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Research Article

Current status of Ireland's newest invasive species – the Asian clam *Corbicula fluminea* (Müller, 1774)

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Abstract

The Asian clam *Corbicula fluminea* was first discovered in Ireland in the Rivers Barrow and Nore in 2010. Scuba diving surveys were the primary sampling method used to determine the detailed distribution of this species in the two rivers. Sustainable populations of Asian clam were present in the tidal freshwater reaches of both rivers. No clams were present upstream of the tidal limit. A maximum density of 9,636 individuals m^{-2} was recorded in the River Barrow. This paper presents some basic metrics in relation to the populations present in these two connected river systems.

Key words: Barrow, Nore, alien, non-native, introductions, Scuba diving

Introduction

The introduction and spread of aquatic invasive species (AIS) poses a serious threat to native biodiversity and ecosystem functioning, with potential repercussions for food-webs, biogeochemical cycles and human economy (Kolar and Lodge 2001; Grosholz 2002). Invasive species have been identified as one of the greatest threats to global biodiversity, second only to that caused by direct habitat destruction. The estimated annual economic impact of invasive species is considerable. For example, in the UK the annual economic cost of non-native invasive species has been calculated at £19.3 million $year^{-1}$ (but could range as high as £29.2 million $year^{-1}$), whereas animal species incur a cost of £7.2 million $year^{-1}$ (ranging up to £14.3 million $year^{-1}$) (Oreska and Aldridge 2011).

Corbicula fluminea Müller, 1774 (Figure 1) is considered to be one of the most important non-native species in freshwater ecosystems (Pimentel et al. 2005; Sousa et al. 2008), displaying considerable geographic dispersion and invasive behaviours (Mouthon 1981; Araujo et al. 1993; McMahon 1999, 2000). *Corbicula fluminea* is known to competitively impact on native macro-invertebrate communities (e.g. McMahon 1991), significantly reduce phyto-plankton biomass (Lucas et al. 2002; Lopez et al. 2006), alter benthic habitats and substrates (Hakenkamp et al. 2001) and add biologically available nitrogen and phosphorus to aquatic ecosystems (Lauritsen and Mozley 1989). The invasive success and subsequent dispersion of *C. fluminea* relies on their biological and behavioural characteristics (e.g. early sexual maturity, rapid growth, short life span, high fecundity, extensive dispersal capacities and its association with human activities) (Sousa et al. 2008).

Corbicula fluminea is generally described as a hermaphroditic species, with an average annual fecundity of >68,000 (Williams and McMahon 1989). Typically, this species reproduces twice a year, initially from spring to summer and again in the late summer to autumn period. Released juveniles (*c.* 250 µm diameter) anchor to sediments, vegetation or hard surfaces by means of a single mucilaginous byssal thread. Sexual maturation takes from 3 to 6 months, when the shell height reaches 6–10 mm (Williams and McMahon 1989; McMahon 1999). The life span of Asian clams is extremely variable but, on average, ranges from 1 to 5 years (Sousa et al. 2008).

Figure 1. Asian clam (*Corbicula fluminea*) specimens from the River Barrow, collected in May 2010 (Photograph by S. Evers).

The first documented occurrence of this genus outside its native Asiatic range was from the United States in the 1920s, with further expansion to Europe in 1980 (Mouthon 1981; McMahon 1999). Within the last year there have been a large number of new *C. fluminea* records emerging, charting the spread of this species across Europe. For example, in France this species has now spread into the Canal de la Somme and rivers Oise and Vilaine (Marescaux et al. 2010); in Spain it has invaded the Iberian Peninsula rivers - Mero, Sil and Deva (Lois 2010) and the first record for the Republic of Moldova was recently reported (Munjiu and Shubernetski 2010). The first record of *C. fluminea* in neighbouring Britain was in 1998 (Baker et al. 1999). The Asian clam is now abundant in several UK rivers (including the Thames River, with its 20 tributary rivers and interconnections to the extensive waterway network of England) (Elliott and Ermgassen 2008).

Corbicula fluminea was first discovered in Ireland in the tidal, freshwater section of the River Barrow (Co. Carlow) in April 2010 (Sweeney 2009). It was subsequently recorded from the lower tidal reaches of the connected River Nore. The aim of this paper is to describe the current known status of *C. fluminea* in these connected river systems in the south-east of Ireland and to provide some basic metrics in relation to their population. The data are not intended to be exhaustive and more detailed investigations into the biology, ecology and invasive habits of the Asian clam in Ireland are proposed.

Study area

The Rivers Barrow and its tributary, the River Nore (Figure 2), drain much of the land in the south-east of Ireland. This river system ultimately discharges to the sea at Waterford harbour. The River Barrow is the second longest river in Ireland (192 km) (after the River Shannon) and has a catchment area of approximately 2,983 km^2. The River Nore is 140 km long and joins with the River Barrow north of New Ross (Figure 2). The geology of the upper reaches of both rivers is dominated by sandstone. With progress southward, the geology changes to limestone and ultimately to one dominated by granite.

Both rivers are important recreational and conservation habitats. Being part of the navigable waterways network of Ireland, these systems are subject to regular boat traffic and significant usage by stakeholders. In 1999 both rivers were selected as Special Areas of Conservation (SAC), reflecting the wealth of protected species that they support. These include the freshwater pearl mussels

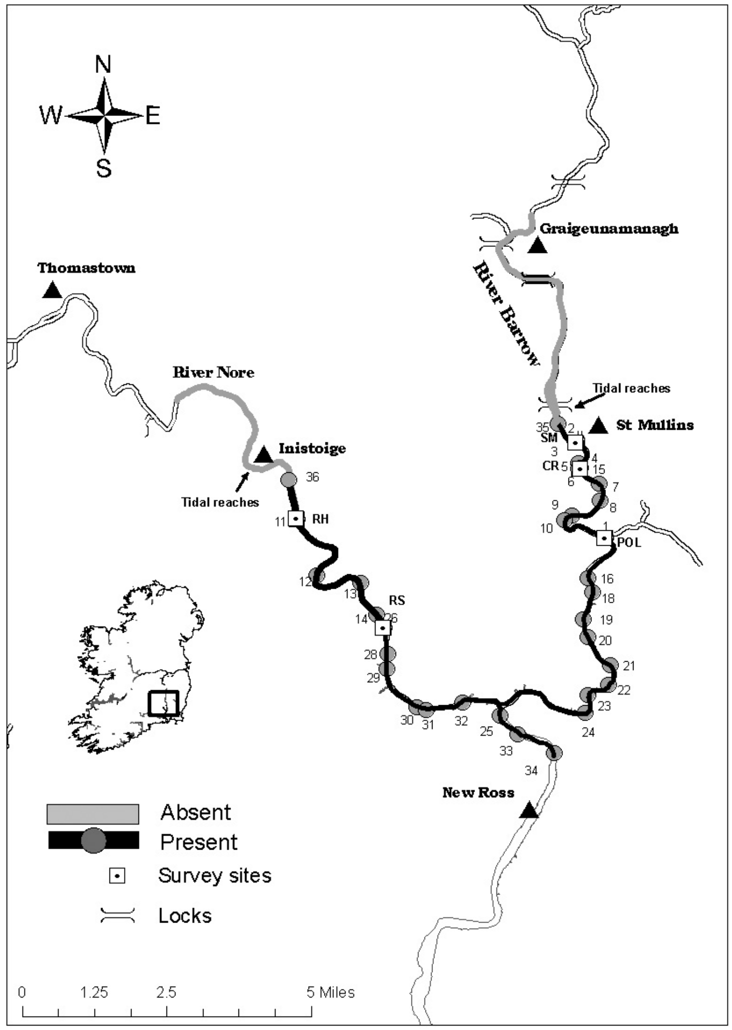

Figure 2. Distribution of *Corbicula fluminea* in the Rivers Barrow and Nore in 2010. SM = St. Mullin's; CR = Coolrainy; POL = Poulmounty; RH = Red House; and RS = Russell Sound.

[*Margaritifera margaritifera* (Linnaeus, 1758) and *Margaritifera durrovensis* (Phillips, 1928)], smelt [*Osmerus eperlanus* (Linnaeus, 1758)] and sea lamprey [*Petromyzon marinus* (Linnaeus, 1758)] in the River Nore and smelt and twaite shad [*Alosa fallax* (Lacépède, 1800)] in the River Barrow.

The River Nore is navigable by recreational cruiser traffic as far upstream as Inistioge (approximately 55 km upstream from the open ocean at Hook Head) while the River Barrow navigation is connected with the wider Irish navigation network. The River Barrow is hydro-morphologically altered, with a number of artificial channels constructed along the water-course in order to connect the waterway with the Irish navigation network. The flow is regulated by a number of weirs. The first of these weirs is located circa 1 km upstream of St. Mullin's (Figure 2). Both rivers are influenced by tidal water movements. This extends as far upstream as the first weir above St. Mullin's (52°30'7"N, 06°56'21"W) on the River Barrow and just north of Inistioge (52°29'41"N, 07°03'40"W) on the River Nore (Figure 2). In these river sections, water levels fluctuate widely (by up to 3 m in height) under the influence of daily tides. While the lower reaches of the Rivers Barrow and Nore are tidal, they are not subjected to any saline influence above the town of New Ross.

Methods

Investigations covered the river stretch from Thomastown on the River Nore and Graiguenamanagh on the River Barrow to New Ross (Figure 2). *Corbicula fluminea* specimens were observed and collected by using a variety of sampling methods. Principal among these was the use of SCUBA dive surveys. Other complementary methods included snorkeling, Berg-Ekman grab sampling, the deployment of a remotely operated vehicle (ROV) and kick sampling in shallow water. The choice of sampling method depended on water depth, water transparency and flow velocity. The river was sampled approximately every 500 m while travelling downstream by boat. Divers were generally deployed where the water was > 1 m deep. The presence or absence of live Asian clams was recorded at each location using a handheld GPS.

More intensive investigation was carried out on three sites on the River Barrow (St. Mullins – SM (20/04/10), Coolrainy – CR (13/05/10) and at the Poulmounty River confluence – POL (12/05/10)), and at two sites on the River Nore (Red House - RH (13/07/10) and Russell Sound – RS (13/07/10)), in order to determine population characteristics of *C. fluminea* at these locations (Figure 2). Dive surveys were undertaken at St. Mullin's and Coolrainy on the River Barrow where water depth ranged from between 1.5 to 4.5 m, depending on the stage of the tide. The remaining sites were sampled from the shore when low tide exposed significant gravel shoals.

At each site, replicate $0.25m^2$ quadrat samples, randomly positioned, were taken. All of the surface-dwelling clams within each quadrat were hand picked and retained in marked bags. A separate bag was used to retain all of the burrowed clams, to a depth of *circa* 15 cm. From these, the density of surface dwelling and burrowed (at the time of sampling) clams per square meter was calculated. Only clams of ≥5 mm were recorded, due to time constraints. Shell height (umbo to gape) was recorded to the nearest 0.1 mm using electronic calipers and size frequency plots were generated.

Samples for granulometric analyses were collected at one site on the River Barrow (CR) and two on the River Nore (RH and RS). The samples were collected from within the quadrats following extraction of the resident clams. Every effort was made to collect as much sediment as possible, to a depth of circa 15 cm. This material was subsequently dried at 70°C until the dry weight remained constant. The material was thoroughly mixed and a 1 kg subsample was passed through a series of sieves (ranging from 62.5 µm – 31.5 mm). Water chemistry data was provided by the Environmental Protection Agency (Lucey 2009).

Results

The first record of *Corbicula fluminea* in Ireland came from the River Barrow at St. Mullin's in April 2010 (Sweeney 2009). Subsequent sampling in April, June and July 2010 has revealed the presence of sustainable populations of the Asian clam in both the Rivers Barrow and Nore (see Appendix 1). *C. fluminea* was found at all sampling locations between St Mullin's on the River Barrow and from a point *circa* 1 km downstream of Inistioge on the River Nore, to the confluence of these two rivers. *C. fluminea* individuals were also recorded at each sampling location between the confluence and New Ross town. Intensive sampling failed to recover any Asian clam specimens above the first navigation weir north of St. Mullin's or north of Inistioge (Figure 2).

The densities of Asian clam individuals varied appreciably within and between the three sites on the River Barrow (see Appendix 1). At the farthest upstream site (SM), quadrat counts varied between 8 and 147 clams m^{-2} while at Coolrainy, *circa* 1 km downstream, the highest densities were recorded, ranging between 1,300 and a maximum figure of 9,636 clams m^{-2}. Some 5 km farther downstream, at Poulmounty (POL), the variation was less extreme and densities ranged between 732 and 1,196 clams m^{-2}.

Density values for *C. fluminea* in the River Nore were much reduced in comparison (Appendix 1). The mean number of individuals recorded ranged from 3 clams m^{-2} at RH to 320 clams m^{-2} at RS.

At all five sample sites, whether above water level or submerged, there was a considerable variation between the number of clams visible on the sediment surface and those burrowed in the sediment, by a factor of between 2.2 to 11.2. This variation in vertical distribution may be a response by clams to sampling disturbance. However, it does illustrate the need to sample at both surface and sub-surface levels.

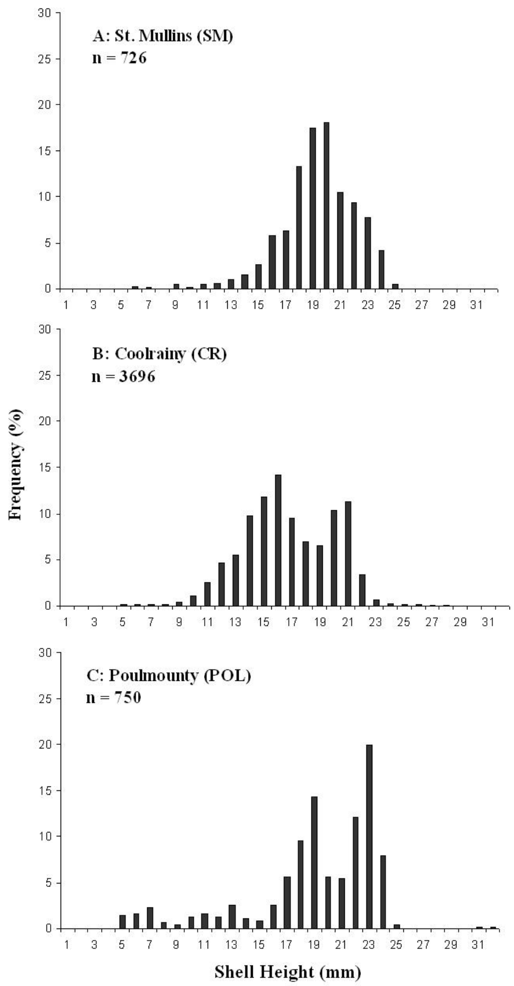

Figure 3. Length frequency histograms from pooled quadrat samples taken from the River Barrow sites: A. St. Mullin's (SM), B. Coolrainy (CR) and C. Poulmounty (POL) in 2010.

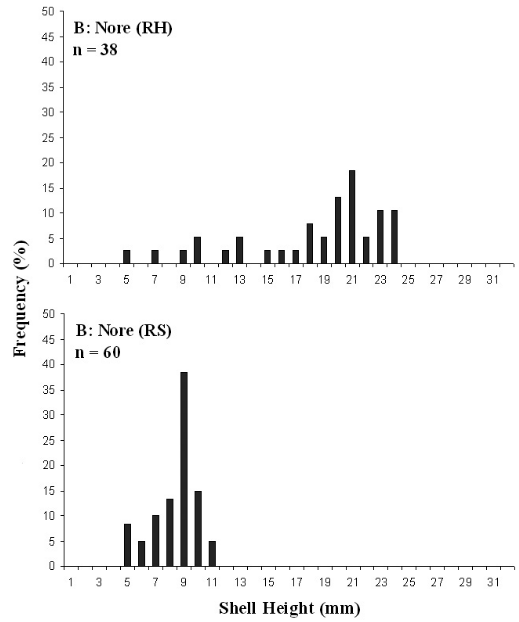

Figure 4. Length frequency histograms from pooled quadrat samples taken from the River Nore sites in 2010: A. Red House (RH) and B. Russell Sound (RS).

A total of 5,270 individual *C. fluminea* shells from the five river sites investigated were measured and size class frequency histograms were produced (Figures 3 and 4). Shell dimensions ranged from 5.05 to 32.71 mm (only clams >5 mm were included).

Size length distribution data was used to define generational cohorts. Based on shell height (SL) distributions in the Barrow, the Poulmounty population appeared to be composed of three annual cohorts: 5–11 mm, 12–19 mm and 21–26 mm, respectively. Both the St. Mullin's and Coolrainy populations appeared to be dominated by two and three year old cohorts, with SL ranging from 9-25 mm. At these sites, few representatives from the one year old cohort (SL < 9 mm) were recorded. In the Nore, the Russell Sound population appeared to comprise a single one year old generation ranging in shell height (SL) from 5–11 mm, while the Red House site supported a population comprising one and two year old cohorts, ranging in SL from 5–11 mm and 15–23 mm, respectively.

Analysis of sediment composition at Coolrainy (CR), where maximum *C. fluminea* density values were recorded, revealed that sediment in the range of 0.8–4.0 mm, representing coarse sand (Krumbein and Pettijohn 1938), clearly dominated. In the Nore, clams were recorded both within mud (*circa* 62.5 µm) at RH and in substrates dominated by pebbles (circa 8–32 mm) at RS.

Mean values for a number of pertinent water chemistry parameters collected by the Environment Protection Agency (EPA) between 2007 and 2010 are presented in Table 1. The summary results demonstrate that the pH and conductivity levels in both rivers are similar and that the water is relatively hard.

Table 1. Mean values (± standard error) for a number of water chemistry parameters recorded between 2007 and 2008 at St. Mullin's (River Barrow) and at Inistioge (River Nore), Lucey (2009).

Location	Dissolved Oxygen (% sat)	pH	Conductivity (µS/cm)	Total Hardness (mg/l $CaCO_3$)	Alkalinity (mg/l $CaCO_3$)
St. Mullins (Barrow)	104.4 ± 1.9	8.3 ± 0.04	578.2 ± 12.2	296.3 ± 13.5	254.6 ± 7.5
Inistioge (Nore)	108.3 ± 3.1	8.2 ± 0.03	576.7 ± 14.6	/	/

Discussion

Rapidly accelerating world trade and international travel have allowed both deliberate and inadvertent movement of species between different parts of the globe, often resulting in unexpected and sometimes disastrous consequences. As an island on the western edge of Europe, Ireland has been subjected to far fewer non-native species introductions over the last century than other European counties (e.g. 112 in Ireland (Minchin 2007) as opposed to 2,271 in England (English Nature 2005). Accepting this, the number of non-native freshwater species recorded in Irish watercourses has increased significantly in the late 1900s (Stokes et al. 2004; Caffrey and Acevedo 2008) and the majority of the more ecologically damaging species have been introduced in the last 20 years (Caffrey and Acevedo 2007). These include species such as the amphipod [*Chelicorophium curvispinum* (Sars, 1895)] discovered in 2003 (Lucy et al 2004), chub (*Leuciscus cephalus* Linnaeus, 1758), discovered in 2004 (Caffrey et al. 2008), curly-leaved waterweed (*Lagarosiphon major* Ridley, 1928), discovered in 2005 (Caffrey and Acevedo 2008; Caffrey et al. 2009), Chinese mitten crab (*Eriochier sinensis* H. Milne Edwards, 1853) discovered in 2006 (Minchin 2006), bloody-red shrimp (*Hemimysis anomala* Sars, 1907), discovered in 2008 (Minchin and Holmes 2008) and water primrose (*Ludwigia grandiflora* (Michx.) Greuter and Burdet, 1987) discovered in 2009 (Caffrey internal report). Such priority invasive species have the potential to significantly impact biodiversity and the Irish economy.

The presence of *Corbicula fluminea* was first confirmed in the freshwater tidal reaches of the River Barrow in April 2010 (Sweeney 2009). In June 2010 its presence in the connected River Nore was confirmed. Both catchments are designated within a Special Area of Conservation (SAC) as they support a number of protected fish and macroinvertebrate species (i.e. twaite shad, sea lamprey, smelt, Atlantic salmon and freshwater pearl mussel). The introduction and successful establishment of the Asian clam in these rivers will pose a direct threat to their conservation status and threaten the fragile communities for which these rivers have been designated.

Results from preliminary surveys conducted between April and July 2010 have demonstrated that the Asian clam is well-established in the lower reaches of the River Barrow. The density levels recorded over the 16.2 km length of tidal river from St. Mullin's to New Ross were high, reaching a maximum of 9,636 individuals m^{-2} at Coolrainy (Appendix 1). The mean densities recorded here are considerably higher than many reported from abroad (e.g. McMahon 1999; McMahon and Bogan 2001; Müller 2003; Werner and Rothhaupt 2007 and Elliott and Ermgassen 2008), although densities up to 18,000 individuals per m^2 have been reported in the US (Doherty et al. 1987). An examination of the size-frequency modal distributions indicates that *C. fluminea* has been established within the Barrow catchment for some years. Cohort examination suggests that three generational classes exist. However, with a small number of individuals exhibiting shell heights above these ranges (e.g. 32.7 mm), it is possible that there may be some older individuals present. According to the literature, the life span of the Asian clam is extremely variable, although the normal range is from 1 to 5 years (McMahon 2000; Sousa et al. 2008). Further examination of the age structure of the clam populations in the Rivers Barrow and Nore will be conducted.

The Asian clam density figures recorded for the River Nore were lower than those recorded in any infested section of the River Barrow and suggest that the clam is not as well established here yet. This could be because the clam has only recently invaded the river, although individuals to 24.66 mm and of multiple year cohorts were present. Alternatively, it might suggest that the habitat present in this river is less suitable than in the River Barrow. Further studies will be required to shed light on this matter.

A greater number of small *C. fluminea* shells (between 5 and 8 mm) were recorded at Poulmounty (POL) compared to any of the other Barrow sites. This suggests that settlement of the one year old cohort was generally poor, that cohort survivorship within that generation was poor or alternatively, that the sampling method employed at Poulmounty favoured the smaller sized individuals. At Poulmounty the substrate was exposed when the quadrats were deployed and there was no interference from water current or turbidity when the clams were being hand picked and counted. The sites at St. Mullin's and Coolrainy are constantly submerged and quadrat sampling was conducted by divers. It is possible that a proportion of the smaller individuals may have been obscured due to turbidity in the water or washed away in the current during sampling. Accepting this limitation, it is evident that, when sampling water greater than *c.* 1.5 metres deep, diving surveys can provide more accurate estimates of Asian clam abundance than other bottom sampling methods (Wisniewski 1974; Mellina and Rasmussen 1994). SCUBA diving also affords an opportunity to closely observe the underwater habitat and the specific conditions that the clams are exposed to. Our efforts to sample using the Berg-Ekman grab proved relatively unsuccessful as rocks, stones, gravel and even clam shells commonly prevented the jaws of the sampler from closing securely. A further factor that mitigated against the successful use of the grab was the constant flow in these tidal waters.

It is unclear what vectors or distribution pathways have facilitated the spread of *C. fluminea* into Ireland. As a connected navigation river, the Barrow River is highly vulnerable to the introduction of AIS. At the mouth of the Barrow, Waterford Harbour is one of the major Irish ports proximal to mainland Europe, and it is strategically located in relation to Ireland's main markets in Britain and continental Europe. As such, it has considerable domestic and commercial traffic. Consequently, the import of 'hitchhiker' species into the Barrow system is a veritable risk. Results from the present survey demonstrate that the largest and most established population in the system is present at Coolrainy, some considerable distance from the most downstream record. It is therefore suggested the Asian clam may have been intentionally introduced into this section of river, either made for the purpose of propagating a food source or from discarded bait material.

Following intensive sampling, no *C. fluminea* specimens were recorded upstream of the first navigation weir on the River Barrow or upstream of Inistioge on the River Nore (see Figure 2). This suggests that the Asian clam invasion is confined to the tidal freshwaters below these locations, at the present time. In both rivers, recreational craft have ready access upriver and anglers move freely throughout the river catchments. Therefore, there is considerable potential for upriver spread. Previous studies have indicated that *C. fluminea* have well developed dispersal capabilities, most of which are anthropogenically mediated and include introductions as part of fish stocking programmes, as juveniles in bilge water, as fish bait, in dredged sand or gravel, as aquarium dumps or intentionally as food items (McMahon 1999, 2000; Darrigran 2002). In addition, natural dispersal can occur when the mucilaginous byssal threads of juvenile clams become entangled in floating debris or on the feet or feathers of waterfowl (McMahon 1999). The action of water currents and tidal movements can also disperse the clams, and particularly juvenile forms (Figuerola and Green 2002). It is also recognised that the Asian clam has strong powers of locomotion and can move upstream of its own accord (Voelz et al. 1998). It is considered that juvenile clams were transported between the upper tidal limits of the River Barrow and the tidal length of the River Nore *via* tidal water movements (see Figure 2).

Eradication of *C. fluminea* from the Barrow and Nore rivers will be virtually impossible, will incur significant costs and will be highly disruptive to the habitat and its associated biota. While acknowledging this, it is proposed to trial a number of methods that might assist in the control and/or containment of *C. fluminea* (i.e. reduce the density, the potential impacts and the opportunity for *C. fluminea* to disperse, or be spread, within and outside these catchments) in the Barrow and Nore rivers.

Options might include the use of a benthic barrier or jute matting (Caffrey et al. 2010) to cover the clams *in situ,* thus inducing anoxia and subsequent death (Matthews and McMahon 1999) and the use of specifically prepared biobullets, as targeted against zebra mussel (*Dreissena polymorpha* Pallas, 1771) (Aldridge 2006).

Failure to act rapidly to control the proliferation of *C. fluminea* in the Barrow and Nore rivers could result in the demise of a number of resident protected fish and invertebrate species. It will also contribute to the potential for widespread dispersal of this priority invasive species within these catchments and to other catchments throughout Ireland.

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Supplementary material

The following supplementary material is available for this article.

Appendix 1. Locations and density of all *Corbicula fluminea* records in the Rivers Barrow and Nore in 2010.

This material is available as part of online article from:
http://www.aquaticinvasions.net/2011/AI_2011_6_3_Caffrey_etal_Supplement.pdf