Freshwater Bivalve Survey in the Upper Tidal Thames

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Executive Summary

Hidden beneath the muddy, turbid water of the Tidal Thames is an ecosystem of great ecological importance. The Zoological Society of London's (ZSL's) Tidal Thames Conservation Programme (TTCP) was set up in 2004 and is focused on securing London as an internationally important site for aquatic wildlife and demonstrating globally that this can be achieved in an urban environment. We also focus on raising awareness of the biological value of the Tidal Thames to inspire Londoners to reconnect with nature and have better environmental stewardship

In keeping with this mission, each November between 2007 and 2010 ZSL conducted a bivalve survey of the benthic habitat in the upper Tidal Thames. This survey was carried out again in 2014 after the discovery of the quagga mussel in Wraysbury reservoir near Heathrow Airport in October of that year. This work has been conducted in partnership with the Marine Conservation Society, Thames Landscape Strategy and the Environment Trust for Richmond upon Thames

The main native species of bivalve recorded during the period of study were the depressed river mussel (*Pseudanodonta complanata*), duck mussel (*Anodonta anatina*) and painter's mussel (*Unio pictorum*). The swollen river mussel (*Unio tumidus*) is also known to be present at the site, but has never been recorded in the surveys. These species provide vital ecosystem services such as water filtering, nutrient cycling and habitat creation. Our data show that these species are now present only in very low numbers in the upper Tidal Thames, suggesting that their ability to play a functional role in a healthy aquatic ecosystem is compromised.

Two main species of invasive non-native bivalve were also found during the surveys, the zebra mussel (*Dreissena polymorpha*) and Asian clam (*Corbicula fluminea*). In addition to these two species, the quagga mussel (*Dreissena rostriformis bugensis*) was also present in the 2014 survey. These species pose significant threats to native aquatic biodiversity through colonisation of native bivalves, altering of water clarity and nutrient loads and the transmission of pollutants to predator species.

Over the five years surveyed, the zebra mussel and Asian clam appear in consistently higher numbers than native bivalves. The greatest number of zebra mussels was found in 2007 and appears to decrease year on year. The Asian clam was found initially in very low numbers in 2007 and 2008, and then underwent a significant expansion in 2009 before declining in subsequent years. However, due to the data gap between 2010 and 2014 it is not possible to know for certain the current population trajectories of these species.

There is extensive literature documenting the impact of zebra mussels and Asian clams on native bivalves. Therefore, although no relationship was found in our data, it is highly likely that these invasive species have played a role in suppressing the populations of native bivalves. It is also probable that various environmental factors such as water quality decline have had a deleterious effect on native bivalve populations and invasive non-native species should not be seen as the sole cause of decline.

Given the difficulty in controlling established population of invasive bivalves, and the recent arrival of the quagga mussel, monitoring and preventative action is paramount. ZSL is working with volunteers and partners in the London area to increase public awareness of this issue and promote the 'Clean, Check, Dry' protocol for all water users. In addition, ZSL, Kingston University and the London Invasive Species Initiative are developing eDNA and genomic approaches to identify invasive species in water samples from the Thames. With further development this technique has the potential to increase detectability of species and provide a cost-effective alternative when compared to traditional methods for surveying aquatic invasive species (netting and transects).

Acknowledgements

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Aims and Objectives

- Assess the current state of native freshwater bivalves in the upper Tidal Thames.
- Determine the prevalence of invasive non-native bivalves in the upper Tidal Thames.
- Make recommendations for the control of invasive non-native bivalves to reduce their environmental impact in the Tidal Thames.

Introduction

Invasive non-native species (INNS) are widely accepted to be a major area of conservation concern globally. The International Union for the Conservation of Nature (IUCN) now considers INNS as one of the major drivers of species extinction. Aquatic ecosystems, such as the Tidal Thames, are particularly susceptible due to increased international shipping and water connectivity over the past century. The concentration of these activities in the capital has led to 72% of known UK freshwater INNS being present in the Tidal Thames, making the Tidal Thames one of the most invaded waterways in the world (Jackson and Grey 2012).

Amongst the most environmentally harmful group of INNS found in the Tidal Thames are freshwater bivalves. To date, nine non-native species of bivalve have been found in the Tidal Thames, including the invasive zebra mussel (*Dreissena polymorpha*), Asian clam (*Corbicula fluminea*) and recently discovered quagga mussel (*Dreissena rostriformis bugensis*). Together these species pose a significant threat to native UK bivalves and other aquatic biodiversity (Bodis *et al.* 2014, Souse *et al.* 2014 and Sousa *et al.* 2010). There are multiple routes through which bivalves infestations can impact host ecosystems and local biodiversity.

Both the zebra and quagga mussel grow on the shells of native bivalves in numbers as high as 1000 individuals per native (Bodis *et al.* 2014). This colonisation has a detrimental impact on the hosts health and ability to reproduce, in extreme cases the native bivalve can be suffocated and killed under the load of colonisation. Instances have been reported of native populations being eradicated just years after the introduction of zebra mussels (Strayer and Malcom 2007).

Additionally, large numbers of invasive bivalves can transform the habitat around them by altering water clarity and through the production of faeces and psudofaeces. These alterations often severely disrupt native flora and fauna which can have a knock-on effect up the food chain (Sousa *et al.* 2014 and Karatayev *et al.* 1997). This bottom-up effect is compounded when aquatic pollutants accumulate in the bodies of invasive bivalves and are transferred to higher trophic species such as predatory birds (Sousa *et al.* 2014 and Morrison *et al.* 1998).

In addition to the manifold environmental impacts, invasive bivalves also inflict major economic costs. By growing in extremely high abundances, these species can cause damage to water pipes and ships hulls (Williams *et al*. 2010). In addition, the increase in water clarity and nutrient levels often associated with high numbers of bivalves can increase sedimentation and block water ways (Sousa *et al.* 2014). The high growth rates of these species make control efforts especially difficult and expensive, with regular manual removal often being required (Hoddle 2011).

Key Native Bivalves

Freshwater bivalves play a fundamental role in the healthy functioning of aquatic ecosystems; their abundance can be successfully used as an indicator of river biodiversity (Aldridge *et al.* 2007). The benefits are conferred through vital ecosystem services such as nutrient cycling, habitat creation and water filtration. Six freshwater bivalve species of the order Unionodia (often called Unionids) are native to the UK. Three species were included in ZSL's survey of the upper Tidal Thames. The swollen river mussel (*Unio tumidus*) is also known to be present at the site, but has not been recorded in the surveys.

Depressed river mussel (*Pseudanodonta complanata*)

A freshwater bivalve native across much of Europe, currently listed on the IUCN red list as 'threatened' (Van Damme, D. 2011). Populations are declining across much of its range and they have now disappeared from as many as 30% of waterways in which they were once abundant (Maclean 2010). In the UK the depressed river mussel is recognised as one of the most threatened species on the Governments Biodiversity Action Plan (JNCC 2007).

Duck mussel (*Anodonta anatina*)

Found in slow moving, low land waters across much of Europe and parts of Asia this hardy generalist is currently listed as 'least concern' on the IUCN red list (Lopes-Lima 2014). However, the population is known to be declining globally and it is recognised in Ireland as a priority species (Anderson 2011).

Painter's mussel (*Unio pictorum*)

The painter's mussel is currently in the 'least concern' category on the IUCN red list and is found in reasonable numbers throughout much of Europe and Russia (Van Damme, D. 2011a). Despite its high tolerance to poor water quality (Killeen *et al.* 2004), it is still thought to be susceptible to invasive bivalve infestations (Bauer and Wächtler 2001).

Key Invasive Non-Native Bivalves

Three main species of invasive bivalve account for the majority of the damage caused to native species and local biodiversity. These species exhibit the classic traits of successful INNS as they adopt a 'r' life strategy, characterised by high fecundity, rapid growth and maturation rates and high dispersal potential (Sousa *et al.* 2014).

Zebra mussel (*Dreissena polymorpha*)

A highly successful invasive species native to the Ponto-Caspian region, the zebra mussel can now be found in much of Europe and North America. Although first discovered in the UK in 1824 its population remained largely stable from 1850 to the late 1900s. After a brief decline in the 1990s the species has undergone a rapid expansion across much of the UK (Aldridge *et al.* 2004). The reason for this expansion is not clear, but it may be due to a new introduction of individuals better adapted to environmental conditions in the UK (Aldridge *et al.* 2004).

Quagga mussel (*Dreissena rostriformis bugensis*)

Also native to the Ponto-Caspian region, the quagga mussel is closely related to the zebra mussel and similar in appearance. First discovered in the UK in October 2014 (WWT 2014), there is serious concern that the quagga mussel will follow a similar pattern as in the USA where it has spread across the western states causing major environmental and economic damage (Benson *et al.* 2014, Watters *et al.* 2012). In 2014, the quagga mussel was put at the top of a list of 30 invasive species of concern to the UK, as a result of the high likelihood of its establishment and potential impact on biodiversity (Roy *et al.* 2014).

Asian clam (*Corbicula fluminea*)

The Asian clam is native to southern and eastern Asia and was first recorded in the UK in 1998. The method of introduction into the UK is unknown, but it remained relatively isolated in the Norfolk Broads catchment until 2004. In 2004 the first specimen was found in the Tidal Thames at Richmond lock and the species is now spreading over the Southeast (Elliot and Ermgassen 2008). The Asian clam competes with native bivalves for space and resources and appears resistant to the impact of zebra and quagga infestations (Bodis *et al.* 2014).

Methodology

The survey site is located on the Tidal Thames, in the borough of Richmond upon Thames, in Southwest London (Fig. 1). The section of river lies upstream of Richmond half-lock and is usually semi tidal. During November each year, the lock is opened for maintenance and a full low tide exposes the benthic habitat; offering an opportunity to sample the bivalve communities. Two sites on each bank were selected for surveying, giving a total of four sites to minimise any bias from variable substrates on the river floor.

At each site three transects were marked out from the riverbank to the water line at 5 m intervals. A 0.25m^2 quadrat was laid at the riverbank end of each transect and then moved in 2 m intervals down towards the waterline. Longer transects were used when surveys were conducted nearest to peak low tide, resulting in variation in transect length between surveys. The number of quadrats on each transect varied from 2 to 10 depending on the water level. Each quadrat was examined by hand to a depth of 3cm and all living individuals were identified and counted. Surveys were carried out by ZSL conservation biologists, and a team of citizen science volunteers (Fig. 2).

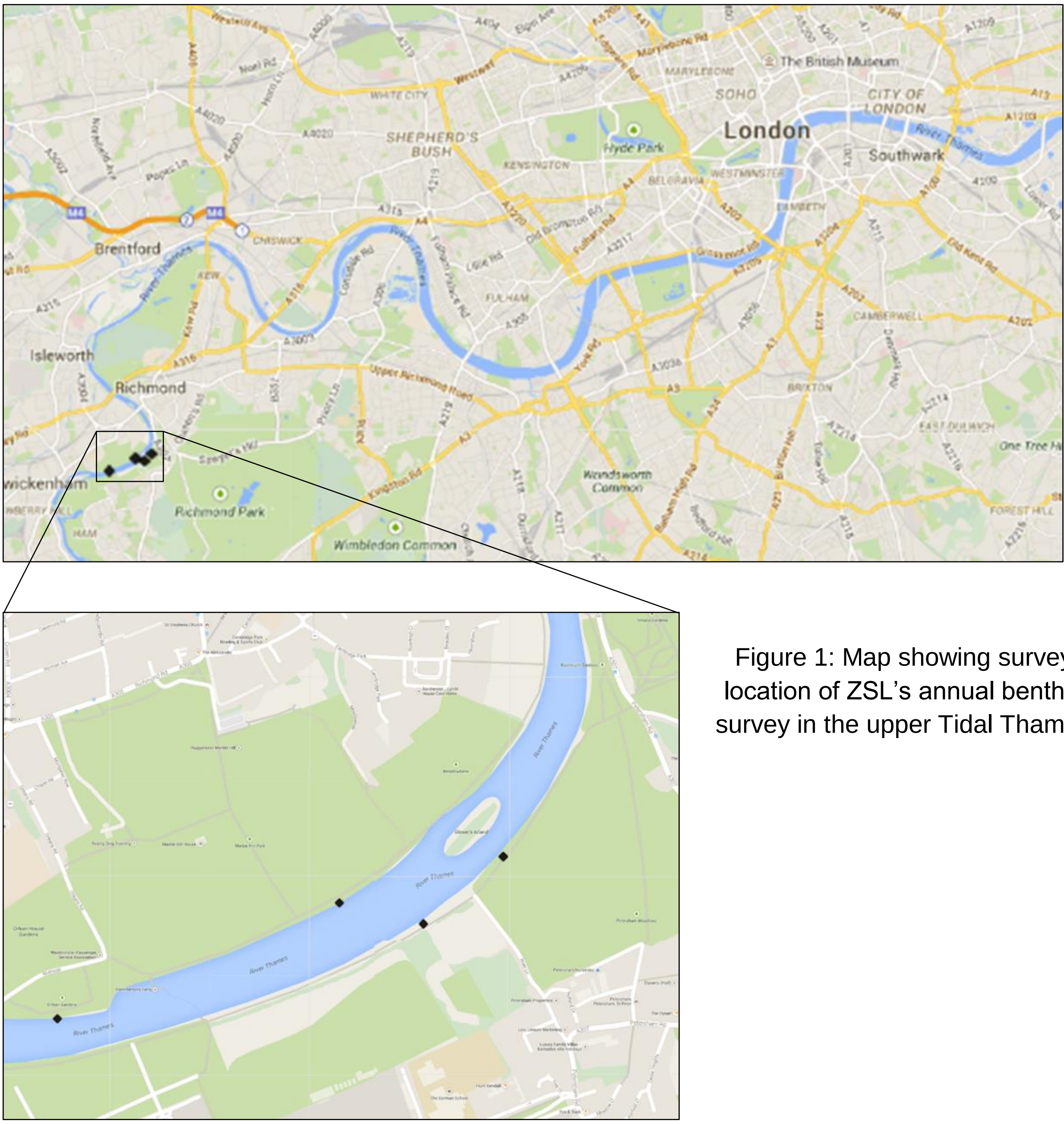

Figure 1: Map showing survey location of ZSL's annual benthic survey in the upper Tidal Thames

Figure 2: Conservation Biologists from ZSL and a group of volunteers conducting survey at Richmond upon Thames

Results

Native Bivalves

Very low mean densities of native bivalves were recorded over the entire period covered by the survey (0.6/ 0.25m^2) (Fig. 3). The depressed river mussel was present in all years except for 2014, however was only found in exceptionally low numbers (>0.2/ 0.25m^2). The highest density of duck mussels was recorded in 2007 (0.59/ 0.25m^2), however the species was absent in both the 2009 and 2014 surveys. The painter's mussel was the only native species found in all five years, with peaks in 2007 (0.41/ 0.25m^2) and 2009 (0.59/ 0.25m^2).

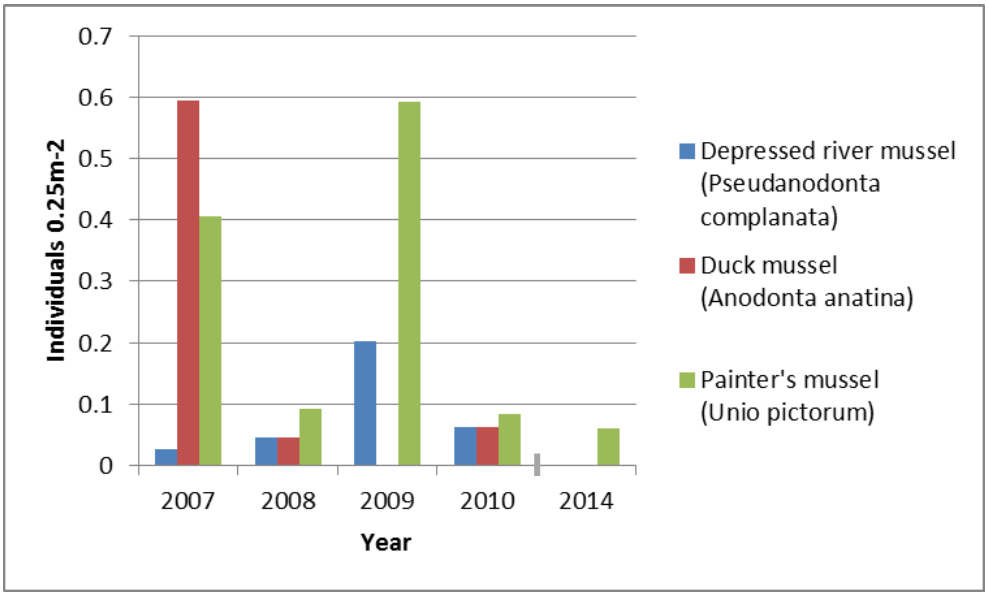

Figure 3: The number of native bivalve individuals found per 0.25m^2 for the 5 years the survey

Invasive Non-Native Bivalves

Annual mean densities for invasive species identified during the surveys were in general much higher than native species. The abundance of Asian clams ranges between 2.46 and 154.85 individuals per $0.25m^2$, while the abundance of zebra mussels ranges between 0.56 and 14.81 individuals per $0.25m^2$ (Fig. 4) The Asian clam was initially found only in low numbers, peaked in 2009 and then appears to decline in subsequent years (Fig. 4). The zebra mussel was found in greatest abundance in 2007 and appears to have declined year on year over the period of study (Fig. 5). In 2014, the quagga mussel was identified for the first time, with four individuals discovered in four separate quadrates. Distance from shore was also investigated for invasive non-native bivalves, however no effect on overall trends was found (Appendix 1).

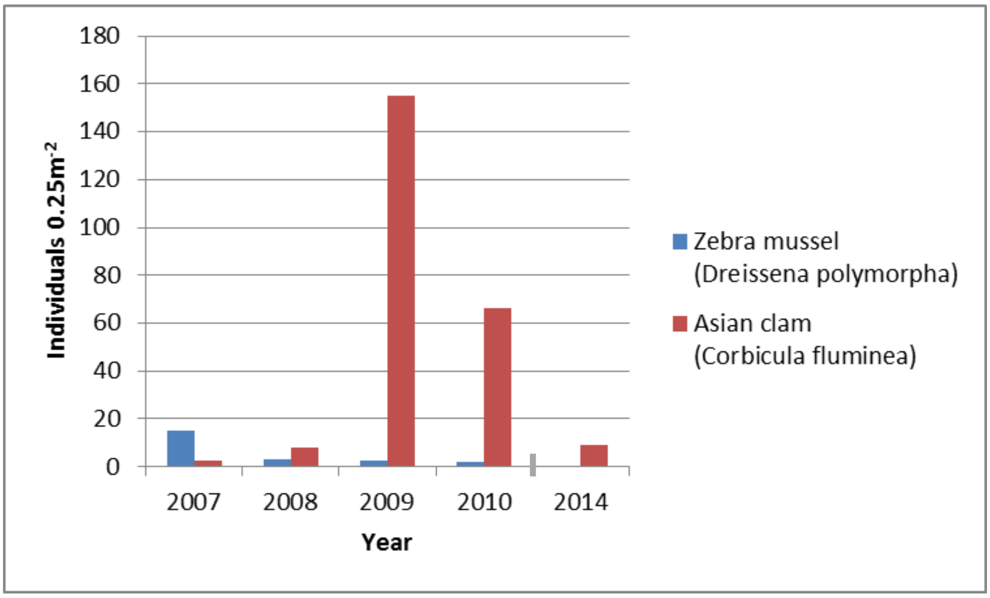

Figure 4: The number of invasive bivalve individuals found per $0.25m^2$ for the 5 years the survey.

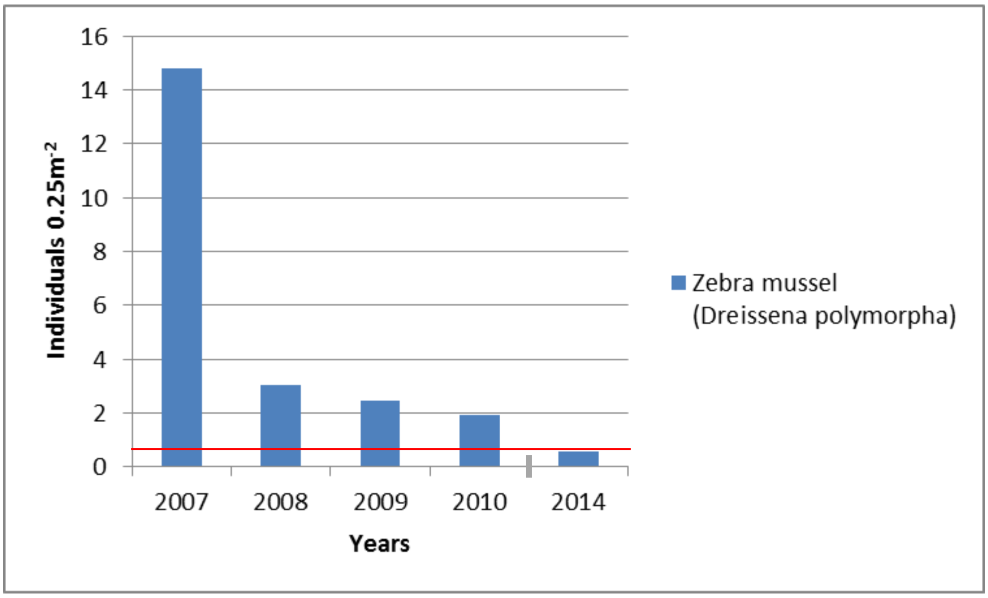

Figure 5: The number of zebra mussels found per $0.25m^2$ for the 5 years the survey. The red line shows the highest recorded abundance of native species for comparison.

Discussion

Although the data shows no overall trend in the three native species, the lowest densities were recorded in the 2014 survey where two species were absent entirely. However, the data gap between 2010 and 2014 means it is not possible to determine whether this is indicative of a trend towards local extinction. Relatively low numbers of both invasive species of bivalves were also found in 2014, suggesting that particularly harsh environmental conditions may have limited all bivalve growth (Bodis *et al*. 2014 and Nalepa and Schloesser 1992). More data will be needed in subsequent years to explain the near total absence of native species in 2014, however with low densities having been recorded since the beginning of the data set there is clear cause for concern.

The zebra mussel appears to have a steady decline over the period of the study. However, due to the missing data between 2010 and 2014 it is not possible to determine if this decline continued over this period. Data will need to be collected in subsequent years in order to ascertain the current population trend of zebra mussels.

The Asian clam appears in low densities in the 2007 and 2008 surveys, and peaks dramatically in 2009. Part of this peak is likely to be explained by the longer transects of up to 26m in 2009, as a previous study suggests that Asian clam abundance increases towards the centre of the waterway (Elliott and Ermgassen 2008). When only the near-shore data is studied, between 0m and 2m, the 2009 peak is less dramatic and is preceded by an increase in 2008. There is no clear reason for this 2009 peak and it is possible that it was driven by favourable environmental conditions in this year. By 2014 it appears that Asian clam numbers are back to their pre-2009 densities although the same problems with interpretation occur due to the 2010-2014 data gap.

Although the presence of invasive bivalves undoubtedly has an impact on native unionids, as discussed previously, they are unlikely to be the single cause of consistently low densities. Many other factors such as climate, pollutants and disturbance can impact bivalve communities (Maclean 2010). In the USA, unionids are known to have undergone steep declines prior to the arrival of invasive species (Karatayev *et al.* 1997). Without historical data sets from this site it is impossible to determine the specific impact of the zebra mussel and Asian clam on native unionids. Whilst these invasive species bring a number of concerns which require attention, reducing their numbers will not necessarily result in the recovery of native populations.

The appearance of the quagga mussel in the 2014 survey confirmed that this species is now present in a major UK waterway and has the potential to undergo a rapid expansion. The quagga mussel has many of the same environmental and economic impacts as the zebra mussel (as detailed previously), however it is thought to be even more invasive. Although there have been cases of quagga mussels displacing zebra mussels entirely (Zhulidov *et al.* 2010), it is believed that their niches do not entirely overlap and therefore the quagga mussel is likely to increase the cumulative impact of these two species (Roy *et al.* 2014).

Given the environmental and economic impacts of these species, it is essential that efforts are made to reduce their population size and range. In closed water bodies several treatment options are available such as chlorine and UV filtration (Sousa *et al.* 2014). However, these treatments are unusable, or become less effective and more harmful to native aquatic life, in open or moving water such as the Tidal Thames (Aldridge *et al.* 2004 and Aldridge *et al.* 2006). In an attempt to reduce the collateral damage of chemical dosing, researches at the University of Cambridge have created coated chlorine BioBullets®. These BioBullets® increase the uptake of chlorine by target organisms and thus substantially reduce the required chemical dosage (Aldridge *et al.* 2006).

Although this novel treatment method offers hope for combating invasive bivalve outbreaks in open water systems, more research is needed to fully understand potential impacts on native organisms.

In light of these difficulties it is important that a proactive approach is adopted in the Tidal Thames to reduce the spread of invasive non-native bivalves. This approach should involve strong public awareness campaigns (Finnoff *et al.* 2007), increased monitoring of water bodies and preventative measures to reduce the spread of invasive bivalves from human activity. Through our engagement with volunteers and the London Invasive Species Initiative, ZSL is actively raising public awareness of this key conservation issue and encouraging good practice for all water users. An element of this work is our endorsement of the 'Clean, Check, Dry' protocol to prevent water users from inadvertently transporting invasive bivalve larvae.

Recently introduced non-native species, with the potential to become invasive, often remain at low densities for a period before populations expand rapidly (Sakai *et al.* 2001). Eradication or management of non-native bivalves becomes more difficult once they have become established in an area or have become invasive (Sousa *et al.* 2014), thus early detection is vital for effective extirpation or containment. To aid with timely and cost effective surveillance, ZSL, Kingston University and LISI are developing genomic tools to detect presence of invasive species in water samples from the Thames. It is likely that such techniques will begin to play an increasingly important role in surveillance and monitoring to manage non-native bivalves and other aquatic non-native species in the Tidal Thames.

Conclusion

Although no direct trend was observed between the three key invasive non-native species and native unionids it is highly likely that their presence has played a role in the consistently low densities. The arrival of the quagga mussel is likely to increase the pressure on native unionids as well as add to the already high economic and environmental costs of established invasive bivalves. In order to combat the arrival of this species, a co-ordinated and cross-sectorial response is urgently required. To aid efficient action it would be highly beneficial that monitoring is increased in potentially susceptible water bodies and that plans are in place for the immediate response to new discoveries. ZSL will continue the freshwater bivalve survey annually to check the spread of the quagga and other INNS bivalves in the upper Tidal Thames. All results from the survey work are shared with relevant local bodies.

Like many other species, freshwater bivalves are likely to be impacted by advancing climate change. As temperatures are pushed up, the 'climate space' for native bivalves in the UK will begin to shrink. If species are to survive it is vital that they are able to disperse into this remaining climate space. As many native freshwater bivalve populations have low densities and reproductive capacity, their dispersal potential is almost non-existent. Conservation efforts should be focused on these rare species to ensure they have the ability to expand into suitable regions in the future. (Maclean 2010).

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Appendix 1

Distance Analysis

Although the distance from shore correlated significantly with the abundance of Asian clams (rs= 0.34, S= 14696717, p= <0.0001), this effect was largely influenced by a strong correlation in the 2009 survey (rs=0.74, S=8746.99. p=<0.0001) and the relationship disappeared if this year was removed (rs=0.74, S=8746.99. p=<0.0001). Furthermore, abundance boxplots for the near (0-2m, n=78), middle (4-8m, n=75) and far (8-28m, n=84) shore habitat showed a broadly similar yearly pattern; suggesting that distance was not biasing the overall trend (Fig. 6). No relationship was found for zebra mussels (rs=0.08, S=2040260, p=0.2175).

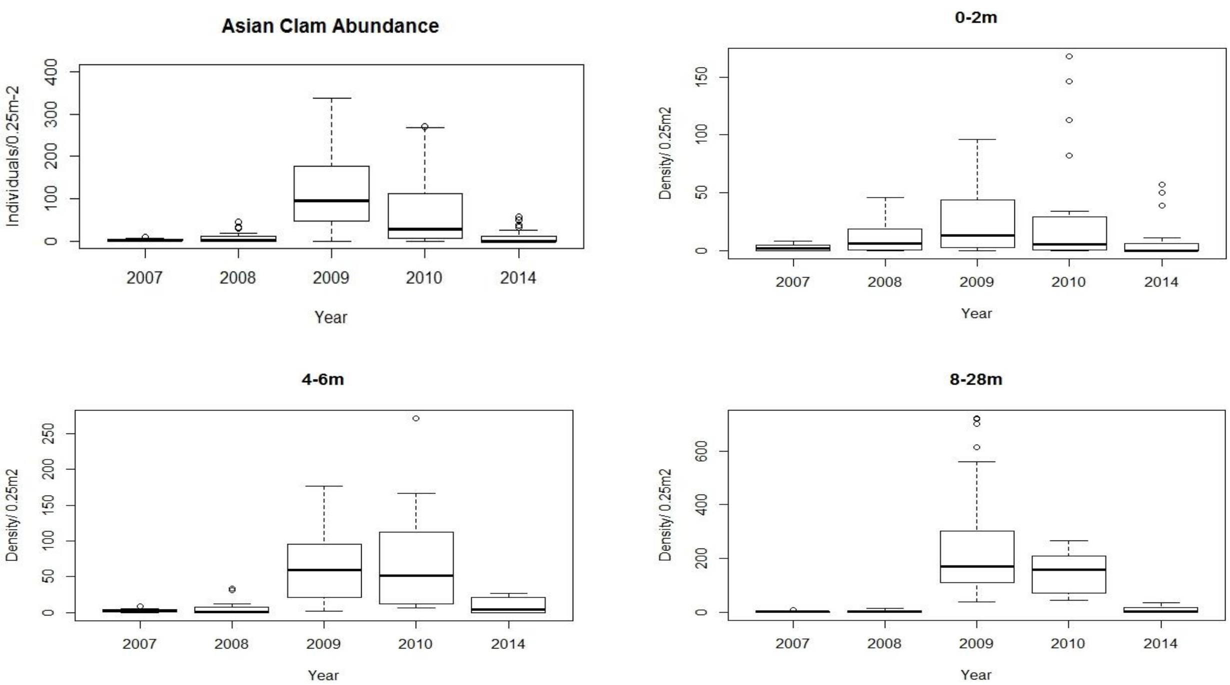

Figure 6: Box plots showing the densities of Asian clams over the period of study in total, near (0-2m), middle (4-6m) and far (8-28m) shore categories.