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Research Article

IRELAND: A NEW FRONTIER FOR THE ZEBRA MUSSEL *DREISSENA POLYMORPHA* (PALLAS)

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Abstract

Zebra mussels are thought to have colonised Ireland about 1993/4 arriving as fouling on the hulls of leisure craft from Britain. The species has spread to at least 57 Irish lakes, either with fouled craft using the inland navigation or with overland movements of craft on trailers or by other means. Zebra mussels have changed the trophic structure of lakes and there have been impacts on some recreational activities and water abstraction. The species may be expected to spread to other Irish lakes. Small craft are recognised as an important vector and further imports of craft to Ireland may result in the introduction of further non-native species.

INTRODUCTION

The zebra mussel *Dreissena polymorpha* is an invasive species that attains 35mm+ in length. It has a high growth rate and produces great numbers of larvae. Densities of >100,000 m^{-2} and a biomass of >5kg m^{-2} are possible

(Minchin *et al*. 2002). The species can cause extensive fouling to solid substrata resulting in blockages to abstraction piping and tainting of municipal water and can smother unionid bivalves (Minchin and Moriarty 2002). As filter feeders they can reduce the abundance of plankton, cause enrichment to the benthos and result in an increase of water transparency. The impacts are sufficiently profound that the species has been described as an ecosystem engineer (Karatayev *et al.* 2002).

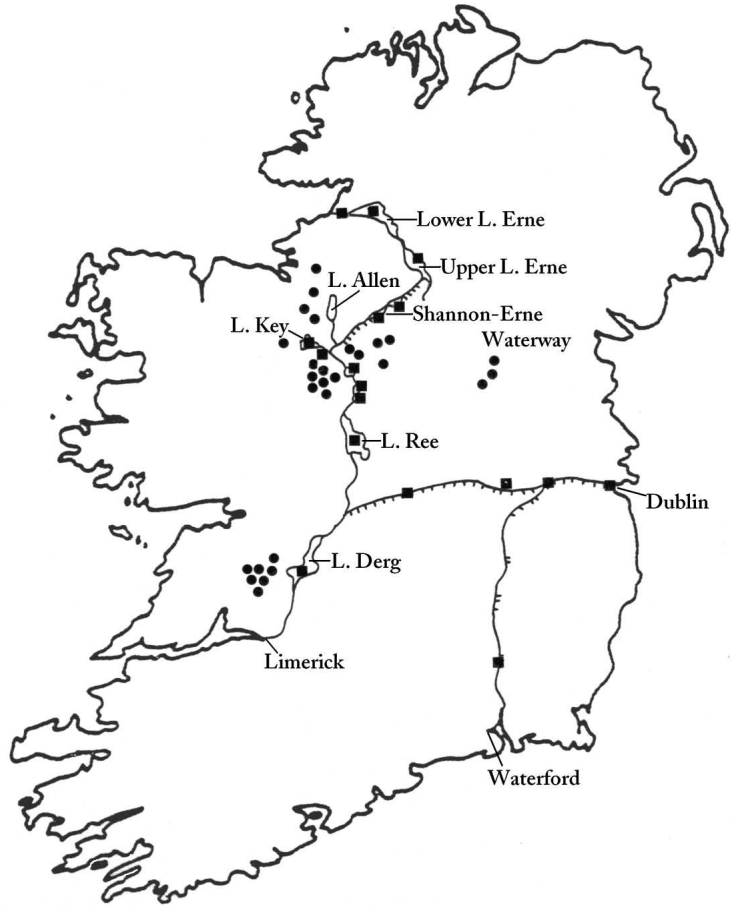

Fig. 1. Loughs (L.) with zebra mussel populations in Ireland. The inland waterways are shown. Squares indicate loughs with populations on the interconnected waterway, dots indicate loughs with populations not connected to the waterways.

The zebra mussel is native to the larger rivers draining to the Caspian and Black seas. They formerly existed in the Sea of Azov, before it became too saline as a result of excessive irrigation. In the late 1700's following the building of canals that linked different river basins the zebra mussel spread to the Curonian Lagoon in the Baltic Sea (Olenin *et al.* 1999). Their early spread to northern European ports was most probably with exports of damp timber. The timber was held in rafts in-water before being loaded as cargo. At this time timber was not de-barked and sawn prior to export as is the practice today. Zebra mussels had appeared in the Thames River, Britain, by 1824 (Kerney and Morton 1970) and to some other northern European ports by 1826 (Kinzelbach 1992). The spread of zebra mussels to Ireland took place about 170 years later and most probably took place following imports of used craft from Britain (Pollux *et al.* 2003). In Europe the zebra mussel continues to expand with recent range extensions in Italy (Occhipinti Ambrogi 2002), Spain (A. Palau pers. comm.) and the Gulf of Finland (Orlova and Panov 2004). We summarise here the zebra mussel arrival, expansion, impact and management in Ireland.

Arrival and expansion

The first record for the zebra mussel in Ireland was from the River Shannon. This followed a mortality of tank reared salmon in the spring of 1997 (McCarthy *et al.* 1998). This fish culture station lies at the downstream end of a reservoir dam that diverts water through a headrace to a hydroelectric station (Figure 1). Pipes, supplying water by gravity feed to the fish tanks, became blocked with detaching zebra mussel druses. In the dock basin or the port of Limerick (5km downstream of the hydroelectric station) accounts of mussels were reported by harbour staff from the dry-dock area in 1995. Upstream at the hydroelectric station sluices raised in the spring of 1997 showed evidence of a 1995 settlement. This would indicate an earlier colonisation within the upstream reservoir that supplies the hydroelectric station with water and from the closely connected lake, Lough Derg. As far as it can be deduced colonization may have taken place in 1993 or 1994 (Minchin & Moriarty, 1998). There were two plausible explanations as to how zebra mussels could have become established in Ireland. Either with ships' discharged ballast water containing larval zebra mussels to the confined dock area of Limerick or with imports of used leisure craft. The port of Limerick trades with several North European estuarine and freshwater ports where zebra mussels already exist, including some Baltic Sea ports, and so there is a possibility of larvae being transferred. However, imports of leisure craft from Britain and continental Europe have been responsible for much of the expansion of the boating leisure industry in Ireland and some or these on arrival were found with living zebra mussels attached to their hulls.

These observations and genetic similarities with the population in the midlands of Britain indicate that this is the most likely source and means of arrival (Pollox *et al.* 2003).

Zebra mussels rapidly colonised the small to large interconnected lakes on the inland waterways with upstream movements of leisure craft (Minchin *et al.* 2002). Vessels of up to *ca* 30m overall length can use the waterway from Limerick and can enter the Erne Navigation *via* a canal re-opened in 1994, the Shannon-Erne Waterway. There are also connections to Dublin and Waterford by canals and rivers (Figure 1). Much of the zebra mussel spread is thought to have taken place in 1996. Local populations developed in marina regions and where there were public quays followed by an expansion to most lake-regions in 1998/99. Some have not become colonised, such as Lough Allen, in the upper Shannon Navigation, due to a low pH and low total hardness, these are conditions unsuitable for larvae and settled stages. Several million zebra mussels may attach to a barge; and private cruisers or their dinghies may become fouled with thousands of individuals (Minchin *et al.* 2003). Barges are known to have entered the Erne Navigation from the Shannon passing through the linking canal in 1996 and so may have been responsible for creating a founder population in the Erne in that year (Rosell *et al.* 1999). In Ireland the main period of boat usage coincides with the spawning period for zebra mussels, which takes place throughout the summer and so populations could have evolved from spawning events (Minchin and Gollasch 2003). On occasions during rallies take place, these are occasions when large number of boats socially gather in one region. Should spawning take place from several vessels, a powerful inoculum is possible. Zebra mussels could also have formed new populations as a result of druses being dislodged from hulls or arising from those surviving mussels following the end-of-season (in the autumn) cleaning of hulls after being brushed or dumped back into the water.

The transmission of zebra mussels took place from 1998 or earlier with overland transmission of small craft to lakes not connected to the inland navigation. The craft responsible are narrow open boats that are ~6m in length and used for angling, some of these have been found with thousands of attaching zebra mussels. On two occasions, angling boats being moved overland on trailers, were found with more than 10,000 individuals. These boats are regularly moved between lakes in accordance with fly hatches, times when fly-fishing for brown trout *Salmo trutta* is often successful. By August 2004 fifty-seven lakes out of a total of 178 lakes studied had been colonised by zebra mussels. Some of the infested lakes have no facilities to launch a boat or any possible access for an angling boat. In these cases some other means of transmission will have taken place. Some lakes may have been deliberately

infested in the mistaken belief that the presence of zebra mussels improves water quality through increases of water clarity. This may have been encouraged because lakes that had been infested at an earlier time have clearer water and resulted in alleged improvements to brown trout fishing. Other modes of transmission may occur such as the movement of commercial fishing and/or angling gear between lakes and with larvae carried downstream with water movements (Horvath *et al.* 1996).

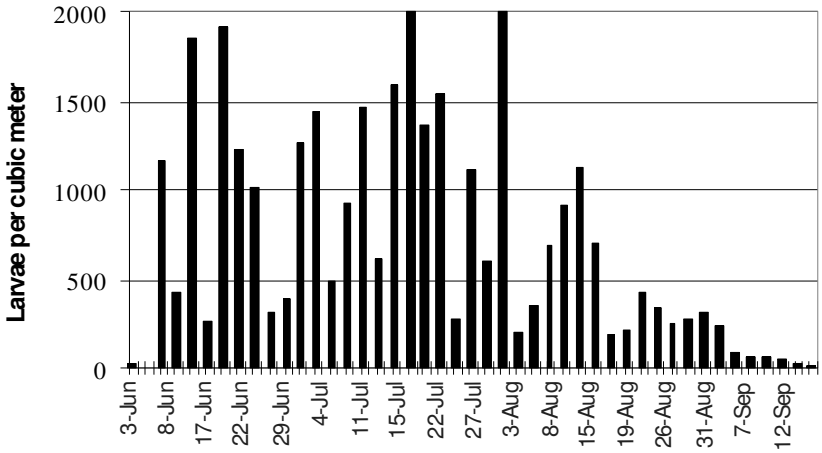

Fig. 2. Estimated numbers of larvae collected in vertical plankton tows during an expansive phase of a zebra mussel population in Lough Ree, 1999.

Biological observations on the zebra mussel

Larval stages

In Ireland water temperatures of 15°C are required before larvae appear in substantial numbers. This is known to take place in May in some shallow bays in Upper Lough Erne and in Lough Key; but larvae are usually present in lakes in June and attain their greatest abundance during June to August (Lucy 2005). Larvae remain in the plankton for two to three weeks (Lucy and Sullivan 2001). Zebra mussel larvae become carried downstream with river flows or transmitted to different lake regions following different combinations of wind strength and direction. Their distribution in the plankton can greatly vary at one site due to wind induced current movements redistributing larvae (Lewandowski 1982). In one lake study, Lough Key, the distribution of larvae varied by up to x700. Larval densities in rivers downstream from lakes appeared to be much lower. In a shallow partly enclosed bay on Lough Ree, larvae were present from June to

the end of September, the extent of the study period (Figure 2). Larvae settled at 210um to 230um but on windy days post-larval stages of up to 540um were recovered in vertical plankton tows; these were most probably dislodged by wave action from sites where previously they had settled. Settlement on horizontal collector plates attained 0.6 x 10^6 m^{-2} individuals in July of 1999 in this same bay and occurred at the time of peak expansion of the zebra mussel population. However, mortality during and after settlement is very high and estimated to exceed 90% (Nichols 1996).

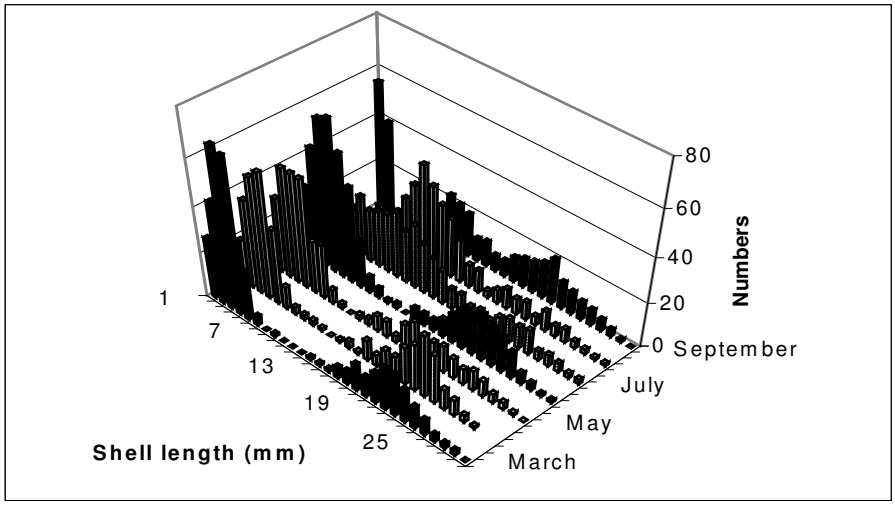

Fig. 3. Monthly size distributions of settled zebra mussels, Lough Derg, 1999.

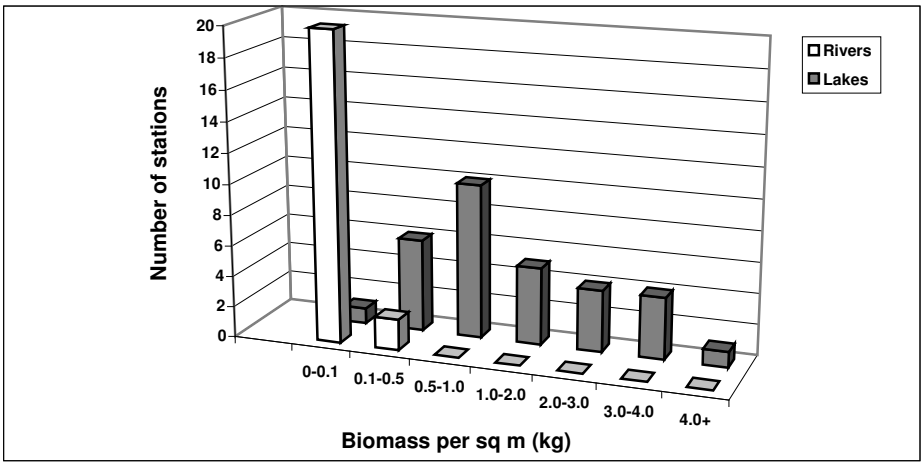

Fig. 4. Biomass of zebra mussels for all lake and river stations on the Shannon, 2000.

Attached stages

Temperatures within Irish lakes generally range from 3° to 23°C and occur within the acceptable range for zebra mussel survival and reproduction. The large limestone expanse in the Irish midlands area will mean that many Irish lakes are suitable for colonisation. Those lakes in metamorphic and igneous regions of the north-west, west, south-west, and parts of the east coast are unlikely to be colonised due to low calcium levels and lower pH values. The majority of lakes lie mainly within a swathe of drumlins, formed during the last glacial period in the north midland region. These lake regions support an important local angling industry, here visitors fish mainly cyprinids (Cyprinidae: rudd *Scardinius erythrophthalmus,* roach *Rutilus rutilus* and bream *Abramis brama),* eels *Anguilla anguilla* and pike *Esox lucius*.

The largest zebra mussels obtained were 36-40 mm shell length, in areas where, and at times when zebra mussel densities were low. Zebra mussel collections were usually made up of specimens that attained 12-28mm shell length and often exhibited two size frequency modes (Figure 3). Some river regions, such as the area between Upper and Lower Lough Erne, had zebra mussel populations that seldom attained 15mm with a single size frequency mode. The biomass and abundance of zebra mussels varied greatly between stations within a lake, but biomass was greater within lakes when compared with rivers (Figure 4). The biomass at any one lake site varied each year; but most lakes had regions within them where the biomass exceeded 3 kg m^{-2} within 3 to 5 years of initial colonisation (Figure 5). The greatest biomass recorded was 7kg m^{-2} in Lough Erne. In rivers, where there was a moderate flow, densities never exceeded 0.5kg m^{-2}.

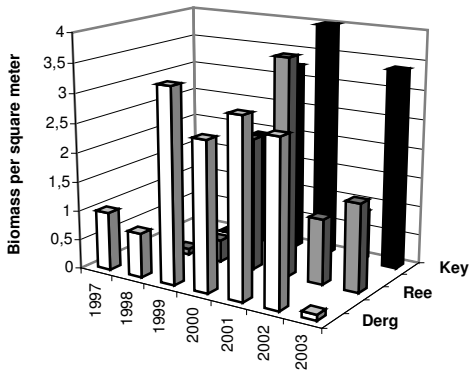

Fig. 5. Biomass (kg) of zebra mussels at selected stations at three Irish loughs on the Shannon River.

Impacts of zebra mussels

Ecological impacts

Zebra mussels foul most hard surfaces and have been found close to the surface to depths of 17^{+}m. In rocky areas, bedrock, boulders and gravels there all provided suitable surfaces for attachment. Over muddy substrates zebra mussels attached to subsurface stems, leaves and exposed rhizomes of aquatic plants. The most important plant substrates are the common reed *Phragmites australis,* the common club rush *Schoenoplectus lacustris* and the water lily *Nuphar lutea,* which commonly occur in lake shallows (Sullivan *et al.* 2002). Several other plants were used for attachment including exposed tree roots and the detached pondweed *Lemna trisulcata*. Where the abundant unionids *Anodonta anatina* and *Anodonta cygnea* occurred on soft sediments the zebra mussel attached to the exposed part of their shell and caused them to expire. They then attached to their vacant shells. These shells soon became unavailable for attachment as the gradual accumulations of sediments covered over them. Unionid populations have notably declined in most infested lakes and are are not known to exist in loughs Derg, Ree and Key. Zebra mussels were also found to attach shells of gastropods *Lymnea* spp. and *Viviparus viviparus*.

Zebra mussels are sufficiently abundant to turnover the water by filtration about every ten days in one lake studied, Lough Key. This activity reduces the amount of plankton and is probably responsible for increases to water clarity. It is presently unclear what impacts this will have on the development and behaviour of fish species present. The increased light penetration, enables rooting macrophytes to colonise deeper water, and such effects appear to be taking place in shallow bays. The feces and pseudofeces produced by the zebra mussels creates an energy-rich resource currently exploited by amphipods and other macro-invertebrates. The Ponto-Caspian amphipod *Chelicorophium curvispinum* has recently become associated with some zebra mussel habitats, since its first known occurrence in June 2000 (Lucy *et al*. 2004).

Impacts to humans

At most lake bathing areas, zebra mussels cause of foot lacerations. These cuts may lead to infections especially when bathing areas are situated close to marinas, where there can be discharges of human and/or animal wastes.

Angling tourism is important to the north midlands of Ireland; here concerns have been raised by some cyprinid anglers about impacts of zebra mussels on fishing gear. Monofilament fishing lines are frequently cut resulting in lost baits. It is the practice to hold captured fish within barrel shaped keep nets until the day's angling is finished when they are returned to the water. These keep

nets can be damaged by rubbing on sharp zebra mussel shells on the lakeshore bed. The principal impacts are summarised in Table 1.

Table 1

Impacts as a result of the presence of zebra mussels in Ireland.

	Nature of impact	Degree of impact
Pipe blockages	Reduced flow to water abstraction	Private supplies and one municipal supply affected
	Tainting of water	May not be related to zebra mussels
	Boat engine overheating	Six marine engines required replacement in 1997-8
	Cultured fish mortality	A single event
Fouling of surfaces	Reduction of boat speed	Affecting many boots remaining in water over-winter
	Sinking of moorings	Moorings became submerged in two lake regions
	More frequent cleaning	Affecting most craft
	Greater use of antifoulants	Increased coverage of antifoulants on cruisers and yachts
	Fouled culverts reducing lock turnover efficiency	No serious impacts noted
	Unpleasant smells with drop of water level	Occurring on Lough Ree during summer droughts
Environmental changes	Reduction of chlorophyll and water clearances	Noted in most large lakes
	Declines/extinction of union bivalves	Notable declines, none seen in some lakes for four years
	Fouling of snails	Some impacts in lakes
	Fouling of aquatic plants	Extensive fouling in most infested lakes
	Apparent increases of rooted macrophytes	Some shallow harbours appear to have more plant growth
	Alteration to substrate	Increased hard surface areas
	Changes to species abundance	Opportunities for amphipoda and other seston feeders
	Appearance of blue-green algal blooms	May not be related to zebra mussels
Human impacts	Laceration of bathers feet	Frequent within bathing groups
	Damage to fishing nets and lines	A reason for decline in angling tourism
	Increased labour in eel fishery	Nuisance in Lough Erne eel fishery
	Interference from aquatic plant growth	Unclear whether this affects fishing activity
	Smells affecting: environmental quality	Drops in water levels result in decaying zebra mussels

Private water supplies from lakes have been affected from pipe blockages and there are concerns that this may also become a problem for municipal water supplies (Minchin and Moriarty 2002). Abstraction of any water for industrial use can also be compromised in the same way. Abstracted water can also become tainted following the demise of mussels fouling intake pipes.

Fouling of boat hulls has led to a more frequent winter servicing with removal from the water for hull cleaning. This is because the fouling reduces boat speed leading to a greater use of fuel. Mussels can also cause blockages to cooling intakes leading to engine failure. Further fouled instruments projecting from the hull will not function.

Management of zebra mussels

Zebra mussels were present in Ireland for about four years before their discovery. This provided sufficient time for a locally dense population to evolve, and enabled sufficient fouling on boats to create upstream populations when they cruised on the waterway during the summer. There is evidence that this took place in 1996. As the main period of boat activity coincided with the spawning period it was inevitable that the species rapidly became established on the navigation. The spread by angling boats may, in some cases, have also

commenced from1996 but certainly did so from 1998 onwards. The expansion to previously uncolonised lakes makes management difficult as there are approximately 3,500 lakes in Ireland. Several of these lakes could form hubs from which further expansions become possible.

The initial management approach included the involvement of stakeholders, production of leaflets and television coverage. This did much for a general awareness as to how zebra mussels were spread and what impacts could be expected. The aim was to share the responsibility of management with affected stakeholders. Although this appeared to be initially successful, the level of interest subsequently declined. Present management involves regional awareness campaigns mainly directed at anglers, so as to prevent introductions to specific angling lakes.

Clearly the best prevention would have been to ensure that all imported craft were cleaned prior to their arrival in Ireland by trailer and ferry. Should an inoculum be discovered in a lake soon after arrival, removing all recoverable individuals could be used as a control strategy. This would reduce the reproductive output making it less likely that establishment would take place. One small lake in Ireland was managed in this way. Although, regular monitoring of important lakes would almost certainly have provided information early enough to have aided reduction in the spread rate, it is considered that risk analysis would have been the most effective means of preventing entry, provided that the correct vectors were identified. It is only recently that this management approach is gaining general acceptance for aquatic species.

Zebra mussels will continue to spread in Ireland. Knowledge of both their ecology and of water chemistry characteristics in lakes and rivers where abstraction takes place will provide practical information to mitigate effects once zebra mussels arrive.

The main issue for management is that a potent vector has been identified. Other species may arrive in the same way and some associates of zebra mussels may also have also arrived with imported boats. Leisure craft continue to be imported and other invasive species already spreading in Europe could arrive in Ireland using this route. New arrivals have implications for managing water quality under the European Union Water Framework Directive.

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