sand abstractors). Develop and maintain a list of contacts for each sector.

Action 3.2: Identify the activities of each sector that may contribute to the transfer of zebra mussels and categorise these activities as high, moderate or low risk.

Action 3.3: Identify which sectors require basic information or training about invasive species issues and how to prevent the spread of zebra mussels. Identify whether any sectors require specific codes of practice for their activities or development of new legislation. If codes of practice are required they should be developed in consultation with stakeholders and north-south co-operation.

Objective 4:

Continue research on the spread, impacts and the level of awareness of the zebra mussel in Northern Ireland. Ensure research is made widely available.

Action 4.1: Maintain the level of expertise on zebra mussels in Northern Ireland.

Action 4.2: Implement a structured surveillance programme of the most vulnerable lakes.

Action 4.3: Continue research into the ecological and economic impacts of the zebra mussel in Northern Ireland.

Action 4.4: Complete a risk assessment of Water Service facilities that are located on lakes that have been identified as vulnerable and develop a contingency plan for action if zebra mussel infestation of facilities occurs.

Action 4.5: Continue to disseminate findings of research in scientific literature and make provisions to inform the general public on important findings.

Action 4.6: Review the effectiveness of the zebra mussel education and awareness programme. Repeat surveys of the level of awareness of the zebra mussel among important lake user groups after three years.

Objective 5:

Develop contingency protocols for immediate response if new lake invasions are reported.

Action 5.1: Appoint a named section within an agency as responsible for rapid confirmation of a reported zebra mussel sighting.

Action 5.2: Follow the general protocol for responding to a report of zebra mussel spread (appendix 6)

Action 5.3: Prepare a generic press release that can be sent out immediately once a new invasion is confirmed.

Action 5.4: Compile and maintain a contact list of appropriate government agencies that will need to be informed.

Action 5.5: Compile and maintain a contact list of appropriate government agencies in the Republic that will need to be informed, in those cases where a lake is located in both jurisdictions.

Action 5.6: Compile and maintain a contact list of stakeholders for Lough Neagh and Lough Melvin.

Objective 6:

Develop a mechanism to co-ordinate action, policy and information sharing on an all island basis.

Action 6.1: Initiate liaison with the Environmental Protection Agency and National Parks and Wildlife Service for a drive towards harmonisation of legislation between the two jurisdictions.

10 Strategy Implementation

The success of the strategy in achieving its objectives will depend on its implementation.

There needs to be a co-ordinated approach between the various Government agencies with responsibilities and interests in this area.

An implementation plan setting out the tasks that need to be undertaken to deliver the objectives should be prepared. This should include:

* Tasks
* Identification of lead and partner agencies
* A resource and cost assessment
* Quantifiable targets and timescales
* Review points at which performance can be assessed against objectives

Table 6 - Example of an implementation plan.

Objective/ Action	**Tasks**	**Timeline**	**Resource Assessment**	**Lead Agency**	**Partners**
Objective 1: To raise awareness among the public and target groups in order to encourage them to take action to minimise the spread of the zebra mussel					
Action 1.3 Slipway signs	1. Design signs 2. Make signs 3. Place signs at launching points	1 week 3 weeks 3 weeks	Staff time Finance	EHS	DCAL Rivers Agency Angling Assoc. DARD

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APPENDIX 1

Irish lakes known to be invaded by zebra mussels (D. Minchin & F. Lucy, 2003)

Lough/Lake Reservoir	River System	Grid Reference
Acres	Shannon Nav.	G96 09
Allen	Shannon Nav.	G96 11
Arrow	Unshin	G81 11
Assaroe Res.	Erne Nav.	G89 60
Avoher	Owengarney	R52 74
Ballaghkeeran	Shannon Nav.	N07 44
Ballinasloe Harbour	Suck, Shannon	M85 30
Black	Stream to Shannon	M95 86
Bo	Foerish, Shannon	G79 18
Boderg	Shannon Nav.	N01 92
Bofin	Shannon Nav.	N04 89
Bran	Stream to Shannon	G96 02
Carnadoe	Shannon Nav.	M99 89
Clonlea	Owengarney	R51 73
Cloonboniagh	Eslin, Shannon	M06 92
Clooncoe	Rinn, Shannon	N11 91
Coologe	Shannon-Erne Nav.	H23 13
Coosan	Shannon Nav.	N05 45
Creenagh	Rinn, Shannon	N10 96
Cullaunyheeda	Rine	R47 74
Derg	Shannon Nav.	R70 73
Derragh	Inny, Shannon	N39 79
Derrycassan	Erne Nav.	H22 11
Derryvaragh	Shannon	N46 63
Doon (lower)	Owengarney	R54 73
Dooneen	Clooncraft, Shannon	M95 90
Drumharlow	Shannon Nav.	G90 01
Erne, lower	Erne Nav.	H12 55
Erne, upper	Erne Nav.	H33 27

Lough/Lake Reservoir	River System	Grid Reference
Errew	Rinn, Shannon	N10 93
Forbes	Shannon Nav.	N07 81
Gara (lower)	Boyle, Shannon	G71 01
Garadice	Shannon-Erne Nav.	H20 11
Gill	Garvoge	G71 35
Gortinty	Stream to Shannon	M01 95
Grange	Shannon Nav.	M97 87
Keenheen	Stream to Erne	H16 07
Key	Shannon Nav.	G84 04
Kilglass	Shannon Nav.	M98 85
Kilgory	Owengarney	R53 78
Killinure	Shannon Nav.	N05 46
Kiltybarden	Erne Nav.	G08 10
Limerick Dock	Shannon Nav.	R57 57
McHugh	Eslin, Shannon	N04 97
Nablahy (lower)	Finlough, Shannon	M94 88
Nablahy (upper)	Finlough, Shannon	M95 88
Oakport	Shannon Nav.	G88 03
Parteen Reservoir	Shannon Nav.	R67 67
Quivvy	Erne Nav.	H39 21
Ree	Shannon Nav.	N00 46
Ringsend Hbr.	Grand Canal	O17 33
Rinn	Rinn, Shannon	N10 92
Rosslara	Graney	R53 82
Sheelin	Shannon	N44 83
Skean	Feorish, Shannon	G85 12
St Johns	Shannon-Erne Nav.	H09 10
Tullamore Hbr	Grand Canal	N33 25
Tully	Stream to Shannon	M98 91

APPENDIX 2

Designated / High quality lakes not suitable for zebra mussels

Lake name	Grid Ref	County
Lough Hamul	H067414	FER
Lough Anlaban	H054563	FER
Lough na freaghoge	H577794	TYR
Lough Carn	H575789	TYR
Loughnabrackey	H572796	TYR
Loughanillan	H575795	TYR
Loughnadarragh	H567778	TYR
Loughnapeast	H575794	TYR
Loughnacrackin	H568786	TYR
Loughnacree	H566787	TYR
Oak Lough	H498841	TYR
Lough Fingream	H573777	TYR
Lough Ora	H066427	FER
Martincrossagh Lough	H058428	FER
Derrynacarbit Lough	H005506	FER
Lough Formal	H047474	FER
Lough Doo	H038505	FER
Lough Nabrickboy (B)	H036502	FER
Lough Navar	H028547	FER
Loughnapeast	H565775	TYR
Loughnaweelagh	H051830	TYR
Innaghachola Lough	H053839	TYR
Carricknagower Lough	H003542	FER
Tullywannia Lough	H044508	FER
Lough Corr	H289769	TYR
Meenagleragh Lough	H030505	FER
Big Dog Loughs	H025495	FER
Cashel Lough Upper	H968196	ARM
Glencreawan Lough	H025565	FER
Aughnadarragh	J443594	DWN
Loughnatrosk	D272199	ANT
Lough Doo	H436301	FER

Lake name	Grid Ref	County
Greenan Lough	J119233	DWN
Straghans Lough	H823307	ARM
Cam Lough	J035245	DOW
Lough Atona	H110292	FER
Lough Sallagh	H531438	TYR
Glenbower Lough	H549446	TYR
Loughanalbanagh	H540441	TYR
Lough Navarad	H558447	TYR
Mill Lough	H742886	LON
Lough Acrottan	H064469	FER
Lough Mulderg	H100451	FER
Binnian Lough	J325242	DWN
Blue Lough	J328252	DWN
Loughnabrick	D258199	ANT
Meenatully Lough	G999653	FER
Lough A Waddy	H042650	FER
Tullynasiddagh Lough	G984652	FER
Lough Natroy	H505462	TYR
Lough Namanfin	H054458	FER
Dungonnell Dam	D197175	ANT
Lough Fad	D255196	ANT
Loughnacally	D257211	ANT
Lough Garve	D211177	ANT
Loughascraban	D248199	ANT
Loughfine	D263203	ANT
Lough Wee	G989646	FER
Mallybreen Lough	H011661	FER
Lough Rushen	H019662	FER
Lough Vearty	G994658	FER
Meenaghmore Lough	G992642	FER
Lough Nafeola	H032645	FER

APPENDIX 3

Groups of lakes used in ranking exercise

Group name	Lakes in group Name	Grid reference
Lough Neagh	Lough Neagh	J030770
	Lough Beg	H950980
	Portmore Lough	J114692
	Lower Bann	H983925
	Traad Point Ponds	H953871
Lough Melvin catchment	Lough Melvin	G905530
	Lattone Lough	H001455
	Dean's Lough	G983456
Erne catchment (designated / high quality)	Derryhowlaght	H300364
	Killymackan Lough	H330207
	Kilturk Lough	H371260
	Cornabrass Lough	H401245
	Drumroosk Lough	H347333
	Lough Head	H354325
	Un-named	H268342
	Corracoash Lough	H352223
	Lough Scolban	G995605
	Lough Nalughoge	H365243
	Killynubber Lough	H389241
	Black Lough	H327226
	Lough Digh	H324332
	Derrysteaton	H388220
	Sessiagh East	H261345
	Gole	H333247
	Abacon Lough	H333253
	Derrymacrow Lough	H366252
	Kilmore Lough	H338318
	Derrykerrib Lough	H400203
	Lough Sarah	H423198
	Castle Lough	H408201
	Pound	H421204
	Annachullion Lough	H519303
	Corraharra Lough	H356228
	Summerhill Lough	H490280
	Rathkeevan Lough	H538302
	Rose Lough	H511298
	Lough Garrow	H435190
	Lough Accussel	H259411
	Back Lough	H232452
	Rossole Lough	H225434
	Sand Lough	H378264
	Cargin Lough A+B	H360274
	Castlehume Lough	H195505
	Ross Lough	H137466
	Cleenish	H261392

APPENDIX 3 (Continued)

Group name	Lakes in group Name	Grid reference
Blackwater-Neagh catchment (designated / high quality)	Round Lough Lough Fadda	H443485 H450484
Blackwater-Neagh catchment	Lough Cullion Lough Nacrilly Carnteel Lough Tullygiven Lake Curran Lough Ballagh Lough Lough Gunnell Carrickavoy Lough Lough Na Blaney Bane Creeve Lough Enagh Lough White Lough Augher Lough	H809655 H821634 H699548 H777527 H808540 H500500 H495501 H582494 H580475 H738512 H758464 H225602 H560537
Oona-Blackwater-Neagh catchment	Black Lough Wood Lough Mullaghbane Moss Crans Lough Carrick Lough McCauslands Lough Guthree Lough Friary Lough Legane Lough Lough Macronan Brantry Lough	H763609 H760601 H735590 H711568 H724552 H737561 H740555 H748558 H737538 H755534 H749539
Lough Foyle SAC / SPA	Longfield Dyke 2 Donnybrewer Dyke 2 Myroe Pond Ballymacran Pond Donnybrewer Dyke 1 Longfield Dyke 1	C530239 C513238 C623275 C631262 C498238 C543237
Monawilkin SAC / SPA	Carrick Lough A Carrick Lough B Monawilkin Lough	H091541 H091541 H082529
Killough SAC / SPA	Strand Lough Reservoirs	J535374 J525379
Heron and Carrigullion SAC / SPA	Carrigullion Lough Heron Lough	J500589 J497582
Killtubbrid Loughs	Kiltubbrid Lough (B) Kiltubbrid Lough (A)	H768393 H768397
Clea Lakes	Clea Lake (A) Clea Lake (B)	J505554 J509548

APPENDIX 3 (Continued)

Group name	Lakes in group Name	 Grid reference
Lough Foyle catchment	Ballyarnet Lake	C450218
	Creggan Lower Reservior	C422174
	Tamnymore Reservoir	C432146
	Mill Pond	C652103
Knockballymore Loughs	Knockballymore (A)	H476268
	Knockballymore (C)	H481271
Erne catchment lakes	Mill Lough	H466313
	Keenaghan Lough	G975598
	Meenameen Lough	H029559
	Lough Coole	H255434
	Derrycarra (Enniskillen)	H236437
	Shankill Lough	H559309
	Bunnahone Lough	H100551
	Lough Bresk	H201601
	Dooletter Lough	H100430
	Carrick Lough A	H091541
	Coolyermer Lough	H181424
	Lankill Lough	H213412
	Kinarla Lough	H215453
	Drumcose Lough	H185507
	Lough Aleen	H139545
	Carran Lough	H139477
	Drumcullion Lough	H275397
	Wolf Lough	H233466
	Galbally Lough	H337603
	Maghera Lough	H300557
	Watsons Lough	H308496
	Lough Eyes	H325435
	Laragh Lough (B)	H223395
	Laragh Lough (C)	H219394
	Lough Raymond	H287387
	Gola Lough	H295383
	Lough Crowey	H257379
	Knock/ Cloonatrig	H261377
	Arda Lough	H283375
	Lough Nabodeen	H287367
	Lough Corban	H310375
	Derrychree Lough	H329267
	Ports Lough	H362260
	Frairs Lough	H368270
	Kilmacbrack Lough	H408295
	Moorlough Lake	H385297
	Lough Narye	H398338
	Forfey Lough	H385354
	Mullynagowan Lough	H431267
	Johnstown Lough	H472278

APPENDIX 3 (Continued)

Group name	Lakes in group Name	Grid reference
Erne catchment lakes	Rossbrick Lough	H458299
	Cornagague Lough	H474304
	Killylacky Lough	H470308
	Tattycam Lough	H440310
	Mount Sedborough Lough	H445308
	Coolnamarrow Lough	H451314
	Drumbarrow Lough	H528315
	Aghafin Lough	H524300
	Drumbominey Lough	H329242
	Un-named	H383232
	Aghnahinch Lough	H422239
	Lough Nacallagh	H418235
	Kilgarrow Lough	H419220
	Lakeview Lough	H445211
	Annaghmore	H433199
	Drumaveale Lough	H473196
	Tullynasiddagh Lough	G984652
	White Lough	H225602
	Screeby Lough	H469495
	Corranny Lough	H478332
Baronscourt Lakes	Fanny Lough	H360830
	Lough Catherine	H365840
	Lodge Lake	H368837
Ravarnet catchment	The Long Lough	J375559
	Bow Lough	J355578
	Gill's Lough	J365582
	Hogg's Lough	J366582
	McKees Lough	J342579
	Wright's Lough	J342585
Lough Neagh satellite lakes	Moyola Water A	H962895
	Mullagh A	H975925
	Mullagh J	H983934
	Stewartstown Reservoir	H859706

APPENDIX 4

Full ranked list of lakes with conditions for the threat of colonisation

Rank	Name	Grid reference	County	Total score	Designated or high quality
1	Lough Neagh -Bann system	J030770	ANT	115	Y
2	Macnean Lakes		FER	80	Y
2	Lough Melvin catchment	G905530	FER	80	Y
3	Mill Lough	H246385	FER	60	Y
4	Erne catchment (designated /high quality lakes)		FER	57	Y
5	Clea Lakes	J505554	DOW	50	Y
6	Blackwater-Neagh catchment (designated/ high quality)		TYR	45	Y
6	Monawilkin SAC/SPA	H082529	FER	45	Y
6	Derryadd Lough	H917605	ARM	45	Y
7	Tullynawood Lake	H860295	ARM	40	Y
7	Lough Cowey	J596543	DOW	40	Y
7	Breandrum Lough	H249431	FER	40	Y
8	Lough Money	J534456	DOW	30	Y
8	Lough Gullion	J006612	ARM	30	Y
8	Lough Ash	C483004	TYR	30	Y
8	Fardrum Lough	H181501	FER	30	Y
8	Doagh Lough	H078521	FER	30	N
8	Craigavon Park Lakes	J053582	ARM	30	N
8	Burdautien Lough	H495283	FER	30	Y
9	Lough Barry	H272360	FER	25	N
9	Leathemstown Reservoir	J215725	ANT	25	N
9	Drumnacritten and Black Loughs	H549331	FER	25	Y
10	Erne catchment lakes		FER	22	N
11	Blackwater-Neagh catchment			20	N
11	Lurgan Park Lake	J089587	ARM	20	N
11	Lough Yoan	H253422	FER	20	Y
11	Lough Aleater	G975495	FER	20	Y
11	Clay Lake	H835325	ARM	20	N
11	Back Lough	H458307	FER	20	Y
12	Oona-Blackwater-Neagh catchment			17	N
13	Tullybrick Lough	H750398	ARM	15	Y
13	Stonyford Reservoir	J217695	ANT	15	N
13	South Woodburn Reservoirs			15	N
13	Seagahan Dam	H903380	ARM	15	N
13	Park Lake Dungannon	H805611	TYR	15	N
13	Mullygruen Lough	H758651	TYR	15	N
13	Mullaghmore Lough	H754639	TYR	15	N
13	Montgomery's Lough	J382541	DOW	15	N
13	Martray Lough	H641583	TYR	15	N
13	Magheralagan Lake	J443434	DOW	15	N
13	Lurgan Lough Upper	H950157	ARM	15	Y
13	Loughkeelan	J563453	DOW	15	N
13	Loughinisland Lake	J425452	DOW	15	N
13	Lough Shark	J065415	ARM	15	N
13	Lough Neagh satellite lakes (undesignated)			15	N
13	Lough Mourne	J413927	ANT	15	N

APPENDIX 4 (Continued)

Rank	Name	Grid reference	County	Total score	Designated or high quality
13	Lough More	H595482	TYR	15	N
13	Lough Gall	H909514	ARM	15	N
13	Lough Enagh			15	N
13	Lough Brickland	J111411	DOW	15	N
13	Knockballymore Lakes			15	Y
13	Kilroosky Lough	H495274	FER	15	Y
13	Killtubbrid Lough			15	Y
13	Killough SPA/SAC			15	Y
13	Heron and Carigullion SPA/SAC			15	Y
13	Glynn Lagoon (A)	D406005	ANT	15	N
13	Glassdrumman Lough	H965148	ARM	15	N
13	Fymore Lough	H595519	TYR	15	Y
13	Drumnavaddy Lake	J135502	DOW	15	N
13	Drummiller Lough	J075461	ARM	15	N
13	Drumman Beg Lough	H895479	ARM	15	N
13	Drumaran Lake	J079471	DOW	15	N
13	Downhill Forest	C759350	LON	15	N
13	Cullentra Lough	H476475	TYR	15	N
13	Crossbane Lough	H809299	ARM	15	N
13	Creightons Green Reservoir	J429785	DOW	15	N
13	Creevy Lough	J397565	DOW	15	N
13	Craigmacagan Lough	D154497	ANT	15	N
13	Corbet Lough	J181449	DOW	15	N
13	Castle Dillon Lake	H904480	ARM	15	N
13	Black Rock Reservoir	J160911	ANT	15	N
13	Begny Lake	J306497	DOW	15	N
13	Ballyward Lake	J270377	DOW	15	N
13	Ballysaggart Lough	H793614	TYR	15	N
13	Ballymacashen Lough	J472596	DOW	15	N
13	Altnadua Lake	J313349	DOW	15	N
13	Baronscourt Lakes			12	N
14	Roughan Lough	H828687	TYR	10	Y
14	Race Course Lough	H241450	FER	10	N
14	Parkhill Lough	H226625	FER	10	N
14	Parabaun Lough	H059572	FER	10	Y
14	Lough Galliagh	H224445	FER	10	N
14	Lenaghan Lough	H198449	FER	10	N
14	Derryleckagh Lake	J129257	DOW	10	N
14	Derrycloony	H585508	TYR	10	Y
14	Clonalig Lough	H900122	ARM	10	Y
14	Clandeboye Lake	J483794	DOW	10	N
14	Black Lough	H711538	TYR	10	Y
15	Upperlands D; New Dam	C873048	LON	5	N
15	Upper Lake	J402432	DOW	5	N
15	Unshinagh Lough	H552331	FER	5	Y
15	Un-named (Tullynagee)	J472635	DOW	5	N

APPENDIX 4 (Continued)

Rank	Name	Grid reference	County	Total score	Designated or high quality
15	Un-named	H763566	TYR	5	N
15	Tynan Abbey Lake	H757418	ARM	5	N
15	Tullyveery Lough	J498551	DOW	5	N
15	Tullynagee Lough	J473639	DOW	5	N
15	Ravarnet catchment			5	N
15	St. Peters Lough	H877194	ARM	5	N
15	Sheetrim Lough	H907194	ARM	5	N
15	Shaws Lake	H974339	ARM	5	N
15	Shane's Lough	J507523	DOW	5	N
15	Pollramer Lough	J403495	DOW	5	N
15	Mullycar Lough	H744569	TYR	5	N
15	Mullan Lough	H763406	ARM	5	N
15	Mullaghmore Lough	H998379	ARM	5	N
15	Moyrourkan Lough (A)	H981424	ARM	5	N
15	Mount Stewart	J552700	DOW	5	N
15	Mossley Dam	J322849	ANT	5	N
15	Milltown Lough	J133235	DOW	5	N
15	Mill Pond	J128212	DOW	5	N
15	McAuley's Lake	J365481	DOW	5	N
15	Marlacoo Lake	H984448	ARM	5	N
15	Main Lake Castle Espie	J491672	DOW	5	N
15	Magherascouse Lough	J442641	DOW	5	N
15	Magherahamlet	J345478	DOW	5	N
15	Magheracranmoney	J475508	DOW	5	N
15	Lowry's Lough	H912447	ARM	5	N
15	Lower Lake Seaforde	J404429	DOW	5	N
15	Lough Ross	H885155	ARM	5	N
15	Lough Mann	J415499	DOW	5	N
15	Lough Foyle catchment			5	N
15	Lough Erne	J323567	DOW	5	N
15	Lough Doo	J611559	DOW	5	N
15	Lough Alina	H884183	ARM	5	N
15	Lisleitrim Lough	H898205	ARM	5	N
15	Lisbane Lough	J378589	DOW	5	N
15	Limestone Lake Castle Espie	J494672	DOW	5	N
15	Legmore Quarry	J135611	DOW	5	N
15	Legalough	H088346	FER	5	N
15	Largy Lough	H299469	FER	5	N
15	Knockballymore B	H479269	FER	5	N
15	Kiltybane Lough	H897197	ARM	5	N
15	Killyvilly Lough	H551334	FER	5	N
15	Killymaddy Lough	H782621	TYR	5	N
15	Killen Lough	H322751	TYR	5	N
15	Killelagh Lough	C834026	LON	5	N
15	Kernan Lake	J087469	ARM	5	N
15	Kathleen's Lough	C931121	LON	5	N

APPENDIX 4 (Continued)

Rank	Name	Grid reference	County	Total score	Designated or high quality
15	Jericho Lough	J488549	DOW	5	N
15	Islandhill Lough	H542307	FER	5	N
15	Inver Lough	H520312	FER	5	N
15	Hollywood Lower Reservoir	J410779	DOW	5	N
15	Heron Lough	J410502	DOW	5	N
15	Hanslough and Doogary Loughs			5	N
15	Grove Hill	H939931	LON	5	N
15	Greer's Lough	J388549	DOW	5	N
15	Glenkeen Bridge Quarry	C823174	LON	5	N
15	Glencordial Reservior	H482754	TYR	5	N
15	Glastry Pit	J635631	DOW	5	N
15	Gibsons Lough	H984352	ARM	5	N
15	Gentle Owen's Lake	H839300	ARM	5	N
15	Fireagh Lough	H430696	TYR	5	N
15	Far Lough	H815664	TYR	5	N
15	Eskragh Lough	H772618	TYR	5	N
15	Enagh Lough	J028319	ARM	5	N
15	Edenderry Lough	H826505	ARM	5	N
15	Dunbeg Lake	J333493	DOW	5	N
15	Dunalis Reservoir	C805305	LON	5	N
15	Dummys Lough	H488275	FER	5	N
15	Dumb Lough	J355573	DOW	5	N
15	Drumyarkin Lough	H528331	FER	5	N
15	Drumquin Lough	H327749	TYR	5	N
15	Drummuckavall Lough	H923128	ARM	5	N
15	Drumman More Lough	H894474	ARM	5	N
15	Drumlougher Lough	H895187	ARM	5	N
15	Drumcor Lough	H395495	FER	5	N
15	Drumboy Lough	H907113	ARM	5	N
15	Dorisland Reservoir	J385880	ANT	5	N
15	Donard View	J486538	DOW	5	N
15	Derrylard Quarry	H958615	ARM	5	N
15	Derryboy Lough	J472563	DOW	5	N
15	Dairy Lough	J370554	DOW	5	N
15	Cullyhanna Lough	H915198	ARM	5	N
15	Crossdall Lough	H764352	ARM	5	N
15	Cromaghy Lough	H513308	FER	5	N
15	Crawford's Lough	H552330	FER	5	N
15	Cornahove Lough	H883142	ARM	5	N
15	Corliss Lough	H886176	ARM	5	N
15	Cluntagh Lough	J297539	DOW	5	N
15	Clontanagullion Lough	J322511	DOW	5	N
15	Cloghcor Lough	H530487	TYR	5	N
15	Claraghmore B	H356761	TYR	5	N
15	Claraghmore A	H355760	TYR	5	N
15	Castlederg (Quarry)	H330959	TYR	5	N

APPENDIX 4 (Continued)

Rank	Name	Grid reference	County	Total score	Designated or high quality
15	Carnagh Lake	H827291	ARM	5	N
15	Cappagh Lough	H910129	ARM	5	N
15	Cam Lough	H553307	FER	5	N
15	Caledon Estate	H757447	TYR	5	N
15	Brown Hill (Quarry)	H819735	TYR	5	N
15	Barrack Hill Quarry	J094484	DOW	5	N
15	Ballywillin Lough	J481532	DOW	5	N
15	Ballywillin F	J487543	DOW	5	N
15	Ballyvarnet Reservoir	J476781	DOW	5	N
15	Ballysallagh Lower Reservoir	J453783	DOW	5	N
15	Ballynakilly Claypit	H853643	TYR	5	N
15	Ballymuckleheaney A	H865875	LON	5	N
15	Ballymartin Lough	J495632	DOW	5	N
15	Ballymacromwell Lough	J522569	DOW	5	N
15	Ballylough	J363377	DOW	5	N
15	Ballylane Lough Reservoir	H964347	ARM	5	N
15	Ballykine Lough (B)	J356537	DOW	5	N
15	Ballykine Lough (A)	J355540	DOW	5	N
15	Ballyfinragh Lough	J618548	DOW	5	N
15	Ballydugan Lough	J458426	DOW	5	N
15	Ballydoolagh Lough	H285481	FER	5	N
15	Ballyalloly Lough	J434681	DOW	5	N
15	Ballintaggart Quarry	H975521	ARM	5	N
15	Annashanco and Lyons Loughs			5	N
15	Annagh Lough	H505504	TYR	5	N

APPENDIX 5

Potential impact of zebra mussels on features and species selected for conservation designation

Although some zebra mussel impacts consistently occur in lakes, they may differ in magnitude between individual waterbodies. Impacts can be direct, such as increasing water clarity as a result of filtering activity; some can be indirect, such as impacts on fish populations through alterations of the food web. Zebra mussels may also provide a novel food source for some bird species. It is difficult to predict accurately what will happen to any particular species or habitat after the establishment of zebra mussels.

Feature / Species	Potential impact
UK PRIORITY HABITAT	
Mesotropic lakes	Zebra mussels have consistently increased water clarity, decreased abundance of phytoplankton and increased macrophyte growth in all Irish lakes after becoming established. They may potentially alter nutrient cycling by decreasing the particulate phosphorus concentrations and increasing concentrations of soluble phosphorus and soluble silica. They may also alter the food web resulting in changes in abundance and species composition of zooplankton, benthic invertebrate and fish populations.
Eutrophic standing waters	As above
Natural eutrophic lakes (Magnapotamion and Hydrochariton type Vegetation)	As above
Oligotrophic to mesotrophic standing waters (vegetation of the Littorelletea uniflorae and / or Isoeto-Nanojuncetea)	Oligotrophic lakes may not support a large population of zebra mussel due to food limitation. Potential impacts are as above
Hard oligo-mesotrophic waters (benthic vegetation of stoneworts, Chara species)	As above
UK PRIORITY SPECIES	
Pollan (*Corregonus autumnalis*)	Colonisation of spawning grounds and reduction of the zooplankton resource may impact on pollan recruitment
Macrophytes (pondweed *Potamogeton perfoliatus*, and shoreweed *Littorella uniflora*)	An increase in water clarity may lead to increased growth of these species

APPENDIX 6

General protocol for responding to a report of zebra mussel spread

1. Confirmation of a reported zebra mussel sighting should be made as soon as practicable

2. An assessment of the scale of the invasion in terms of zebra mussel density, distribution, size class and presence of veligers should be made within a week of confirmation of the sighting.

3. Once the scale of the invasion is known, it must be decided if it is feasible to attempt eradication.

4. It may be feasible to attempt eradication if no veligers are found in the water, it is not the spawning season (May to September) and the zebra mussels are clumped in an area where physical removal using divers or dredging would realistically be achievable.

5. Appropriate government agencies and stakeholder groups must then be informed as to the action that will be taken.

Our aim is to protect and conserve the natural and built environment and to promote its appreciation for the benefit of present and future generations.

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