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Frances E. Lucy and Thaddeus K. Graczyk (Guest Editors)

Research Article

From lakes to rivers: downstream larval distribution of *Dreissena polymorpha* in Irish river basins♣

Frances E Lucy[1,2,3]*, Dan Minchin[4] and Rick Boelens[5]

[1]*Department of Environmental Science, School of Science, Institute of Technology, Sligo, Ireland*
[2]*Centre for Biomolecular Environmental Public Health Research, School of Science, Institute of Technology, Sligo, Ireland*
[3]*Environmental Services Ireland, Lough Allen, Carrick on Shannon, Co. Leitrim, Ireland*
[4]*Marine Organism Investigations, Caragh, Marina Village, Ballina, Co. Clare, Ireland*
[5]*Lough Derg Science Group, Castlelough, Portroe, Nenagh, Co. Tipperary, Ireland*

**Corresponding author*
E-mail: lucy.frances@itsligo.ie

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Abstract

Three different river sizes were examined at various distances downstream of Irish lakes containing zebra mussel populations. The larger rivers contained zebra mussel larvae and adults at a wide range of densities throughout their length. However, smaller rivers demonstrated a rapid decline of larvae and adults with progression downstream. River sections downstream of interconnected lakes were also examined as part of this study. The fate of the zebra mussel larvae in medium and small rivers remains unknown.

Key words: *Dreissena polymorpha*, zebra mussel, Ireland, larvae, river

Introduction

The majority of studies on *Dreissena polymorpha* (Pallas) have been carried out in lakes and reservoirs (Bij de Vaate 1991; Stańczykowska and Lewandowski 1993; Karatayev et al. 1997; Garton and Johnson 2000; Nalepa et al. 2001; Lucy et al 2005) and some have involved large rivers and canals (Kern et al. 1994; Martel 1995; Allen et al. 1999; Jack and Thorp 2000; Stoeckel et al. 2004; Schloesser et al. 2006). Few investigations have taken place in small rivers or streams (Horvath et al. 1996; Horvath and Lamberti 1999a; Bobeldyk et al 2005).

Zebra mussels in rivers can originate from upstream lakes (Stoeckel et al. 1997, 2004; Horvath et al 1996; Horvath and Lamberti 1999a) or may be produced from river populations as in the case of the Rhine (Kern et al. 1994). The flow of the river can modify some environmental factors, which may influence zebra mussel populations, for example planktonic food supply, suspended solids and water temperatures (reviewed in Karatayev et al. 1998). The lotic conditions within a river system may have an impact on larval survival and recruitment, as some zebra mussels may become purged from rivers before they reach the stage of settlement (Kern et al. 1994; Stoeckel et al. 1997).

Rivers in Ireland are considerably smaller than most of those found on continents, and many are third order streams. The Shannon is the largest river having a 254km navigation, connected by a canal to the Erne system at the northern end of its catchment. Close to the Shannon estuary, at its southern end, is a hydroelectric scheme with a

♣ This paper was presented at the special session "Dreissenology" of the 15th International Conference on Aquatic Invasive Species – ICAIS 2007, September 23-27, 2007, Nijmegen headrace that diverts water away from the lower section of the Shannon River thus reducing its flow. Many Irish river catchments include lakes with interconnecting stretches of river.

The zebra mussel is thought to have arrived in Lough Derg, on the Shannon system between 1993 and 1994 (Minchin and Moriarty 1998; Minchin et al 2002a). By 1996 zebra mussels had spread upstream to the Erne (Rosell et al. 1999) and Lough Key (Lucy et al. 2005). Zebra mussels continue to expand their range in Ireland with cruising craft on the inland waterways; by overland transport of angling boats to smaller catchments including the Rine River (Minchin 2003; Minchin et al 2006) and by other means. Once established in an uninfested lake zebra mussels can alter communities in downstream environments. Although several surveys of adult populations have been carried out at various sites on the Shannon and Erne Rivers (Minchin et al. 2002b, 2003, 2005; Rosell et al. 1999; Maguire 2002), there have been no investigations into the distribution of larvae downstream of colonised lakes. The present investigation examines the relative risk of downstream transport of larvae in rivers of different size.

Methods

Sampling stations

Forty-one river stations downstream of lakes, with known zebra mussel populations, were chosen from five rivers, the Shannon, Erne, Inny, Rine and Unshin Three sections of the Shannon River were examined and four sections of the Rine River, each downstream of a lake. The Rine River connects several small lakes (Annex 1). These rivers had sections that were classed as follows: large rivers with a depth >2m and >40m wide; medium rivers with depths of 0.5-2m and variable widths from >20m and small rivers with depths ≤0.5m and ≤20m wide. Stations were selected according to ease of access, usually beside bridges (Figure 1). The longest section examined was Shannon A. - 60km of large river draining Lough Ree (105km^2) and entering Lough Derg (117km^2). From Lough Derg southwards, two sections were examined, one along the headrace to the hydroelectric dam, considered here to be a large 'river', and south to the upper estuary below the dam (Shannon B.). The second section examined was from beside the entrance to the headrace and was made-up of spilled water from a retaining dam (Shannon C.); this reduced the water flow to this part of the lower Shannon River and was considered to be a medium river. Upper Lough Erne is a slow moving river draining down to lower Lough Erne over about 20km. The Inny flows from Lough Derravaragh (11km^2) to Lough Ree over ~40km and was classed as a medium river. Both the Unshin River, which drains Lough Arrow (12.5km^2) and the Rine River were considered small rivers. The Rine River interconnects a series of small lakes (<4km^2) and sampling took place at the nearest accessible points downstream from these.

Sampling and analytical methods

Sampling took place in early August, a time when larval densities peak in some Irish lakes (Lucy 2006). One hundred and fifty litres were hand poured by bucket through a 70µm mesh plankton net. The net was rinsed using a high powered spray. The screw capped end of the net was removed and rinsed carefully into a 25ml tube and later soaked in a solution of acetic acid to dissolve any remaining larval shells.

deviations were obtained. At each site in small and medium rivers, ten stones from the riverbed were handpicked or raked to the surface and examined for the presence of zebra mussels. Zebra mussels were already known to exist at all large river stations (Minchin et al. 2005). The size distributions (shell lengths) of mussels present were measured to the nearest millimetre. The width, depth and flow of rivers were estimated at each station.

Results and discussion

The examination for larvae at each of forty-one stations, combined with searches for settled stages of the zebra mussel at each river site, provided information on the extent of downstream colonisation from upstream infested lakes (Annex 1). All rivers had suitable areas for settlement. While the five rivers had low water levels, and low flow rates at the time of the study, it is possible that downstream transport may be greater when water levels are higher. Nevertheless, larval and settled mussel numbers declined with distance from lakes, and in medium and small rivers were rarely found at distances greater than 8km downstream, in medium and small rivers.

Figure 1. From top left: River Erne; River Shannon hydroelectric dam, headrace foreground right, river background right; macrophytes on River Unshin; necklace of lakes, close to River Rine (photo by Martin O'Grady).

Large rivers showed considerable variation in the number of larvae recovered at stations, yet all stations yielded larvae from all samples taken. Each of the large rivers surveyed were known from previous investigations, to contain well established populations along their lengths, although at lower densities than were found within lakes (Minchin and Boelens, unpublished).

The greatest numbers of larvae were found in the Shannon headrace canal leading to the hydroelectric power-station. At the time of sampling, there was no perceptible water movement and larvae may have originated both from the lake upstream and/or from the resident population in the canal. In the large, slow-moving and meandering River Erne, the larval numbers were low except at the most downstream station, an area where an obvious gyre, may have concentrated the larvae. The mid-section of the Shannon River between Lough Ree and Derg (Shannon A.) also had high densities of larvae, as well as adults, at most stations (Figure 2). The width and depth of these large rivers may favour recruitment due to their relatively low flow rates, lack of turbulence and suspended solids, increased settlement and the availability of plankton as a food source (Wetzel 2001). These large river populations have more in common with the zebra mussel colonised rivers of Europe and North America, than they do with the smaller Irish systems in this study.

The rapid decline of larvae downstream from lakes in medium and small rivers is not easily explained. Some recruitment was noted in areas within 2km downstream of lakes, both in the case of the Inny River (1.6km downstream), where two year classes of settlement are evident (Figure 3) and on the Unshin River (0.4km below Lough Arrow), where a single year class was present attached to gravels. The turbulence in smaller river systems such as the Unshin, Inny

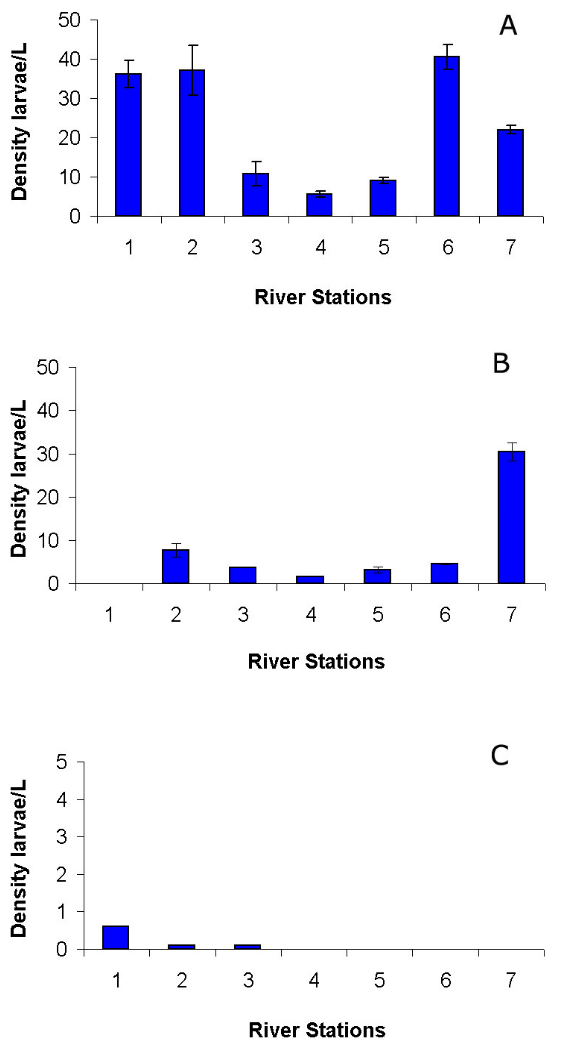

Figure 2. Zebra Mussel Larval Densities form River Stations at Shannon A (A), Erne (B) and Inny (C).

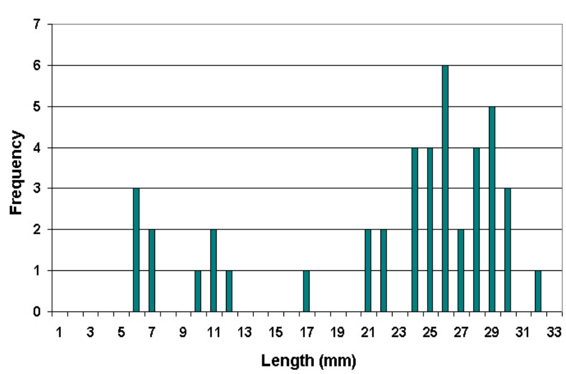

Figure 3. Adult *Dreissena* size distribution from River Inny.

and Rine may contribute to veliger mortality, as shown elsewhere in both field (Horvath and Lamberti 1999a) and laboratory studies (Rehman et al. 2003). The larger volume to surface ratios in larger rivers could also mean that there is less removal of larvae by suspension feeders. The extensive macrophyte beds in the Unshin River may result in the removal of larvae from the water column (Figure 1). Although the Inny River, a medium-sized river, is fed by a similar sized lake (Lough Derravarragh, 11km^2 vs Lough Arrow, 12.5 km^2), it is wider and deeper than the Unshin River, a small river, (Annex 1) and had fewer macrophytes present. Larvae here were present in the first three stations, up to a distance of 8km downstream of the lake outfall. Larval densities declined with progression downstream indicating that either mortality and/or settlement had taken place en route.

In the smaller rivers, the extent of vegetative cover by aquatic macrophytes was greater. Indeed in a separate study (Minchin and Boelens, unpublished) larval densities were found to be considerably less in areas of macrophyte stands in a lake. There may however, be other factors involved in reduced survival in small river/ stream systems.

In the Rine River, larvae were absent from five of the seven stations located in four sections below lakes. Larvae were only found 1.4km below the relatively small Castle Lake, yet diminishing numbers of settled stages were found up to 6km downstream, their abundance declining with distance (Annex). This indicates that at times larvae were capable of extending their range downstream and of settling. Consequently the low flow rates at the time of the investigation may have been a limitation of this study. Longer term studies would provide a fuller indication of variability in zebra mussel larvae densities and settlement (Lucy 2006).

This investigation broadly agrees with the findings of Horvath and Lamberti (1999), who concluded that small outflowing streams support only small populations of zebra mussels and for a limited distance downstream. Horvath and Lamberti (1999a) suggested streams can supply larvae to downstream ecosystems. In this study long-distance spread has only been demonstrated in the larger, slow-moving rivers. Consistent with previous research, this indicates that zebra mussel recruitment in these large rivers is principally supplied from substantial lake reservoirs (Minchin et al 2002b; Maguire 2002).

The ecological and environmental processes determining larval success in lotic systems are still not properly understood because they require combined modelling of environmental conditions, catchment hydraulics and life stages of lake veligers (as in Stoeckel et al. 2004). In Irish systems there is further variation due to the large differences in rainfall during and between summers (www.met.ie). Hydrometric conditions may be important, with large larval losses during periods of greater water flow. Larvae have been found over tidal sands purged to coastal water from below Lower Lough Erne following periods of extensive rainfall. Yet, some of the larvae in the upper tidal area of the lower region of the Shannon are likely to survive as these are not exposed to salinity changes. Adult zebra mussels were found nearby.While it has already been suggested that years of high rainfall impact on lake settlement (Lucy et al 2005), concomitant increases in water volumes, turbulence, flow-rates and suspended solids have an unknown impact on riverine recruitment.

This study supports the source-sink hypothesis where lakes supply donor populations to outflowing rivers, and where self-sustaining populations are absent rather than the downstream march theory where riverine metapopulations are self-recruiting (Horvath et al. 1996). This is particularly apparent in the case of medium and small rivers where samples showed inconsistent presence and absence of both larval and adult dreissenids throughout river stretches.

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Annex 1. Results of survey for larvae and adults of *Dreissena polymorpha* Irish River August 2006 (SD – standard deviation; D-distance down-stream).

Station	Locality	Lat/Long	Width (m)	Depth (m)	Flow (m/s)	Larvae/L	SD	Adult	D (km)
Large	**Shannon River A: Lough Ree to Lough Derg**								
1	Athlone Cruisers	53º26'N, 07º57'W	>50	>2	flow	36.2	3.5	Yes	1.2
2	Athlone Lock	53º25'N, 07º56'W	>50	>2	flow	37.1	6.3	Yes	3.1
3	Clonmacnoise Jetty	53º19'N, 07º59'W	>50	>2	flow	10.8	3.1	Yes	18.6
4	Shannon Bridge	53º16'N, 08º02'W	>50	>2	flow	5.6	0.7	Yes	26.8
5	Banagher Bridge	53º11'N, 07º59'W	>50	>2	flow	9.0	0.8	Yes	40.6
6	Meelick Lock	53º10'N, 08º04'W	>50	>2	flow	40.5	3.2	Yes	48.1
7	Portumna Bridg	53º05'N, 08º11'W	>50	>2	flow	22.0	1.1	Yes	60.8
Large	**Shannon River B: D/S Lough Derg to Tidal Stretch**								
8	Killaloe Bridge	52º48'N, 08º25'W	≥ 50	>2	0.2	51.03	3.5	Yes	1.7
9	Parteen Weir	52º45'N, 08º28"W	≥ 100	>2	still	26.33	3.2	Yes	7.7
10	Headrace, O'Briens Bridge Canal	52º45'N, 08º30'W	50	>2	slow	15.35	1.8	Yes	10.0
11	Headrace, Ardnacrusha Bridge	52º42'N, 08º35'W	50	>2	slow	47	5.0	Yes	18.8
12	Parteen (tidal)	52º42'N, 08º37'W	≥ 30	>2	variable /tidal	58	4.9	Yes	21
Large	**Erne Rive**								
13	Inishmore Viaduct	54º15'N, 07º37'W	50	>2	0.7	7.7	1.6	Yes	1.0
14	Coradilla	54º17'N, 07º36'W	60	>2	0.3	3.7	0.1	Yes	5.1
15	Cleenish	54º18'N, 07º36'W	55	>2	0.9	1.6	0.1	Yes	6.7
16	Ballinalack Marina	54º18'N, 07º38'W	60	>2	0.9	3.2	0.7	Yes	9.4
17	Killyhevlin Hotel	54º20'N, 07º37'W	50	>2	0.5	4.5	0.1	Yes	14.2
18	Enniskillen public park	54º21'N, 07º39'W	100	>2	0.3	30.5	2.1	Yes	18.4
Medium	**Inny River**								
19	Downstream (D/S) Lough Derravaragh	53º38'N, 07º24'W	18	1	0.2	0.6	0.0	Yes	0.8
20	Hospital Bank	53º39'N, 07º26'W	15	1	0.1	0.1	0.0	Yes	2.1
21	Ballinalack Bridge	53º37'N, 07º26'W	15	≥ 1	0.25	0.1	0.0	Yes	6.6
22	Ballycorkey Bridge	53º37'N, 07º31'W	12	≥ 1	0.1	0.0	0.0	None	12.5
23	Ballynacarrow Bridge	53º35'N, 07º36'W	20	1	0.2	0.0	0.0	None	22.0
24	Clynan Bridge	53º34'N, 07º40'W	40	≥ 1	0.9	0.0	0.0	None	28.7
25	Shrule Bridge	53º33'N, 07º46'W	25	1	1	0.0	0.0	None	40.0

Annex 1 (continued)

Station	Locality	Lat/Long	Width (m)	Depth (m)	Flow (m/s)	Larvae/L	SD	Adult	D (km)
Medium	**Shannon River C**								
26	Parteen Weir	52º45'N, 08º28'W	≥100	≥1	still	26.3	3.2	Yes	0.0
27	O'Briens Bridge on river	52º45'N, 08º30'W	≥100	≥1	still	31.7	0.8	Yes	2.3
28	Castle Oaks Bridge	52º42'N, 08º30'W	45-50	<0.5	0.5	0.6	0.3	None	11.3
29	Plassey Bridge	52º41'N, 08º35'W	≥40	<1	0.2	0.0	0.0	None	13.3
Small	**Unshin River**								
30	Bellarush Bridg	54º05'N, 08º21'W	8	0.05-0.2	0.6	1.9	0.1	Yes	0.4
31	Knocknaross	54º06'N, 08º22'W	6	0.05-0.6	2.4	0.0	0.0	None	4.5
32	Riverstown	54º07'N, 08º23'W	14	0.1-0.4	3.6	0.0	0.0	None	8.5
33	Coolbock Bridge	54º08'N, 08º25'W	15	0.2-0.3	3.5	0.0	0.0	None	11.1
34	Lisconny Bridge	54º09'N, 08º27'W	20	0.05-0.15	3.5	0.0	0.0	None	14.5
Small	**Rine River**								
35	Derrymore Bridge (Section 1)	52º52'N, 08º40'W	5	0.3-0.6	0.0	0.0	0.0	Yes	0.6
36	Teerovannan Bridge (Section 2)	52º50'N, 08º40'W	3.5	0.5-0.3	0.1	0.0	0.0	Yes	2.2
37	Woodfield Bridge (Section 3)	52º40'N, 08º42'W	6.5	0.5-0.6	0.3	0.0	0.0	Yes	1.2
38	Agouleen Bridge (Section 3)	52º47'N, 08º44'W	6	0.1-0.5	0.2	0.0	0.0	Yes	4.9
39	Pollagh Bridge (Section 3)	52º47'N, 08º44'W	8	0.1-1	0.2	0.0	0.0	Yes	6.4
40	Annagore Bridge (Section 4)	52º45'N, 08º46'W	8	0.2-0.4	0.5	2.9	0.4	Yes	1.4
41	Owengarney Bridge (Section 4)	52º44'N, 08º46'W	9.5	0.4-0.6	0.1	0.8	1.5	None	7.5