RAPID RISK ASSESSMENT SUMMARY

Updated: September 2015

Asian Clam (*Corbicula fluminea*)

- Freshwater bivalve, usually <30mm, with a yellow-brown shell.
- One of the worlds most widespread aquatic invasives, in the DAISIE top 100.
- High reproductive output, rapid growth rate and spread.
- Established and spreading in a number of rivers in southeast England.
- Broad habitat tolerance (still and flowing), could be limited by cold temperatures (needs 15°C to breed).
- Potential impacts on freshwater ecosystems, and on raw water users.

History in GB

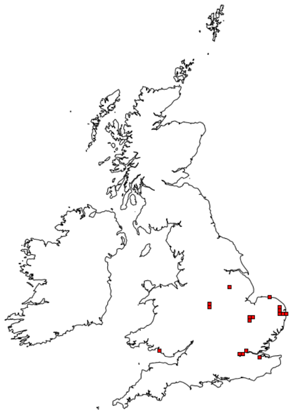
First recorded in GB on the River Chet on the Norfolk Broads in 1998, but by 2002 had spread to all major rivers in the Broads. Since then has been discovered in the Thames (2004), the Great Ouse (2005), the River Trent, midlands (2007), Port Talbort in Wales (2011), and the River Medway (2012).

Native distribution

Native to southern and eastern Asia, Australia, and Africa.

[awaiting native range map]

Distribution in GB



Source: NBN 2014

Impacts

Environmental (major)

- Has high filtration rates which affect water quality, stripping nutrients and altering dynamics.
- Can affect all components of the freshwater ecosystem, altering entire ecosystems.
- Outcompetes other species; represents over 95% of benthic biomass in some freshwater bodies.
- Expected impacts on native species. Impact on depressed river mussel demonstrated in field experiments replicating conditions in GB.
- Has provided substrate for another bivalve invader (*Dreissena polymorpha*) in the Norfolk Broads.

Economic (moderate)

- Pest in Europe (cost £200k pa in Portugal) and North America, where closure of a nuclear power plant due to biofouling, and inspection of all other plants, cost £1 billion pa.
- Potential significant impacts on the British power generating and water treatment industry through biofouling.

Social

- None known.

Climate change

- Likely to benefit as more of GB will be above the 15°C required for reproduction.

Introduction pathway

Fouling—private craft such as sailing boats or motor-yachts are suspected to be the source of the original population in the Norfolk Broads; and potentially angling gear

Intentional introduction— Irish populations were probably intentionally introduced as a food item

Spread pathway

Natural—dispersal rates as high as 276 km/yr were observed in the River Rhine.

Human— can be spread as adults and larvae on boats, wetsuits, angling equipment (nets and stink bags), in ship's ballast water and with overland boat transmissions

Summary

	Risk	Confidence
Entry	VERY LIKELY	VERY HIGH
Establishment	VERY LIKELY	VERY HIGH
Spread	RAPID	VERY HIGH
Impacts	MAJOR	HIGH
Conclusion	HIGH	HIGH

Information about GB Non-native Species Risk Assessments

The Convention on Biological Diversity (CBD) emphasises the need for a precautionary approach towards non-native species where there is often a lack of firm scientific evidence. It also strongly promotes the use of good quality risk assessment to help underpin this approach. The GB risk analysis mechanism has been developed to help facilitate such an approach in Great Britain. It complies with the CBD and reflects standards used by other schemes such as the Intergovernmental Panel on Climate Change, European Plant Protection Organisation and European Food Safety Authority to ensure good practice.

Risk assessments, along with other information, are used to help support decision making in Great Britain. They do not in themselves determine government policy.

The Non-native Species Secretariat (NNSS) manages the risk analysis process on behalf of the GB Programme Board for Non-native Species. Risk assessments are carried out by independent experts from a range of organisations. As part of the risk analysis process risk assessments are:

- Completed using a consistent risk assessment template to ensure that the full range of issues recognised in international standards are addressed.
- Drafted by an independent expert on the species and peer reviewed by a different expert.
- Approved by an independent risk analysis panel (known as the Non-native Species Risk Analysis Panel or NNRAP) only when they are satisfied the assessment is fit-for-purpose.
- Approved for publication by the GB Programme Board for Non-native Species.
- Placed on the GB Non-native Species Secretariat (NNSS) website for a three month period of public comment.
- Finalised by the risk assessor to the satisfaction of the NNRAP.

To find out more about the risk analysis mechanism go to: www.nonnativespecies.org

Common misconceptions about risk assessments

To address a number of common misconceptions about non-native species risk assessments, the following points should be noted:

- Risk assessments consider only the risks posed by a species. They do not consider the practicalities, impacts or other issues relating to the management of the species. They therefore cannot on their own be used to determine what, if any, management response should be undertaken.
- Risk assessments are about negative impacts and are not meant to consider positive impacts that may also occur. The positive impacts would be considered as part of an overall policy decision.
- Risk assessments are advisory and therefore part of the suite of information on which policy decisions are based.
- Completed risk assessments are not final and absolute. Substantive new scientific evidence may prompt a re-evaluation of the risks and/or a change of policy.

Period for comment

Draft risk assessments are available for a period of three months from the date of posting on the NNSS website*. During this time stakeholders are invited to comment on the scientific evidence which underpins the assessments or provide information on other relevant evidence or research that may be available. Relevant comments are collated by the NNSS and sent to the risk assessor. The assessor reviews the comments and, if necessary, amends the risk assessment. The final risk assessment is then checked and approved by the NNRAP.

*risk assessments are posted online at:
https://secure.fera.defra.gov.uk/nonnativespecies/index.cfm?sectionid=51
comments should be emailed to nnss@apha.gsi.gov.uk

Rapid Assessment of: ***Corbicula fluminea***
Author: **Dr. Alexandra Zieritz**
Version:
Final (April 2016) – Draft 1 (July 2012); Peer Review (July 2012); NNRAP review (February 2013); Draft 2 (April 2013); NNRAP review (October 2013); Programme Board approval (March 2015); Publication on NNSS website (September 2015)

GB Non-native species Rapid Risk Assessment (NRRA)

1 - What is the principal reason for performing the Risk Assessment? (Include any other reasons as comments)

Response: *To assess the risks associated with this species in Great Britain. The Water Framework Directive Alien Species Group has identified this species as an unknown risk and has requested a risk assessment be produced.*

2 - What is the Risk Assessment Area?

Response: *Great Britain (i.e. England, Scotland, Wales and their islands)*

3 - What is the name of the organism (scientific and accepted common; include common synonyms and notes on taxonomic complexity if relevant)?

Response: *Corbicula fluminea* (O. F. Müller, 1774), Asian clam, Asiatic clam

The most commonly used synonyms for *Corbicula fluminea* are *Corbicula manilensis* and *Corbicula leana*.

Morphological and molecular analyses by Pigneur *et al.* (2011) revealed that there are three *Corbicula* morphotypes in Western Europe, which belong to three distinct nuclear and mitochondrial lineages. Two of these – including the form present in GB – are currently termed *Corbicula fluminea*, the third one is referred to as *Corbicula fluminalis*. Pigneur *et al.* (2011) further suggest that due to the low genetic divergence between and within the three forms, and the possibility of hybridisation through androgenesis between forms, these invasive lineages of *Corbicula* may represent a polymorphic species complex. The authors therefore propose to use the nomenclature 'form R' (= the form widespread in Europe including GB), 'form S' and 'form Rlc' for the three West-European *Corbicula* lineages (see Marescaux *et al.* (2010) for photographs of the three forms).

4 - Is the organism known to be invasive anywhere in the world?

Response: Yes
C. fluminea is one of the world's most wide-spread aquatic organisms (Siripattrawan, Park & O Foighil, 2000; Mueller, 2003). While historically, the genus *Corbicula* occurs in temperate to tropical southern Asia, Africa south of the Sahara, southeast Asian islands, and central and eastern Australia (Morton, 1986), *C. fluminea* is now present on almost all continents and invasive in North America, South America and Europe. Invasive populations can reach densities of up to several thousand individuals m^{-2} (Wittmann *et al.*, 2012), which can have serious environmental and economic impacts (see section 'Impact summary' and references therein). As a consequence, *C. fluminea* is widely regarded as one of the most damaging invaders, being listed on the DAISIE database (www.europe-aliens.org) as one of Europe's 100 'worst' invasive species.

History of global spread:
The first published records outside its extant original range are from 1924 and 1937 in Nanaimo, Vancouver Island, British Columbia, Canada, and in Raymond, Pacific County, Washington, respectively (Burch, 1944; Counts, 1981, 1985). The clam then quickly spread throughout North America (McMahon, 1982), and arrived in

South America in the 1970s (Ituarte, 1981) and in southwest Europe in the 1980s (Mouthon, 1981). After its arrival in Portuguese and French estuaries, it spread to Germany, Spain, the Netherlands, Belgium, the Czech Republic, and other Central and Eastern European countries (e.g. Kinzelbach, 1991; Vaate, 1991; Alf, 1992; Araujo, Moreno & Ramos, 1993; Beran, 2000; Paunović *et al.*, 2007). After the opening of the Danube-Main-Rhine canal in 1992, the species spread along the River Danube from west to east, and now inhabits large parts of that river, extending to Romania (Bodis *et al.*, 2011a). The species has succeeded in colonising many of the major European watersheds and can reach high densities in some rivers and lakes (e.g. Mouthon, 2003; Bodis *et al.*, 2011b). It now occurs in almost all Europe as far east as Poland and Ukraine, as far south as Italy, Macedonia and Bulgaria (http://www.europe-aliens.org), and including GB since 1997/98 (see section 5 below for details on history of spread in GB). In 2010, the first Irish population of *C. fluminea* was recorded in the River Barrow (Sweeney, 2009). Within the following years, further populations of this species were recorded in the Rivers Nore and Shannon, as well as in Lough Derg (Caffrey *et al.*, 2011).

5 - What is the current distribution status of the organism with respect to the Risk Assessment Area?

Response: At the moment, *C. fluminea* is known to be established and spreading across the following river systems in Southeast and Central England: (1) the Northern and Southern Norfolk Broads drainage including the River Chet, River Waveney, River Bure and Rockland Broad; (2) the Great Ouse system including the New Bedford River and the River Cam; (3) the River Thames within the London area; (4) the River Medway-system at Burham Marsh; and (5) the River Trent system including the Trent and Mersey Canal (Grand Trunk Canal). Recently, the first sighting from Wales has been reported at (6) Llewellyns Quay, Port Talbot, Swansey Bay. As will be shown in the following, the spread of *C. fluminea* across British freshwaters has been fast and is continuing.

History of spread in GB (if not indicated otherwise, data provided by © Environment Agency):
In GB, *C. fluminea* was first discovered in 1998 in the River Chet on the Norfolk Broads, and it is believed to have arrived in Norfolk in 1997 (Howlett & Baker, 1999). By 2002, it had already colonised all of the major rivers of The Broads drainage system, and in places densities of over 2500 individuals m^{-2} have been recorded. Now it can be found in many rivers in this area, including the Rockland Broads (first sighting 1999), the River Yare (first sighting in 1999), the Rivers Bure, Thurne and Ant (first sightings 2000), the River Waveney (first sighting 2001) (Mueller, 2003).

In 2004, the first specimen of *C. fluminea* was noted at Teddington on the River Thames. The species has now spread across this river and reaches high densities (Elliott & Ermgassen, 2008).

In 2005, it was first detected in the Great Ouse system (Willing, 2007), and several sightings have been recorded in the New Bedford River since. In 2012, the first sighting has been made in the River Cam in the vicinity of Cambridge (Elizabeth Harper, pers. comm.).

In 2007, the first sighting from the River Trent was reported, and further specimens were found in subsequent years at the Trent & Mersey Canal/Grand Trunk Canal.

In 2011, the first sighting in Wales was recorded at Port Talbot, Swansey Bay.

In 2012, a sighting from Burham Marsh from the River Medway system has been reported.

6 - Are there conditions present in the Risk Assessment Area that would enable the organism to survive and reproduce? Comment on any special conditions required by the species?

Response: Yes.
The species has been established, reproducing and extending its range in various lowland river systems across Southeast and Central England. The current rate of spread (see section 5), as well as bioclimatic analyses regarding potentially suitable areas for this species indicate that additional river systems and canals within GB will be invaded by *C. fluminea* in the near future (Mueller, 2003).

C. fluminea is known to inhabit a wide range of freshwater habitats. Populations can thrive in both standing and flowing, oligotrophic and eutrophic waters, and tolerates salinities of approximately 5-14 ppt (Gainey, 1978; Morton & Tong, 1985; http://www.europe-aliens.org; Sousa, Antunes & Guilhermino, 2008a). It is common on oxygenated muddy to sandy sediments, but also occurring among gravel and cobbles (e.g. Araujo *et al.*, 1993; Killeen, Aldridge & Oliver, 2004). Habitats occupied in Britain range from shallow, essentially lentic environments to relatively wide, deep, flowing rivers and associated channels, irrigation and drainage cuts.

Possibly the most important range-limiting environmental variable for *C. fluminea* in GB is temperature. The Asian clam tolerates water temperatures from 2-34°C (McMahon, 1983), and can survive several weeks in water of 0°C (Mueller & Baur, 2011). While upper lethal temperatures are extremely unlikely to be reached in British water bodies, lethally cold temperatures are likely to occur in high altitude areas. More significantly, reproduction of this species requires water temperatures of at least 15°C (McMahon, 2000); this further reduces the size of the area within GB that could potentially be invaded by reproducing populations (Mueller, 2003) (see section 'Establishment summary' for details on predictions for future spread).

Recent work conducted in Irish rivers and lakes has shown that the vast majority of watercourses on the island are suitable for colonisation in respect of pH and calcium (Lucy, Karatayev & Burlakova, 2012). This situation is probably quite similar in GB.

7 - Does the known geographical distribution of the organism include ecoclimatic zones comparable with those of the Risk Assessment Area or sufficiently similar for the organism to survive and thrive?

Response: Yes
The European and British areas already invaded by *C. fluminea* include regions and river systems which share a strong bioclimatic match to much of Britain's freshwaters which have not yet been invaded by this species.

8 - Has the organism established viable (reproducing) populations anywhere outside of its native range (do not answer this question if you have answered 'yes' to question 4)?

Response: n.a. (see section 4)

9 - Can the organism spread rapidly by natural means or by human assistance?

Response: Yes. The organism has shown its potential to spread rapidly across three continents as well as within GB by various natural and human vectors (see section 'Spread summary' for details).

10 - Could the organism itself, or acting as a vector, cause economic, environmental or social harm in the Risk Assessment Area?

Response: Yes, *C. fluminea* is recognised as a serious pest with very important economic and ecological effects (e.g. Sinclair & Isom, 1963; McMahon, 1983). The current effects in British freshwaters are, however, relatively poorly understood (see section 'Impact Summary' for details).

Entry Summary

Estimate the overall likelihood of entry into the Risk Assessment Area for this organism (comment on key issues that lead to this conclusion).

Response: ***very likely***

Confidence: ***very high***

Comments (include list of entry pathways in your comments):
C. fluminea has already entered GB and is likely to do so again. Location and timing of finds of the Asian clam in the respective river systems suggest that the species may have been introduced as many as 3 to 4 times into British freshwaters within the past 15 years – most probably via the European mainland (e.g. Rhine delta), where the species is present in very high numbers. The exact number, origin and vector of introduction to GB are, however, unknown.

Based on molecular analyses and the close proximity of the Norfolk Broads to mainland Europe, Mueller (2003) argues that a European origin is the most likely scenario for this first British population. Given the lack of commercial shipping in the Broads, he further suggests that this was facilitated by private crafts such as sailing boats or motor-yachts, which are common on this river system. The population from the tidal River Thames, first reported in 2004, may represent a separate invasion from the European mainland, as do those from Port Talbot (2011) and possibly Burham Marsh (2012). On the other hand, it seems plausible that populations present in inland reaches of the Great Ouse (2005) and Trent River (2007) systems originate from the previously established populations at the Norfolk Broads and/or the River Thames.

The Asian clam was very probably intentionally introduced to Ireland from the Netherlands as a food item (J. Caffrey, pers com). This possibility should also be considered in GB.

Establishment Summary

Estimate the overall likelihood of establishment (comment on key issues that lead to this conclusion).

Response: ***very likely***

Confidence: ***very high***

Comments (state where in GB this species could establish in your comments, include map if possible):
C. fluminea has been established, reproducing and spreading in several British river systems for about 15 years.

Taking into account calcium levels, pH, and mean long-term air temperature in the coldest and warmest months, respectively, Mueller (2003; fig. 7.8) provides predictive scenarios regarding which areas in GB can be considered potentially suitable for the establishment of dense *C. fluminea* populations. His results indicate that areas most likely to be successfully colonised by *C. fluminea* are most of lowland England (with the exception of the far south-west) and south Wales. Due to too low summer temperatures to allow for reproduction, in the present climate, populations are unlikely to establish in all of Scotland, Northern Ireland, and much of upland Wales. In general, it should be noted that invasive *C. fluminea* populations are hermaphroditic and able of self-fertilisation (Rajagopal, van der Velde & de Vaate, 2000; Dubois & Martinez-Orti, 2010); thus, introduction of a single individual can be sufficient to develop a new population.

Spread Summary

Estimate overall potential for spread (comment on key issues that lead to this conclusion).

Response: ***rapid***

Confidence: ***very high***

Comments (include list of spread pathways in your comments):
Given its current rate of spread across GB over the past 15 years or so (see section 5 above), the Asian clam is likely to spread further and have significant ecological effect upon other British river catchments. Once a new catchment has been entered, dispersal rates can be as high as 276 km yr^{-1}, as was observed during the invasion of the River Rhine (Leuven *et al.*, 2009).

Asian clam larvae (pediveligers) produce a byssus causing it to be dragged by water currents, and juveniles and adults may produce tacky mucus strings that can also result in dispersal. Byssus drifting-related transport (Prezani & Chalermwat, 1984) and unassisted upstream movement (Voelz, McArthur & Rader, 1998) are likely to have played a significant role in the species' dispersal. Natural dispersal by animals is suspected on account of the tacky mucus threads that may adhere to wading waterfowl, birds and fishes. The main actors in *C. fluminea*'s recent spread are, however, humans (Thompson & Sparks, 1977; McMahon, 1982). It is used in ornamental ponds, aquaria, and can be moved entangled in macrophytes, through recreational boats, on scuba divers' wetsuits or in angling equipment, in ships' freshwater ballast and with overland boat transmissions (Rosa *et al.*, 2011).

According to Mueller (2003), in GB, the main vectors of *C. fluminea* are probably boats – both in overland transport and whilst in use on waterways, and waterbirds.

According to the reviewer, however, anglers play a far greater role than boaters (J. Caffrey pers com). Many of the areas that support populations of Asian clam in Ireland are active coarse fisheries, where anglers leave large keep nets suspended in the water for hours at a time. Following the fishing event, commonly the nets are placed in sealed 'stink bags' where the clam or juvenile can live for days or weeks. The wet nets are then taken from the 'stink bag' and placed in the water at the next fishing location, releasing the clam into the water at this site. A number of our new finds in Ireland are at known angling locations, mainly on the River Shannon,

Impact Summary

Estimate overall severity of impact (comment on key issues that lead to this conclusion)

Response:
Environmental: ***major***
Economic: ***moderate***

Confidence:
Environmental: ***high***
Economic: ***medium***

Comments (include list of impacts in your comments):
C. fluminea has become a major pest in Europe and North America because of its high reproductive output, rapid growth rate and great powers of dispersal. It can affect all components of the freshwater ecosystem, causing serious ecological and economical problems. The actual current and potential impacts of the species in GB are, however, relatively poorly understood (Aldridge & Mueller, 2001).

Environmental effects:
The combination of *C. fluminea*'s high filtration rates, ability to produce large quantities of pseudofaeces and attain enormous population densities can have numerous and wide-ranging environmental effects (Aldridge & Mueller, 2001; Mueller, 2003). For example, various studies in North America and mainland Europe have shown substantial reductions of phytoplankton and turbidity over dense beds of *C. fluminea* (Cohen *et al.*, 1984; Leff, Burch & McArthur, 1990; Sousa *et al.*, 2008b). The species represents over 95% of the benthic biomass in some freshwater bodies, consequently sequestering an enormous portion of the carbon available for benthic production (Karatayev *et al.*, 2003) and increasing sedimentation rates (Prokopovich & Herbert, 1965; Prokopovich, 1969). The combined effects of this invasive species can lead to altering whole ecosystem

dynamics and functioning (Phelps, 1994). By transforming habitat characteristics, *C. fluminea* also influences the composition and diversity of benthic communities including macroinvertebrates (Hakenkamp *et al.*, 2001; Werner & Rothhaupt, 2008a; Schmidlin, Schmera & Baur, 2012). The species has also been shown to compete directly with native macroinvertebrates such as filter feeding bivalves and snails feeding on organics in sediments (Strayer, 1999; Sousa *et al.*, 2011).

Whilst data on the environmental effects of *C. fluminea* in GB is scarce, replicated field experiments by Mueller (2003) showed that it negatively affects growth and survival rates of the endangered Depressed river mussel *Pseudanadonta complanata*. Similarly, Elliott & Ermgassen (2008) highlight their concern for the future of *Pseudanadonta* which inhabits similar habitats and is thus in danger of becoming displaced by the Asian clam. The authors further state that *C. fluminea* is also likely to substantially affect other native biota and ecosystems in the UK. Most notable in this respect are aforementioned impacts on ecosystem dynamics, resulting from the substantial filtration capacities of high density *Corbicula* populations such as those found in the River Thames and the Norfolk Broads drainage system, and exceeding several hundred to thousands individuals m^{-2}. Yet another negative effect of the clam has been reported by Mueller (2003), who observed that in the Norfolk Broads, the Asian clam has provided substrate for another bivalve invader, the Zebra mussel *Dreissena polymorpha*, to move into muddy substrates.

Economic effects:
C. fluminea's greatest economic impact has been biofouling in raw water systems of the United States (Isom, 1986; Williams & McMahon, 1989). Shells can reduce flows in drainage and abstraction pipes in low-flow areas and during periods of low peak usage, and can clog the narrow gauge piping of condensers and heat exchangers of power plants. A range of literature is available on the Asian clam's negative effects on North American plants, including power stations, drinking water treatment plants, sand and gravel companies, irrigation canals and drinking water supplies (e.g. Sinclair, 1964; Prokopovich & Herbert, 1965; McMahon, 1983). For example, in 1980, Asian clams clogged the service water system of a nuclear power plant in Arkansas, resulting in the shutting down of the plant and inspection of every nuclear plant in the country to determine if *C. fluminea* fouling posed a safety threat. The surveys, associated downtime, repair measures and equipment replacement cost an estimated 1 billion US dollars per year (Isom, 1986; Mueller, 2003).

Equivalent studies addressing the problem in Europe are much scarcer (Jenner *et al.*, 1998). Rosa *et al.* (2011) explored the industrial effects of the species in Portugal. Their results indicate that, compared to the situation in North America, the impacts of this pest in the Portuguese freshwater-dependent industry remain relatively mild. No cement plants or pulp and paper mills have reported any infestations yet, and first infestations in drinking water treatment plants and thermal power stations have "not been dramatic". The irrigation sector appeared as an exception to this general trend, with a significant proportion of the national systems, especially those feeding sprinkler irrigation structures, reporting significant impairment and increasing economical losses due to the presence of the Asian clam. Overall, the authors estimate annual cost of *C. fluminea* infestations to the Portuguese freshwater-dependent industry at up to €200,000.

Rosa *et al.* (2011) argue that one plausible explanation for the mild industrial impacts in Portugal is that the Asian clam populations in the Portuguese waterbodies are mostly at the lag time phase (i.e. early phase after colonisation of a new environment during which the species adapts to the novel environmental conditions). and thus, relatively easy to manage. Another possible explanation for the moderate Asian clam infestations in Portuguese industries is the fact that the species is prone to die-offs (reported by e.g. Phelps, 1994; Vohmann *et al.*, 2010).

Although differences between the North American and European populations may exist, Rosa *et al.* (2011) further note that given *C. fluminea* belated arrival in Europe in comparison to the American continent , it may be only a matter of time and natural invasion progress until more dramatic consequences are experienced on the European continent.

Whilst to date, no adverse economic impacts have been assessed in GB, this is likely to change once *C. fluminea* becomes established in waterways with a higher intensity of industrial activity (Aldridge & Mueller, 2001). Macrofouling of industrial facilities which draw water from infested waterways is the main concern in this respect. Mueller (2003) places the potential economic costs of *C. fluminea* to the British power generating and water treatment industry to several millions of pounds a year. The species could potentially affect around 12 inland power stations, each of which is located on waterways currently suitable for the survival and reproduction of *C. fluminea*.

Climate Change

What is the likelihood that the risk posed by this species will increase as a result of climate change?

Response: ***high***

Confidence: ***high***

Comments (include aspects of species biology likely to be effected by climate change (e.g. ability to establish, key impacts that might change and timescale over which significant change may occur):

Based on the 15°C threshold for summer reproduction and the climate change predicted to occur across the UK by 2080, Mueller (2003) argues that 80% of the GB landmass would be able to support *C. fluminea* populations. For example, climate change would render all of Wales and Northern Ireland warm enough for *C. fluminea* to reproduce by 2080, where in the current climate this is unlikely. Observations by Weitere *et al.* (2009) supports this conclusion. These authors showed that reproduction success and growth rates were strongly enhanced by experimental warming during winter. They further argue that this positive effect of moderate winter warming on the clams' fitness is probably one reason for the recent invasion success of *C. fluminea* in the northern hemisphere.

Conclusion

Estimate the overall risk (comment on the key issues that lead to this conclusion).

Response: ***high***

Confidence: ***high***

Comments: As has been shown above, since its first arrival in the Norfolk Broads in 1997, *C. fluminea* has been established and reproducing in several British river catchments. In Britain, it grows at rates comparable to those in other populations, reaches reproductive size within a year and attains large sizes (Mueller, 2003). Over the past 15 years, the species has continuously expanded its range and there is evidence that this included several further invasions from the European mainland. This suggests that the clams will continue to colonise other British waterways in the future. While environmental and economic impacts of the species in GB are insufficiently understood, there is an amount of evidence of serious negative impacts of that species in other invaded areas such as North America and mainland Europe.

Management options (brief summary):

1 - Has the species been managed elsewhere? If so, how effective has management been?

Response: Yes, but published research regarding control practices in the peer-reviewed scientific literature is scarce.

In Lake Tahoe, Wittmann *et al.* (2008; 2012) used gas impermeable benthic barriers to reduce dissolved oxygen concentrations available to *C. fluminea* . At an average water temperature of 18°C, this resulted in 100% *C. fluminea* mortality after 28 days under small barriers, and 98% mortality under larger barriers after 120 days. *C. fluminea* abundances remained significantly reduced one year later. However, non-target benthic macroinvertebrate abundances were also reduced, with variable taxon-specific recolonisation rates. The authors concluded that prolonged exposure to anoxia using benthic barriers can provide an effective short term control strategy for this species.

Similar mortality levels were achieved in a field study at a production plant at the New River, USA, by Doherty *et al.* (1986). Thus, *C. fluminea* mortality exceeded 90% after 28 days of exposure to 0.25 mg L^{-1} total residual chlorine at ambient temperatures of 20-25 °C.

Rosa *et al.* (2011) mention that in drinking water treatment plants and thermal power stations, regular cleaning of the respective water systems seems to be good enough to prevent noticeable clogging and efficiency issues due to clams accumulation.

2 - List the available control / eradication options for this organism and indicate their efficacy.

Response:
Given the species relatively high oxygen requirements, prolonged exposure to extreme hypoxia by using bottom barriers or large plastic sheets may provide an efficacious control strategy (Matthews & McMahon, 1999; Wittmann *et al.*, 2012). Suction dredging may be used to physically remove clams from sediments (Wittmann *et al.*, 2008). Other mechanical methods, such as using screens and traps, can effectively dispose of older clams and remove body tissue and shells from the system (see http://wildlife.utah.gov/pdf/AIS_plans_2010/AIS_12hAsianClam-Dan-Final.pdf). Chemicals, such as small concentrations of chlorine, bromine or molluscicides, can kill juveniles and sometimes adults (Doherty *et al.*, 1986). In the USA, where intakes pipes are fouled, thermal regulation is sometimes employed, whereby water in the pipes is heated to temperatures exceeding 37 degrees Celsius (http://www.issg.org/database/species/ecology.asp?fr=1&si=537). Other factors that may affect population density and distribution of Asian clams include exposure to excessively high or low temperatures, salinity, drying, low pH, silt, pollution, bacterial, viral and parasitic infections, inter- and intraspecific competition, predators, and genetic changes (Sickel, 1986; Werner & Rothhaupt, 2008b). Efficacy of most of these methods has, however, not been discussed in the peer-reviewed literature yet.

While exploring the efficacy of dredging for Asian clam in the River Barrow, it was noted by the reviewer and collaborators that the clams in this system were very susceptible to disturbance and large numbers of clam that had been passed over by the dredge but not removed were dead when the site was examined by divers 2 days later (unpublished data).

3 - List the available pathway management options (to reduce spread) for this organism and indicate their efficacy.

Response:
In order to limit the further spread of *C. fluminea* across GB, anglers, boaters and other waterway users should be encouraged to inspect and clean all equipment that has been exposed to or used in waterways when moving from one area to another. This will necessitate a public outreach programme to likely vectors (e.g. anglers). A GB-wide system of monitoring should be initiated to maximise the opportunities for containment and eradication of newly established populations. The species use as an ornamental should be discouraged, and legislation and inspections are needed to prevent new arrivals on geographically separated areas (www.europe-aliens.org).

4 - How quickly would management need to be implemented in order to work?

Response: *C. fluminea* reproduces at water temperatures above 15°C, is able of self-fertilisation, and an adult clam may produce as many as 70,000 juveniles in a year (Aldridge & McMahon, 1978). A single individual is therefore sufficient to start a new population, and populations may increase and establish rapidly. Upon the discovery of a new population, control and eradication efforts should therefore be attempted as soon as possible. This should be complemented with urgent responses in relation to signage, education and outreach.

References

Provide here a list of the references cited in the course of completing assessment

Aldridge DC, Mueller SJ. 2001. The Asiatic clam, *Corbicula fluminea*, in Britain: current status and potential impacts. *Journal of Conchology* **37:** 177-183.

Aldridge DW, McMahon RF. 1978. Growth, fecundity, and bioenergetics in a natural population of the asiatic freshwater clam, *Corbicula manilensis* Philippi, from North Central Texas. *Journal of Molluscan Studies* **44**.

Alf A. 1992. Ein bemerkenswerter Fundort von *Corbicula fluminalis* Müller 1774 im Rhein - mit Anmerkungen zur Ökologie und zu weiteren Vorkommen der Art in Baden-Württemberg. *Lauterbornia* **9:** 65-72.

Araujo R, Moreno D, Ramos MA. 1993. The Asiatic clam *Corbicula fluminea* (Mueller,1774) (Bivalvia: Corbiculidae) in Europe. *American Malacological Bulletin* **10:** 39-49.

Beran L. 2000. First record of *Corbicula fluminea* (Mollusca: Bivalvia) in the Czech Republic. *Acta Societatis Zoologicae Bohemicae* **64:** 1-2.

Bodis E, Nosek J, Oertel N, Toth B, Feher Z. 2011a. A comparative study of two *Corbicula* Morphs (Bivalvia, Corbiculidae) inhabiting River Danube. *International Review of Hydrobiology* **96:** 257-273.

Bodis E, Nosek J, Oertel N, Toth B, Hornung E, Sousa R. 2011b. Spatial distribution of bivalves in relation to environmental conditions (middle Danube catchment, Hungary). *Community Ecology* **12:** 210-219.

Burch JQ. 1944. Checklist of west American mollusks. Family Corbiculidae. *Minutes of the Conchological Club of Southern California* **36:** 18.

Caffrey JM, Evers S, Millane M, Moran H. 2011. Current status of Ireland's newest invasive species – the Asian clam *Corbicula fluminea* (Müller, 1774). *Aquatic Invasions* **6:** 291–299.

Cohen R, Dresler P, Phillips E, Cory R. 1984. The effect of the Asiatic clam, *Corbicula fluminea*, on phytoplankton of the Potomac River, Maryland. *Limnology & Oceanography* **29:** 170-180.

Counts CLI. 1981. *Corbicula fluminea* (Bivalvia: Sphacriacea) in British Columbia. *Nautilus* **95:** 12-13.

Counts CLI. 1985. *Corbicula fluminea* (Bivalvia: Corbiculidae) in the state of Washington in 1937, and in Utah in 1975. *Nautilus* **99:** 18-19.

Doherty FG, Farris JL, Cherry DS, John Cairns J. 1986. Control of the freshwater fouling bivalve *Corbicula fluminea* by halogenation. *Archives of Environmental Contamination and Toxicology* **15**.

Dubois C, Martinez-Orti A. 2010. Reproduction of the invading mollusc *Corbicula fluminea* (O. F. Mueller, 1774) (Bivalvia: Corbiculidae) and recruitment and distribution of juveniles near a canal in the region of Toulouse (France). *Iberus* **28:** 1-11.

Elliott P, Ermgassen PSEz. 2008. The Asian clam (*Corbicula fluminea*) in the River Thames, London, England. *Aquatic Invasions* **3:** 54-60.

Gainey LF. 1978. The response of the Corbiculidae (Mollusca: Bivalvia) to osmotic stress: the organismal response. *Physiological Zoology* **51**.

Hakenkamp CC, Ribblett SG, Palmer MA, Swan CM, Reid JW, Goodison MR. 2001. The impact of an introduced bivalve (*Corbicula fluminea*) on the benthos of a sandy stream. *Freshwater Biology* **46:** 491-501.

Howlett D, Baker R. 1999. *Corbicula fluminea* (Muller): New to UK. *Journal of Conchology* **36:** 83-83.

Isom BG. 1986. Historical review of Asiatic clam (*Corbicula*) invasion and biofouling of waters and industries in the Americas. *American Malacological Bulletin. Special Edition* **2:** 95-98.

Ituarte C. 1981. Primera noticia acerca de la introduccion de pelecipodos asiaticos en el area Rioplatense (Mollusca, Corbiculidae). *Neotropica* **27:** 79-82.

Jenner H, Whitehouse J, CJL T, M K. 1998. Cooling water management in European power stations: biology and control of fouling. *Hydroecologie Applique Tome* **19:** 225pp.

Karatayev A, Burlakova L, Kesterson T, DK P. 2003. Dominance of the Asiatic clam, *Corbicula fluminea* (Muller), in the benthic community of a reservoir. *Journal of Shellfish Research* **22:** 487-493.

Killeen I, Aldridge DC, Oliver G. 2004. *Freshwater Bivalves of Britain and Ireland*. Field Studies Council.

Kinzelbach R. 1991. Die Körbchenmuscheln *Corbicula fluminalis*, *Corbicula fluminea* und *Corbicula fluviatilis* in Europa (Bivalvia: Corbiculidae). *Mainzer Naturwissenschaftliches Archiv* **29:** 215-228.

Leff L, Burch JL, McArthur JV. 1990. Spatial distribution, seston removal, and potential competitive interactions of the bivalves *Corbicula fluminea* and *Elliptio complanata*, in a coastal plain stream. *Freshwater Biology* **24:** 409-416.

Leuven R, van der Velde G, Baijens I, Snijders J, van der Zwart C, Lenders H, bij de Vaate A. 2009. The river Rhine: a global highway for dispersal of aquatic invasive species. *Biological Invasions* **11:** 1989–2008.

Lucy FE, Karatayev AY, Burlakova LE. 2012. Predictions for the spread, population density, and impacts of *Corbicula fluminea* in Ireland. *Aquatic Invasions* **7:** 465-474.

Marescaux J, Pigneur L-M, Doninck KV. 2010. New records of *Corbicula* clams in French rivers. *Aquatic Invasions* **5:** S35-S39.

Matthews MA, McMahon RF. 1999. Effects of temperature and temperature acclimation on survival of zebra mussels (*Dreissena polymorpha*) and Asian clams (*Corbicula fluminea*) under extreme hypoxia. *Journal of Molluscan Studies* **65:** 317-325.

McMahon R. 1982. The occurrence and spread of the introduced asiatic freshwater clam, *Corbicula fluminea* (Mueller), in North America: 1924-1982. *Nautilus* **96:** 134-141.

McMahon R. 1983. Ecology of an invasive pest bivalve, *Corbicula*. In: Russell-Hunter W, ed. *The Mollusca. Ecology*. New York: Academic Press, 505-561.

McMahon R. 2000. Invasive characteristics of the freshwater bivalve *Corbicula fluminea*. In: Claudi R and Leach J, eds. *Non-indigenous Freshwater Organisms: Vectors, Biology and Impacts*. Boca Raton, Florida: Lewis Publishers, 315-343.

Morton B. 1986. *Corbicula* in Asia - an updated synthesis. *American Malacological Bulletin* **Special Edition No. 2:** 113-124.

Morton B, Tong K. 1985. The salinity tolerance of *Corbicula fluminea* (Bivalvia:Corbiculoidea) from Hong Kong. *Malacological Review* **18:** 91-95.

Mouthon J. 1981. Sur la presence en France et au Portugal de *Corbicula* (Bivalvia, Corbiculidae) originaire d'Asie. *Basteria* **45:** 109-116.

Mouthon J. 2003. Longitudinal and temporal variations of density and size structure of *Corbicula fluminea* (Bivalvia) populations in the Saone and Rhone rivers (France). *Annales De Limnologie-International Journal of Limnology* **39:** 15-25.

Mueller O, Baur B. 2011. Survival of the invasive clam *Corbicula fluminea* (Muller) in response to winter water temperature. *Malacologia* **53:** 367-371.

Mueller SJ. 2003. Ecology and impacts of the non-indigenous Asian clam *Corbicula fluminea* (Mueller, 1774) in Britain. Unpublished PhD, University of Cambridge.

Paunović M, Csányi B, Knežević S, Simić V, Nenadić D, Jakovčev-Todorović D, Stojanović B, Cakić P. 2007. Distribution of Asian clams *Corbicula fluminea* (Müller, 1774) and *C. fluminalis* (Müller, 1774) in Serbia. *Aquatic Invasions* **2:** 99-106.

Phelps H. 1994. The Asiatic clam (*Corbicula fluminea*) invasion and system-level ecological change in the Potomac River Estuary near Washington, D. C. *Estuaries and Coasts* **17:** 614–621.

Pigneur L-M, Marescaux J, Roland K, Etoundi E, Descy J-P, Van Doninck K. 2011. Phylogeny and androgenesis in the invasive *Corbicula* clams (Bivalvia, Corbiculidae) in Western Europe. *Bmc Evolutionary Biology* **11**.

Prezani R, Chalermwat K. 1984. Flotation of the bivalve *Corbicula fluminea* as a means of dispersal. *Science* **225:** 1491-1493.

Prokopovich N. 1969. Deposition of clastic sediments by clams. *Journal of Sedimentary Petrology* **39:** 891-901.

Prokopovich N, Herbert D. 1965. Sedimentation in the Delta–Mendota Canal. *Journal of the American Water Works Association* **57:** 375–382.

Rajagopal S, van der Velde G, de Vaate AB. 2000. Reproductive biology of the Asiatic clams *Corbicula fluminalis* and *Corbicula fluminea* in the river Rhine. *Archiv Fur Hydrobiologie* **149:** 403-420.

Rosa IC, Pereira JL, Gomes J, Saraiva PM, Goncalves F, Costa R. 2011. The Asian clam *Corbicula fluminea* in the European freshwater-dependent industry: A latent threat or a friendly enemy? *Ecological Economics* **70:** 1805-1813.

Schmidlin S, Schmera D, Baur B. 2012. Alien molluscs affect the composition and diversity of native macroinvertebrates in a sandy flat of Lake Neuchâtel, Switzerland. *Hydrobiologia* **679:** 233-249.

Sickel JB. 1986. *Corbicula population* mortalities: factors influencing population control. *American Malacological Bulletin, Special Edition* **2:** 89-94.

Sinclair RM. 1964. Clam pests in Tennessee water supplies. *Journal of the American Water Works Association* **56:** 592–599.

Sinclair SM, Isom BG. 1963. *Further studies on the Introduced Asiatic Clam (Corbicula) in Tennessee*. Tennessee Stream Pollution Control Board, Tennessee Department of Public Health: Nashville.

Siripattrawan S, Park JK, O Foighil D. 2000. Two lineages of the introduced Asian freshwater clam *Corbicula* occur in North America. *Journal of Molluscan Studies* **66:** 423-429.

Sousa R, Antunes C, Guilhermino L. 2008a. Ecology of the invasive Asian clam *Corbicula fluminea* (Muller, 1774) in aquatic ecosystems: an overview. *Annales De Limnologie-International Journal of Limnology* **44:** 85-94.

Sousa R, Ilarri M, Souza AT, Antunes C, Guilhermino L. 2011. Rapid decline of the greater European peaclam at the periphery of its distribution. *Annales De Limnologie-International Journal of Limnology* **47:** 211-219.

Sousa R, Nogueira AJA, Gaspar MB, Antunes C, Guilhermino L. 2008b. Growth and extremely high production of the non-indigenous invasive species *Corbicula fluminea* (Muller, 1774): Possible implications for ecosystem functioning. *Estuarine Coastal and Shelf Science* **80:** 289-295.

Strayer D. 1999. Effects of alien species of freshwater mollusks in North America. *Journal of the North American Benthological Society* **18**.

Sweeney P. 2009. First record of Asian clam *Corbicula fluminea* (Müller, 1774) in Ireland. *Irish Naturalists' Journal* **30** 147–148.

Thompson CM, Sparks RE. 1977. Improbability of dispersal of adult Asiatic clams, *Corbicula manilensis*, via the intestinal tract of migratory fowl. *American Midland Naturalist* **98:** 219-223.

Vaate ABD. 1991. Colonization of the German part of the River Rhine by the Asiatic clam, *Corbicula fluminea* Müller, 1774 (Pelecypoda, Corbiculidae). *Bulletin Zoölogisch Museum* **13:** 13-16.

Voelz NJ, McArthur JV, Rader RB. 1998. Upstream mobility of the Asiatic clam *Corbicula fluminea*: Identifying potential dispersal agents. *Journal of Freshwater Ecology* **13:** 39-45.

Vohmann A, Borcherding J, Kureck A, bij de Vaate A, Arndt H, Weitere M. 2010. Strong body mass decrease of the invasive clam *Corbicula fluminea* during summer. *Biological Invasions* **12:** 53-64.

Weitere M, Vohmann A, Schulz N, Linn C, Dietrich D, Arndt H. 2009. Linking environmental warming to the fitness of the invasive clam *Corbicula fluminea*. *Global Change Biology* **15:** 2838-2851.

Werner S, Rothhaupt K-O. 2008a. Effects of the invasive Asian clam *Corbicula fluminea* on benthic macroinvertebrate taxa in laboratory experiments. *Fundamental and Applied Limnology* **173:** 145-152.

Werner S, Rothhaupt K-O. 2008b. Mass mortality of the invasive bivalve *Corbicula fluminea* induced by a severe low-water event and associated low water temperatures. *Hydrobiologia* **613:** 143-150.

Williams CJ, McMahon RF. 1989. Annual variation of tissue biomass and carbon and nitrogen-content in the fresh-water bivalve *Corbicula-Fluminea* relative to downstream dispersal. *Canadian Journal of Zoology-Revue Canadienne De Zoologie* **67:** 82-90.

Willing M. 2007. *Sphaerium solidum* and *Corbicula fluminea*: two rare bivalve molluscs in the River Great Ouse system in Cambridgeshire. *Nature in Cambridgeshire* **49:** 39–49.

Wittmann M, Reuter J, Schladow G, Hackley S, Allen B, Chandra S, Caires A. 2008. Asian clam (*Corbicula fluminea*) of Lake Tahoe: Preliminary scientific findings in support of a management plan.

Wittmann ME, Chandra S, Reuter JE, Schladow SG, Allen BC, Webb KJ. 2012. The Control of an invasive bivalve, *Corbicula fluminea*, using gas impermeable benthic barriers in a large natural lake. *Environmental Management* **49:** 1163-1173.