The Ponto-Caspian quagga mussel, *Dreissena rostriformis bugensis* (Andrusov, 1897), invades Great Britain

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Abstract

Great Britain has been subject to an increasing rate of invasion from freshwater species of Ponto-Caspian origin. A recent horizon-scan of potential invaders into Great Britain named the Ponto Caspian quagga mussel, *Dreissena rostriformis bugensis* (Andrusov, 1897), as the non-native species least wanted. On 29th September 2014 quagga mussels were discovered in the Wraysbury River, Surrey, during a routine kick sample collected by the Environment Agency. Identity was confirmed using genetic markers (Cytochrome Oxidase I - COI) on five individuals encompassing a broad morphological variation. The absence of very large individuals (max. length 16 mm), absence of shells and absence of quagga mussels in samples collected during March 2014 point toward a recent invasion. The quagga mussels were found attached to submerged rocks, vegetation, bridge walls and shells of zebra mussels, *Dreissena polymorpha* (Pallas, 1771). The collection site is a small (<5m wide), shallow (<50cm deep) stream that is not navigable or regularly fished. This suggests that the species is more widely distributed than the current location, because such a system is unlikely to be the point of introduction. The shallow depth (30cm) in open water at which quagga mussels were abundant is surprising given that zebra mussels have failed to establish in such habitats, despite being present in the catchment for over 100 years. Previously published models predict quagga mussels will establish widely across England, western and southern Wales and central Scotland. The high abundance and inter-connectivity of waterways adjacent to the Wraysbury River suggest further spread is likely. Containment through national biosecurity measures (e.g. ‘Check, Clean, Dry’ of boats and equipment, as promoted by the UK Environment Agency) is recommended, although ultimately it can be assumed that quagga mussels will cause similar widespread ecological and economic harm in Britain as has been experienced in invaded regions of Western Europe and North America.

Key words: dreissenid, invasive, zebra mussel, Wraysbury, alien, non-native, first record

Introduction

In recent years, there has been a dramatic spread of Ponto-Caspian species into Western Europe. This spread has been facilitated by the construction of canals which have linked different river systems. Canal construction has not only provided improved trade routes but has also created a number of invasion corridors from east to west (Bij de Vaate et al. 2002). Many of these new species have driven major ecological changes and caused considerable economic harm. The predominance of facilitative and commensal interactions between Ponto-Caspian species heightens their invasive potential and threatens to drive an ‘invasional meltdown’ (Gallardo and Aldridge 2014).

Recent studies suggest that The Netherlands contains over 20 Ponto-Caspian freshwater species that have yet to be found in Great Britain (Gallardo and Aldridge 2013a). One of the species of greatest concern to Britain’s freshwaters is the quagga mussel, *Dreissena rostriformis bugensis* (Andrusov, 1897), which was identified as the species that posed the greatest risk to Britain’s biodiversity in a recent multi-taxon, multi-ecosystem horizon scan (Roy et al. 2014). Until the early twenty-first century the quagga mussel was a slower invader than the congeneric Ponto-Caspian zebra mussel *Dreissena polymorpha* (Pallas, 1771), a species that already costs Britain approximately £5 million per year (Oreska and Aldridge 2011) and threatens native biota (Aldridge et al. 2004; Sousa et al. 2010; Sousa et al. 2011).
The original native range of the quagga mussel is the Lower Dnieper River and Southern Bug River (Son 2007). However, over the last few decades the quagga mussel has considerably extended its range, establishing widely in Russia, North America and Western Europe (Van der Velde et al. 2007) and is now spreading at a rate in Western Europe that far exceeds that of the zebra mussel (Matthews et al. 2014).

Quagga mussels will affect invaded ecosystems in a number of ways. Clearer waters resulting from massive filtration capacity (Cross et al. 2010) will lead to changes in algal diversity and abundance. Selective removal of green algae by dreissenids can reduce cyanobacteria from competition and lead to toxic blooms (Maclsaac et al. 1996). Grazing of algae by quagga mussels was estimated to match that of zooplankton in Lake Erie, USA (Zhang et al. 2011) and may explain the significant declines in biomass of cyclopoid copepods in Lake Ontario following mussel invasion (Bowen et al. 2011). The abundance of ciliates, *Daphnia* and rotifers reduced by 39, 40 and 45 % respectively in Lake Michigan following dreissenid invasion (Kissman et al. 2010).

Nalepa et al. (2009) found that offshore benthic communities in Lake Michigan experienced a major shift following the invasion of quagga mussels, with the replacement of native amphipods with the new mussel. A meta-analysis of benthic macroinvertebrate communities following *Dreissena* invasions (Ward and Ricciardi 2007) suggests that following invasion, there is an increase in benthic density and taxonomic richness, but a reduced evenness. There were positive effects on densities of scrapers and predators (especially leeches, flatworms and mayflies), but reductions in large snails, sphaeriid clams, unionid mussels and burrowing amphipods. Gammarid amphipods showed a positive response, and this may reflect their tendency to gain shelter from the mussels’ shells (Madgwick and Aldridge 2011). A decline in unionid mussels through quagga mussel fouling has been reported by Schloesser et al. (2006).

Throughout its invaded range, quagga mussels have been seen to replace zebra mussels in most habitats (Wilson et al. 2006; Van der Velde et al. 2010). This has been attributed to the quagga mussel’s lower respiration rates, greater shell growth, greater shell mass, faster filtration rates and greater assimilation efficiency (Diggins 2001; Baldwin et al. 2002; Stoeckmann 2003). Zebra mussels appear to find refugia from quagga mussels in certain habitats, including those with fast flow, and areas with macrophyte substrate onto which zebra mussels preferentially attach (Diggins et al. 2004). In Western Europe, quagga mussels have been found to displace zebra mussels at a rate of 26 to 36 % per year (Heiller et al 2012, 2013). In Russia, the lag for quagga mussels to replace zebra mussels is estimated to be 5–10 years (Orlova et al. 2004).

The possession of a bysuss means that quagga mussels also represent a considerable biofouling risk. By attaching to one-another quagga mussels can block raw water pipes in irrigation systems, power plants and water treatment facilities. In North America, Connelly et al. (2007) estimated the combined economic cost of quagga and zebra mussels to the water and power industries to be $US 161 – 467 million between 1989 and 2004.

On 29th September 2014 a routine macroinvertebrate sample (three minute kick sample) collected by the Environment Agency found specimens of a dreissenid in the Wraysbury River, Surrey, UK (51°26.55’N, 00°31.25’W). Similar sampling conducted at the same site in March 2014 did not record the presence of dreissenids. This paper reports the results of preliminary investigations into the identity, population structure, origins and potential spread of this dreissenid.

**Materials and methods**

**Study site**

The Wraysbury River is a small (<5 m width), shallow (<50 cm depth), slow-flowing stream with a benthos dominated by gravel. Monthly records collected by the Environment Agency for 2013 give mean water chemistry parameters of pH 8.10, Conductivity 845.5 µS/cm, Dissolved Oxygen 10.49 mg/l, Temperature 11.58 °C, Total Oxidised Nitrogen 8.24 N mg/l, Alkalinity 229.63 mg/l CaCO₃. The river forms part of the River Colne system, and is surrounded by a complex network of canals and ditches that ultimately feed into the River Thames. The adjacent landscape contains water storage reservoirs and numerous flooded gravel pits which house dive centres, sailing clubs and angling clubs.

**Morphology**

Specimens collected from the Wraysbury River at the point of first discovery were identified using external and internal shell characteristics by reference to Mackie and Claudi (2009).
DNA extraction, amplification and sequencing

In order to confirm the species identification using genetic markers, five animals were collected from the Wraysbury River at the point of first discovery and fixed in 96% ethanol in the field. Whole genomic DNA from each mussel was isolated using the Jetquick tissue DNA Spin Kit (Genomed) following the manufacturer’s protocol. A fragment of the cytochrome oxidase c subunit I gene (COI) was amplified by PCR using universal primer modified versions, i.e., LCO22me2 and HCO700dy2 (Walker et al. 2006, 2007). The PCR conditions (25 µL reactions) were as follows: each reaction contained 2.5 µL 10x Invitrogen PCR Buffer, 0.5 µL 10mM of each primer, 1.5 µL 50mM MgCl2, 0.5 µL 10mM dNTP’s, 0.1 µL Invitrogen Taq DNA Polymerase and approximately 1 µL DNA template. The cycle parameters were: initial denaturation at 94°C for 3 min, denaturation at 94°C (30 s), annealing at 50°C (40 s) and extension at 72°C (60 s) repeated for 38 cycles and a final extension at 72°C of 10 min. Amplified DNA templates were purified and sequenced (forward and reverse) by a commercial company, Macrogen, using the same primers.

Habitat and population structure

A 100m stretch of the Wraysbury River at the point of first discovery was surveyed on 30th September 2014. To assess population structure all mussels encountered were collected during a ten minute hand sample whilst wading within the channel. All available habitat (e.g. bridge supports, gravel, boulders, submerged vegetation, plastic debris) was sampled in proportion to its relative abundance. Each collected mussel was measured along its longest axis using Vernier Callipers.

Results

Morphology

The species was identified as the quagga mussel, *D. rostriformis bugensis*, based on key external and internal shell characteristics (Mackie and Claudi 2009; Figure 1)

Genetic verification

Both forward and reverse sequences from the five specimens were aligned, and no indels and no stop codons were observed, after translating all sequences to amino acids. All available *Dreissena rostriformis bugensis* sequences from GenBank were downloaded and the final alignment revealed that the new sequences from this study are indeed *Dreissena rostriformis bugensis* (GenBank accession number KP057252).

Habitat and population structure

Live quagga mussels were small in size, but ranged in length from 3 to 16 mm, with a modal length of 13mm (Figure 2). Live mussels were found attached to bridge walls, boulders, plastic debris, submerged wood, and the shells of other
bivalves (Figure 3). Even in open water, live specimens could be found on the underside of cobbles at water depths of 20–30 cm. No empty shells were found, except above the water line where shells still attached to walls and boulders had apparently been stranded during falling water levels.

Discussion

Habitat

It is surprising that the Wraysbury River has been colonised by quagga mussels; zebra mussels have been present in the region for over 200 years (Aldridge 2010) and yet have not established in the river. Dreissenid veliger larvae are highly sensitive to UV radiation (Wright 1998), and this typically precludes them from establishing in shallow waters such as those found at the Wraysbury River. It is possible that the quagga mussel veligers entered the system and established during the unprecedented floods of the Wraysbury River during winter/spring 2013/14, during which the water was especially turbid and had a recorded maximum depth of 70 cm (Environment Agency, Wraysbury River Gauging Station). Once dreissenid mussels have settled and formed their shell valves they become relatively protected from UV light and so this could explain their persistence in the river once the river returned to typical depth conditions of ca. 30 cm.

Date of arrival

The small size of the quagga mussels in the Wraysbury River (16mm maximum length), combined with the absence of empty shells and the lack of records during the Environment Agency’s March 2014 survey suggests that the mussels entered the river during late 2013 or early 2014. This is further supported by data from Lake Mead, USA, where the annual growth rate of juvenile quagga mussels is between 13 and 19 mm (Wong et al. 2012). Well-established quagga mussel populations show a maximum length of 35mm in North American systems (Mills et al. 1999). Maximum lengths reported for Western Europe are typically smaller, with 27 mm reported for the Meuse River (Matthews et al. 2012).

Origins

The current distribution and origin of the quagga mussels in the Wraysbury River remains unclear. The river is very small, has limited public access, is not routinely fished and is not navigable. It is therefore likely that the mussels entered the
system from elsewhere, and that the population is not localised to the Wraysbury River. The Wraysbury River forms part of a highly interconnected system of streams, rivers and canals, including the River Thames and River Colne. The immediate area is also occupied by a number of large, inter-linked water storage reservoirs and flooded gravel pits that house sailing clubs and diving clubs. Further surveys are required to better understand the distribution of the mussel. Molecular analyses of this population and others are needed to help identify the possible origins of this invasion event.

Potential spread and impacts

The large number of adjacent waterways may not only provide a possible source for the mussel, it also provides a considerable risk for future spread. This is exacerbated by the potential of the Wraysbury River to flood into nearby rivers and gravel pits. Perhaps of greatest concern is the River Thames, into which the Wraysbury flows. The Thames has been identified as a hotspot for freshwater invaders (Gallardo and Aldridge 2013a, b; Jackson and Grey 2013), including many Ponto-Caspian species, and this further increases the potential for invasional meltdown (Gallardo and Aldridge 2014). The River Thames also serves as a major corridor for transport into the wider British river and canal network (Aldridge 2010). A number of industries draw raw water from the River Thames, including water treatment works and power plants, and these have already experienced high levels of costly biofouling from zebra mussels (Elliott et al. 2005; Oreska and Aldridge 2010).

Bioclimatic models suggest there is wide habitat suitability within Great Britain for quagga mussels to establish (Gallardo and Aldridge 2013a). It can be assumed that the widespread distribution of zebra mussels in Britain will be similarly matched by quagga mussels, which will replace the zebra mussels in many sites. Distribution is likely to include much of England, western and southern Wales and central Scotland. Quagga mussels favour lentic systems, such as reservoirs and lakes. They are not found in fast flowing rivers, but canals provide ideal habitats. British freshwaters provide a wealth of suitable hard substrates which have already been seen to support the widespread establishment of zebra mussels. As populations establish, shell material enables expansion into muddy substrates (Bially and MacIsaac 2000).

Options for management and control

Given the potential ecological and economic impacts that quagga mussels could have in Britain’s freshwaters, it is desirable to consider whether tools are available for containment. If the population is localised, eradication from the Wraysbury River may be possible through isolation and draining (Ricciardi et al. 1995) or by dosing the water column with degradable control agents, such as BioBullets (Aldridge et al. 2006) or Zequanox® (Meehan et al. 2014). Whilst any control strategy is likely to have consequential deleterious impacts on non-target biota, this might be a short-term consequence worth embracing. However, decision on any control strategy requires the ecological and economic costs and benefits to be balanced against the potential for re-invasion (Caffrey et al. 2014). On a more practical level, there is certainly a place for increased biosecurity measures to limit spread into other waterbodies. Transmission upon waders, boats and fishing gear can be reduced through the standardised check, clean, dry procedures already promoted in Britain’s freshwaters (http://www.nonnativespecies.org/checkcleandry/). Additional protection can be offered by exposing equipment to water at 50 °C for 20 seconds (Comeau et al. 2011).

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