Gulf wedge clam (*Rangia cuneata*)

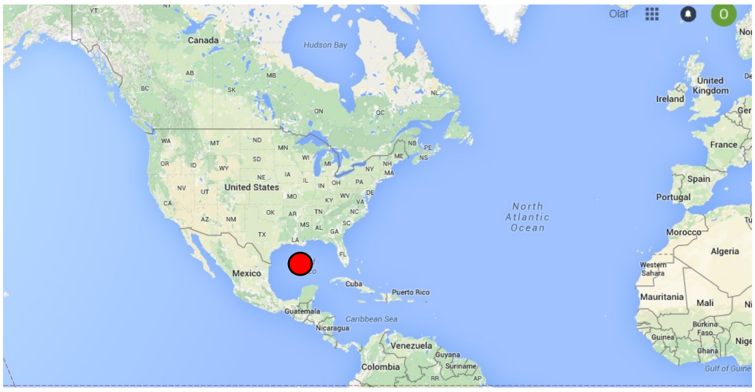
- Bivalve native to the Gulf of Mexico.
- Discovered in GB in 2015, currently recorded in a tributary of the River Witham, Lincolnshire.
- Potentially major impacts on biodiversity due to the ability of *R. cuneata*'s to rapidly dominate a new habitat, this may also affect fisheries and angling.
- Can also damage equipment through obstruction of water pipes from fouling.

History in GB

First discovered in GB in August 2015, at two localities on the South Forty Foot Drain (SFFD), a tributary of the River Witham, Lincolnshire. It is estimated that *R. cuneata* has been present in this location for at least six years. Currently there is a continuous presence of *R. cuneata* along around 10.4km of the SFFD and this population could act (or may have acted) as a source of further spread along the estuaries of eastern England. There are numerous estuaries across GB which have the low salinity conditions required by *R. cuneata*.

Native distribution

Native to the Gulf of Mexico



Distribution in GB

Impacts

The relatively few examples of colonisation in Europe make impact in GB difficult to predict, but may include:

Environmental (major)

- Loss of native bivalve species due to the ability of *R. cuneata* to rapidly dominate a new habitat. This may have indirect impacts on other species and functioning of the entire ecosystem.

Economic (minor)

- Damage to equipment through water pipe obstruction, and control costs to prevent this.
- Problems in upper estuarine fisheries for fish and shellfish due to ecosystem changes.

Social (minor)

- Loss of leisure fishing and associated impacts on local communities.

Introduction pathways

Boat ballast water - larvae transported in ballast water from other affected areas.

Contaminant- live adult mussels transported in sediment carried by maintenance dredgers or mud attached to leisure or maintenance boat anchors.

Spread pathways

Natural (intermediate) - may be limited due to infrastructure and conditions surrounding current population

Human-aided (rapid) - through movement of larvae in boat ballast water, or of sediment contaminated with young clams (e.g. on anchors and associated equipment, dredgers and construction vessels, and angling equipment).

Summary

	Risk	Confidence
Entry	VERY LIKELY	VERY HIGH
Establishment	VERY LIKELY	VERY HIGH
Spread	SLOW	LOW
Impacts	MAJOR	LOW
Conclusion	MEDIUM	LOW

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

GB Non-native Species Rapid Risk Assessment (NRRA)

Rapid Risk Assessment of: *Rangia cuneata* (Gulf Wedge Clam)
Author: Dr Martin John Willing, Conchological Society of Great Britain & Ireland

Version: Draft 1 (*November 2015)*, Peer Review (*December 2015)*, NNRAP 1st review (*December 2015*), Draft 2 (*August 2016*)
Signed off by NNRAP: November 2016
Approved by Programme Board: February 2017
Placed on NNSS website: April 2017

Introduction:
The rapid risk assessment is used to assess invasive non-native species more rapidly than the larger GB Non-native Risk Assessment. The principles remain the same, relying on scientific knowledge of the species, expert judgement and peer review. For some species the rapid assessment alone will be sufficient, others may go on to be assessed under the larger scheme if requested by the Non-native Species Programme Board.

Guidance notes:
- We recommend that you read all of the questions in this document before starting to complete the assessment.
- Short answers, including one word answers, are acceptable for the first 10 questions. More detail should be provided under the subsequent questions on entry, establishment, spread, impacts and climate change.
- References to scientific literature, grey literature and personal observations are required where possible throughout.

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

Response: To rapidly assess the risk associated with this species in Great Britain following the discovery of *Rangia* at two sites in one drain entering the lower River Witham, Lincolnshire.

2 - What is the Risk Assessment Area?

Response: Great Britain

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

Response: *Rangia cuneata* (G B Sowerby I, 1831). Common names include: Gulf Wedge Clam, Atlantic Rangia, Common Rangia

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

Response: Yes

(1) United States: The species is native to the Gulf of Mexico (Hopkins & Andrews 1970). Prior to the 1960s the species was not known living on the US Atlantic coast, but after that time it was recorded, often in abundance, in many east coast estuaries (Pfitzenmeyer & Drobeck 1964) reaching as far north as the Hudson River, New York by 1988 (Carlton 1992). There is uncertainty about the causes for these advances. There have

been suggestions that the *R. cuneata* reappearance (it was present in this area during the Pleistocene) may have been due to either the transportation of *Crassostrea virginica* from the Gulf of Mexico, as larvae in boat ballast water (Pfitzenmeyer & Drobeck 1964) or as waste from dredge gear or spoil barges (Gallagher & Wells 1969). Some suggest that there is also a possibility that some small, but undetected populations may have remained on the Atlantic east coast with a recent ecological change leading to resurgence (Pfitzenmeyer & Drobeck 1964). There is therefore some uncertainty as to the degree to which the appearance of *R. cuneata* on the Eastern Atlantic estuaries can be considered invasive. (see also response to Q9 below).

(2) Europe: *Rangia* is now known to have established populations (some of which are invasive) in at least five countries in Europe. (1)It was discovered in the harbour of Antwerp, Belgium 2005 (Verween *et al* 2006) although *Rangia* was later estimated to have colonised the area in about 2000 (Kerckhof *et al* 2007). By 2013 the species had spread much more widely in the Schelde River and (2) northwards into the Netherlands with the species being described as 'common' in the brackish waters of the Noordzeekanall (province of North- Holland) and the Kanal Teneuzen-Gent (province of Zeeland) (Neckheim 2013). Finds from two further Dutch localities were reported in 2014: from the northern Dutch province of Groningen (Luijter 2014) & from the Port of Rotterdam in the province of Zuid-Holland (Gittenberger *et al* 2014). (3) *Rangia* was found in the Russian sector of the Vistula Lagoon in 2010 (Rudinskaya & Gusev 2012) and *R. cuneata* appeared in the Polish sector of this lagoon in 2011 (Warzocha & Drgas 2013). (3) In 2014 the species was recorded in the Wisła Śmiała River, Gulf of Gdańsk, Poland (90 km west of the Vistula Lagoon) (Janus *et al* 2014). (4) In Germany *Rangia* was found in 2013 at Brunsbüttel on the Kiel Canal (Bock *et al* 2015) and a second population was located in the country in late 2015 in a brackish lagoon near Luebeck, Schleswig-Holstein (Wiese *et al* 2016). (5) In the UK in August 2015 *R. cuneata* was discovered at two localities (Hubbert's Bridge TF 26771 43654 & Wyberton High Bridge TF 30404 43384) approx 3.5 km apart in the South Forty Foot Drain (SFFD), a tributary of the River Witham, Lincolnshire (Willing 2015). (6) In spring 2016 dead *Rangia* shells were found on a beach in the NE Gulf of Riga, Estonia, but no live animals have yet been located in the country (H. Ojaveer p. 65 in ICES 2016).

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

Response: The current distribution in the RRA area has now been established (surveys November 2015 – February 2016 by Environment Agency) to be as a continuous presence along about 10.4 km of SFFD. This population lies between a point lying just upstream of Marston's Farm (TF 22578 430040) and downstream to Black Sluice Lock, Boston (TF 32615 42860). Surveys elsewhere in the lower Witham system (including channels draining into SFFD) and potentially suitable sites in the lower River Nene catchment (including selected brackish side drains) have failed to locate further populations. Additionally surveys (also by the Environment Agency) in the tidal (and more strongly saline) Witham (The Haven) in February 2016 located no evidence of *Rangia* presence. Further surveys continue as does ongoing awareness of the possible presence of the species by Environment Agency regional staff, who have been made aware of the recent *Rangia* finds as well as how to recognise the species should they locate further populations.

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

There are numerous estuaries with the low salinity conditions that *R. cuneata* requires present all around the British coastline. This is especially so where estuaries are not barraged allowing natural salinity gradients to exist between fully marine and freshwater conditions (issue discussed further below)

Special conditions required by *Rangia cuneata*

ADULTS: In its native range (Gulf of Mexico) *R. cuneata* is typically found in estuaries in salinities ranging between 5 - 15‰ (Swingle & Bland 1974). *R. cuneata* is a bivalve with a remarkable salinity tolerance, being able to adapt to salinities varying from 0 - 33‰ (Hopkins *et al* 1974, Cooper 1981) albeit in laboratory conditions at salinities >15‰. At lower salinities it is a bivalve that can cross the 5‰ boundary (the 'horohalinicum') and is one of very few brackish water bivalves able to survive in freshwater (e.g. Ladd 1951).

Thus the clam is the dominant species in three lakes in the upper Barataria estuary, Louisiana, all with typical salinities of < 1‰ (Wong *et al* 2010). In some situations it is able to live in rivers together with typical freshwater taxa such as freshwater mussels (Cain 1975, Willing 2015).

Although *R. cuneata* can survive in captivity at high salinities (>32‰), in the wild it is rarely found living above 15‰ (Hopkins *et al* 1974, Cain 1975) not seeming to be able to maintain a regularly recruiting population outside of a salinity range 1 - 15‰ (Hopkins 1970).

It has been suggested that *R. cuneata* does not regularly live in higher salinity situations due to interspecific completion and predation (Hopkins *et al* 1974, Cain 1975, Bedford & Anderson 1972, Cooper 1981). Johns (2012), however, considers that raised salinity may by itself lead to increased *R. cuneata* mortality citing bivalve deaths following salinity increases (> 15‰) in Texas estuaries during the 2011 drought.

Adult *R. cuneata* have the ability to live anaerobically for up to 2 weeks (Hopkins *et al* 1974), which may give them a competitive advantage in short term anoxic conditions and allow survival in low oxygen conditions that might kill competitor bivalves. Such a situation was observed in the SFFD when *R. cuneata* was the only live bivalve taken from anoxic mud at Hubbert's Bridge; mussels of other species were all freshly dead (unpublished observation: Willing).

BREEDING: The embryonic and larval stages are the critical point in the *R. cuneata* life cycle (Cain 1973 & 1975, Cooper 1981) where a narrower set of conditions, especially salinity, are required. Gametogensis is triggered by a spring rise in temperature to at least 10^0C (Cain 1975) running through to autumn. Although spawning events typically occur in spring/early summer and then again in the autumn (in a range of US populations (Fairbanks 1963, Cain 1973, 1975) it can run over at least a 7 month period if conditions remain suitable (Cain 1975). The <u>key trigger</u> to *R. cuneata* spawning is experience of an abrupt salinity change from either a higher or lower salinity to a range between 3 - 10‰ (e.g. Cain 1973, 1975, La Salle & de la Cruz 1985, Johns 2012). Embryonic and early larval developmental stages require stable salinity within a maximum range of 2 - 10‰ (Cain 1973). As larvae develop they become increasingly resistant to an increasing range of salinities so that when they settle as juvenile clams (typically after about 7 days: Hopkins *et al* 1974) they can survive a salinity range close to that of adults.

Adult *R. cuneata* can typically survive for 8 years with a maximum life of between 14 – 20 years (Hopkins *et al* 1974, Cain 1975). Adults living in salinities too low to allow breeding (>1‰) can breed at irregular intervals (often years apart) whenever occasional saline intrusions raise salinities sufficiently (Cain 1975). This allows *R. cuneata* to maintain populations in some freshwater areas (Cain 1975, Wong 2012, Willing 2015).

SEDIMENTS: In laboratory studies *R. cuneata* larvae show a preference for fine-medium sand over silt / clay (Sundberg *et al* 1993) whilst Peddicord (1977) found that the Condition Index (a measure of 'dry weight growth') of *R. cuneata* was greater in clams from sand than mud. Although larvae appear to show a preference for courser sediments they will settle on a wide range of fine sediments (Fairbanks 1963, Cain 1975, Jordan and Sutton 1984). In Belgium and in the UK *R. cuneata* were found living in silt and mud respectively (Verween *et al* 1974, Willing 2015)

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 western and northern European regions already invaded by *R. cuneata* (see section (2) of question 4 above) as well as many of the estuaries on the US eastern seaboard share a strong bioclimatic match to many of Britain's estuaries (and associated brackish drains and lagoons).

8 - Has the organism established viable (reproducing) populations anywhere outside of its native range (answer N/A if you have answered 'yes' to question 4)?

Response: Yes

See answers in section 4 above. A single shell morphometric study at one British site showed different age classes indicating that periodic recruitment had occurred. It is estimated that *R. cuneata* has been living in the South Forty Foot Drain for at least 6 years (Willing 2015).

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

Response: Yes

Rangia cuneata appears to be able to spread both naturally and with human assistance. Unfortunately the origins of newly established populations both along the east Atlantic coast of USA and in Europe are unclear (see also Q4 above).

There is a well-documented appearance of the mussel in US Atlantic estuaries post 1955 (some examples):
1. North Carolina 1955 (Wells 1961);
2. Virginia 1960 (Wass 1972)
3. Florida (Atlantic coast) 1961 (Woodburn 1962)
4. Potomac River 1964 (Pfitzenmeyer & Drobeck 1964)
5. Upper Chesapeake Bay 1966 (Pfitzenmeyer 1970)
6. Maryland 1968 (Gallagher & Wells 1969)
7. Hudson River, New York (Carlton 1992)

Explanations for spread vary and include ballast water of boats, transportation of oysters, waste from dredgers and resurgence of small but previously undetected founder populations (Gallagher & Wells 1969, Pfitzenmeyer & Drobeck 1964; Hopkins & Andrews 1970, Carlton 1992).

Europe: It has been suggested that the origin of the first detected European population in the Western Scheldt, Belgium (2006) was possibly due to larvae arriving in ballast waters brought across from the US Atlantic or Gulf of Mexico coasts (Verween *et al* 2006). Other possibilities include (a) the deposit of live adult mussels in solid sediment ballast collected in the US, (b) transport as sediments caught up with anchor chains and (c) the discard of live mussels as food waste transported across from the US (*R. cuneata* is widely caught in the Gulf of Mexico and on the US Atlantic coast for food (e.g. Andrews & Grodner 1995, Wakida-Kusuoki & MacKenzie 2004, Gallaher & Wells 1969, Kerchof *et al* 2007). Once established in Belgium *R. cuneata* has spread in the estuaries and brackish waterways of north Belgium but even more markedly in the Netherlands where between four and five separate areas are now colonised, partially by natural means (Neckheim 2013) but also, supposedly by introduction of larvae with ballast waters into the port of Rottterdam (Gittenberger *et al* 2015)

The first Baltic *R. cuneata* population was recorded in 2010 in the Vistula Lagoon (Rudinskaya & Gusev 2012) and then in the Polish sector of the lagoon in 2011 (Warzocha & Drgas 2013). Its original has been suggested as being ballast water (Rudinskaya & Gusev 2012). Although it is probable that spread within the lagoon has been by natural means (breeding has taken place so that in 2012 Rudinskaya & Gusev recorded abundances of the clam ranging between 80 – 920 m^{-2} with a maximum of 4,040m^{-2}) it is possible that human boat traffic and other activities (e.g. dredging) may have assisted spread. The appearance of *R. cuneata* in Wisła Śmiała River, Gulf of Gdańsk has been linked to the possibility that its introduction there may have been due to dredgers that may also have been operating earlier in the Vistula Lagoon (Janus *et al* 2014). Natural reproduction and spread have occurred in this area such that surveys of the area in 2014 (Janus *et al* 2014) found *R. cuneata* in all samples with the clam as the dominant bivalve present producing densities of up to 540 m^{-2}. Once established in an area *Rangia* populations can recover rapidly after periods of adverse environmental change. Thus in the Polish sector of the Vistula Lagoon the *Rangia* population crashed after the severe winter of 2013but in only a year had staged a near complete recovery (Warzocha *et al* 2016).

The origin of the first British populations located in Lincolnshire in 2015 are currently unclear (Willing 2015). Further surveys between November 2015 and February 2016 did not locate any additional populations and so it seems unlikely that those in the SFFD arose from another local population. Studies by the Environment Agency of management documents relating to the SFFD show that no construction boat traffic entered the drain from overseas during recent works and not at the time of possible *Rangia* colonisation between 2008 -09. The EA

(Emma Holden – personal communication) are of the opinion that *Rangia* may have entered SFFD as larvae released in ballast water from a vessel or vessels docked closeby in the tidal portof Boston. Waters from the Port can enter the SFFD at periods of high tide when the Black Sluice locks are opened to admit boat traffic. The lock gates are also not fully water tight and therefore some leakageof tidal water occurs on a daily basis at high tide.

In May 2016 tissue samples from 25 live collected *Rangia* were sent to the Laboratory of Ecology of Aquatic Invertebrates of the I.D. Papanin Institute for Biology of Inland Water, Russian Academy of Sciences 152742 Borok, Yaroslavl region, Russia. These samples are to be DNA sequenced as part of a pan-European project currently underway to try to determine the inter-relationships between all of the European populations. Results from this project may reveal the source of the SFFD population in Lincolnshire (considered at present to possibly arise as a secondary introduction from either Belgium or the Netherlands)

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

Response: Yes

Rangia cuneata has the potential to cause economic as well as environmental harm.

Economic: Water pipe obstruction: *R. cuneata* was implicated in biofouling fire hose pipes at the Getty oil refinery in Delaware (Counts 1980). The first European discovery in Antwerp was in silty sediments within the cooling pipes of an industrial plant (Verween *et al* 2006). The clams are reported to have formed a dense population, which required clearing to restore optimal water flow. Verween *et al* (2006) speculate that the presence of *R. cuneata* within water pipes could lead to the further accumulation of silt which in turn would encourage further *R. cuneata* settlement - a vicious circle leading to a malfunction of the cooling system. Regular sediment clearance might therefore be required to avoid biofouling. See also economic risks associated with possible changes to upper estuarine fisheries. There might be economic benefits associated with *Rangia* colonisation as the clam can occur in some habitats in larger numbers than indigenous bivalve faunas (as in the Vistula Lagoon:
Warzocha *et al* 2016); this might lead to the possibility of commercially important populations of this edible clam becoming established.

Environmental: Once *R. cuneata* has colonised a suitable new habitat it can rapidly assume dominance as in Chesapeake Bay where, over a two year period, the clam increased from 0 m^{-2} to 10,000 m^{-2} (Pfitzenmeyer 1970). In Europe, despite its recent arrival *R. cuneata* has managed to dominate the bivalve faunas in both the Vistula Lagoon (Rudinskaya & Gusev 2012) and the Wisła Śmiała River (Janus *et al* 2014) in only a few years. Thus in the latter location the clam has become the dominant bivalve present, numbers exceeding those of native species such as *Macoma balthica*, *Mya aren*aria and *Cerastoderma glaucum*. Janus *et al* (2014) state that as the southern Baltic has suitable salinities and temperatures to allow continued *R. cuneata* reproduction and growth which they state, "will affect the functioning of the ecosystem". They do not explain how they envisage events developing, but they do present a possible positive outcome based upon the citation of many American publications. This is because the clam as a suspension feeder will ingest large quantities of detritus and phytoplankton and generate numbers of individuals to form an important food source for invertebrates, fish and diving ducks. Recent evidence of ecological benefits arising from the colonisation of *Rangia* are given by Aleksandrov *et al* (2015).They describe studies undertaken in the Russian sector of the Vistula Lagoon between 1991 – 2014 which showed a deterioration in water quality including eutrophication and associate algal blooms. They noted that after the invasion of the lagoon by *Rangia* benthic biomass increased by 8 times with a corresponding suspended chlorophyll decrease of 3 times. They state, "*Water quality is significantly improved from "poor" to "satisfactory" level in 2011-2014, e.g., transparency increased by 2 times. The phytoplankton assimilation numbers increased to maximum (300-400 mgC·mgChl-1·day-1), which are discover in aquatic ecosystems, and primary production remained at previous level. Therefore mollusc invasion improved water quality.*" They also suggest that the benefits extend to other trophic levels (e.g. zooplankton & fish) which were maintained at 'stable long-term levels'.

In the UK *R. cuneata* has the potential to colonise many estuaries, associated brackish channels and tidal reaches subject to occasional saline intrusion. Here, if its rate of spread and reproduction is similar to that seen in the US, the Netherlands and the Baltic sites, it may, within only a few years, come to dominate the bivalve faunas in these locations but there is not, as yet, any know study suggesting that it would replace any native species. As a consequence, its spread may alter, in an as yet unknown way, the ecosystems in such areas. Additionally in freshwaters subject to very occasional saline intrusions or very slightly brackish habitats (salinity <4‰) *R. cuneata* could establish populations and also come to represent the dominant bivalve, as along the SFFD in Lincolnshire (Willing 2015 & personal observations in 2016). As *Rangia* has a relatively large, thick shell and lives on the surface of soft benthic sediments (mud, silt, sand) then both live animals and dead shells may modify these sediments. Thus Warzocha *et al* (2016) in making this observation demonstrate that *Rangia* shells may act as attachment surfaces for Dreissenid mussels such as *D. polymorpha*. The supply of hard shelly surfaces on otherwise unsuitable sediments might assist the colonisation and spread of invasive mussels such as *D. polymorpha* and *D. rostriformis bugensis.* There is therefore a potential secondary negative effect in the arrival of *Rangia* populations.

Social: It is difficult to assess the social consequences of *Rangia* colonisation of upper estuaries and oligohaline lagoons. There is, as yet, no evidence in Europe of *Rangia* displacing native species which, if demonstrated, might have an impact on social activites such as shellfish collection and bait digging. It is possible that the development of a large *Rangia* population in an estuary could (as discussed above) have a beneficial effect in a providing a harvestable commodity and / or in improving water quality.

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):

Rangia cuneata is established in the South Forty Foot Drain in Lincolnshire (Willing 2015) and present over at least 10.4 km of this channel. Its mode of entry is unknown (see details in Q9 above) but may have been from one or more of a number of possible sources. These include (1) in boat ballast water, (2) in deposited sediments from maintenance dredgers or mud attached to leisure or maintenance boat anchors (3) introduced deliberately or accidentally as live clams and (4) accidental transfer of larvae of young clams by anglers on damp keep nets, bait buckets or on contaminated equipment. The *R. cuneata* population in the South Forty Foot Drain is estimated to have been there for at least 6 years. This established Lincolnshire population could act (or has acted) as a source of further spread along the estuaries of eastern England and once established, elsewhere in the country.

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):

The *R. cuneata* population in the South Forty Foot Drain is estimated to have been there for at least 6 years and size classes described in Willing (2015) suggest at least two recruitment events at the Hubbert's Bridge site over that period of time. In July 2016 a selection of large live and dead collected *Rangia* shells were sent to the School of Ocean Sciences, University of Bangor to allow schlerochronology techniques (similar to 'tree-ring dating') to provide a more accurate confirmation of shell age and so provide a more certain entry date of the clams into the SFFD.

There are numerous sites occurring all around the UK coast where *R. cuneata* could establish populations. In its native range (Gulf of Mexico) *R. cuneata* is typically found in estuaries in salinities ranging between 5 - 15‰ (Swingle & Bland 1974) and it is typically found elsewhere on the US Atlantic coast in salinities ranging between 0 - 15‰ (e.g. Cain 1973, 1975). It can also successfully occupy and dominate freshwater bodies with salinities of <1‰ where these are subject to occasional episodes of slight salinity ((Wong *et al* 2010, Cain 1975). (Further more detailed discussion on salinity refer to Q4 above). In Europe (Belgium, Holland and Baltic sites described previously) sites are closely similar to those present around the entire UK coastline. These are most typically upper estuaries where salinities of 5 - 15‰ are present. Additionally where these estuaries lead to un-barraged rivers and other channels and lagoons then saline intrusion will occur on a regular and or periodic basis and produce salinity gradients. In such situations it is suggested that *R. cuneata* could readily establish populations (in both brackish and freshwater areas subject to only occasional saline intrusions, perhaps only once in 5 years (Cain 1975, Wong 2010). A small selection of east and south coast estuaries potentially at risk include the Humber, Nene, Great Ouse, Yare, Waveney, some brackish Broads such as Hickling & Oulton, Alde, Blackwater, Crouch, Thames, Medway, Ouse (E. Sussex), Adur and Arun.

Spread Summary

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

Overall response: *slow*
Confidence: *low*

Sub scores:

Natural spread only:
Response: *slow*
Confidence**:** *medium*

Human facilitated spread only:
Response: *low*
Confidence**:** *medium*

Comments (in your comments list the spread pathways and discuss how much of the total habitat that the species could occupy has already been occupied):

R. cuneata is established in about 10.4 km of the South Forty Foot Drain (SFFD). Its potential to spread further naturally in the Witham system is limited as there are tidal control 'pointing gates' and adjacent navigation locks in the main channel in north Boston which effectively stop saline intrusion further up the river. Few other channels in the system experience saline intrusion. The potential for natural larval spread to estuaries north and south may be limited; *R. cuneata* larvae would encounter fully marine conditions and it is unclear how long they survive in fully marine waters. Cain (1975) notes that although larval growth is best at high temperatures, they survive well at low temperatures. He also notes that the increased salinity tolerance of larvae gives them better survival chances during the pelagic stage which is also greatly extended at low temperatures (beyond the 7 days; Hopkins *et al* 1974) . These considerations might mean that late stage *R. cuneata* larva could travel in sea currents from the Witham estuary to other estuaries nearby.

The most likely means of spread to further estuary systems is by human facilitated means the possibilities being: (1) as larvae in boat ballast water (2) young clams present in sediment caught up with anchors and associated equipment, (3) spread by sediment and or larval infested water by channel maintenance dredgers, bank reinforcing and construction vessels (this is a possible source of entry and spread of *R. cuneata* in SFFD as suggested by the EA in Spalding), (4) with contaminated angling equipment (e.g. bait buckets, soles of waders) Unfortunately it is not known how long *Rangia* or young clams can survive out of water. Similarly the spread of *R. cuneata* up the Atlantic seaboard of the US is assumed (refs: see responses to questions 4 & 9 above) to be by human activities rather than natural larval dispersal.

In GB only one, approximately 10.4 km stretch of the SFFD is known to be occupied by *R. cuneata*. Further surveys between November 2015 and February 2016 failed to find further populations in the Witham area (see section 5 above).. Elsewhere any GB estuary where saline gradients allow the presence of zones of with salinities between 0 - 15‰ as well as having further areas subject to occasional or seasonal salinity changes are potentially able to be colonised by *R. cuneata.* A list of possible potential *R. cuneata* vulnerable estuaries on the east and south –east coasts of England are given in responses to 'Establishment Summary' above.

Despite *R. cuneata*'s origins in the Gulf of Mexico it has nevertheless successfully colonised estuarine habitats right up the eastern US seaboard to New York. It has managed to establish populations in much cooler waters such as in Chesapeake Bay, which regularly experiences freezing winters conditions with sea ice (Gallagher and Wells 1969). This suggests that even the lower temperature waters of northern Britain are unlikely to restrict *R. cuneata* spread into the GB's northern estuaries.

Impact Summary

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

Overall response: *major*
Confidence: *low*

Sub-scores

Environmental impacts:
Response: *major*
Confidence**:** *low*

Economic impacts:
Response: *low*
Confidence: *medium*

Social impacts:
Response: *minor*
Confidence: *medium*

Comments (include list of impacts in your comments):

With relatively few examples of colonisation impact in Europe to study the potential impact of *R. cuneata* spread is difficult to predict. Possible environmental, economic and social impacts are discussed in Q 10 above. It seems likely that if *R. cuneata* is able to spread beyond the Witham system then it has the potential, as at its newly established sites in Belgium / Holland (Neckheim 2013, Gittenberger 2015) and in the Baltic (Rudinskaya & Gusev 2012, Warzocha & Drgas 2013, Janus *et al* 2014) to quickly establish large, recruiting populations and become the dominant bivalve species as it has done in the SFFD in Lincolnshire (Willing 2015, personal & Environment Agency observations 2016). The east and south coasts of England have many estuaries (see response in 'Establishment Summary' above) that offer numerous low salinity upper estuarine areas and associated freshwater areas subject to only occasional saline intrusion.

Climate Change

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

Response: *medium*
Confidence: *low*

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):

Increased water temperatures around the UK may make *Rangia* colonisation and breeding more certain in more northerly estuaries. Low winter temperatures were suggested as a cause of a *R. cuneata* 'mass-mortality' event in Chesapeake Bay in 1968 (Gallaher & Wells 1969) but these were extreme with ice-lined shore. It is reported that low winter temperatures may have a negative impact upon Baltic populations of the clam (Rudinskaya & Gusev 2012). Typical surface water temperatures in the Baltic between January and March range from 0 – 4^0C (Helcom) are markedly lower than averages from around the UK coastline and yet *R. cuneata* has established populations to become the dominant bivalve in two areas on the southern Baltic coast of Russia and Poland (Warzocha & Drgas 2013, Janus *et al* 2014). The severe winter of 2013 saw the loss of many *Rangia* populations in the Vistula Lagoon but Warzocha *et al* (2016) did not link the mortality directly to low water temperatures, but rather to oxygen deficiency resulting from the absence of sea water inflows via the ice-blocked Pilawska Strait. What was remarkable was *Rangia*'s ability to recolonise virtually all of its former

locations within only a year. By comparison with Chesapeake Bay and the southern Baltic typical winter temperatures around British coasts are higher and may therefore be judged as more suitable for *R. cuneata* colonisation. Further sea temperature increases are likely to enhance the clam's ability to both spread and survive lower winter temperatures towards the northern coasts of GB (especially in the relatively shallow waters [most < 6m] that it typically colonises).
Major climatic events are blamed for *Rangia* population oscillations in Lake Pontchartrain (an oligohaline estuary in Louisiana) (Poirrier & Caputo 2015). A drought in 2001 blamed on an El Niño Southern Oscillation was linked to a slight rise in salinity that allowed the competitor (and shell fouling) hooked mussel to become established leading to a collapse of *Rangia* numbers.With a fall in salinity *Rangia* did not initially recover due to a series of other weather events including hurricanes in 2005, 2008 and 2012 causing other environmental problems (e.g. suspended sediment, rapid salinity changes and lowered O2 levels). Only in 2014 did *Rangia* return to pre-2001 levels. This study further demonstrates *Rangia*'s ability to stage recovery following extreme population decline.

Conclusion

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

Response: *moderate*
Confidence: *low*

Comments:

Risk of further *R. cuneata* spread is considered moderate based upon the fact that the clam is already present in the UK but although it has successfully maintained a population in what maybe a sub-optimal habitat for at least 6 years surveys (between November 2015 – February 2016) have shown that the clam has not spread beyond the SFFD. Britain is climatically similar to areas of north Belgium and the Netherlands, the latter region being one where the clam has established and spread. These areas are arguably more suited to the species than the several locations on the south Baltic coast where *R. cuneata* has established large populations within only 2 – 3 years.

R. cuneata is more especially a threat due to its remarkable ability to live in a broad range of salinities extending from freshwater to fully marine conditions (although it is rarely present in more saline water than approximately 15 ‰ salinity). As a consequence it can occupy upper estuarine areas but also freshwater habitats associated with them that experience only very occasional saline intrusions. The one limitation in the clam's lifecycle is the requirement for specific salinity conditions to occur over a relatively short period and it is this that partially limits the ability of *R. cuneata* to spread. Observation of American and European *R. cuneata* populations demonstrate that once the clam has invaded a site it can quickly spread so that within only a few years it can become the dominant member of the bivalve community. It is not yet known, in the longer term, the degree of ecosystem change that this will produce and whether native species will be displaced, perhaps only at a local level. Conversely observations in the Vistula Lagoon show that *Rangia* has become more dominant than any native species and as a consequence of its success has significantly improved water quality in a eutrophic environment (see Section 10 above).

In GB *R. cuneata* has the potential to spread into many estuarine systems and into the lower reaches of tidal rivers associated with them. Once established it is then likely to quickly assume dominance by natural spread. The fully marine conditions that separate many estuaries might impede natural spread; assisted spread from these areas is likely to be the main cause of further invasion. As the total eradication of *R. cuneata* from the Witham system seems unlikely, then the most cost-effective means to slow or stop the spread of this invasive bivalve is devote maximum efforts to minimise the risks of accidental spread by boats and especially angling (which has the potential to spread the clam between different water bodies and catchments) and water-sports equipment.

Management options (brief summary):

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

Response: Management of *Rangia cuneata* populations have not been documented and so the suggestions below are untested and would require further detailed consideration. They are presented as possible options.

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

Response: Eradication options might include the employment of the lipid encapsulated molluscides known as 'BioBullets'. These have been very successfully employed against other invasive, filter feeding bivalves such the Zebra mussel *Dreissena polymorpha* (at water works throughout Britain and on other bivalve species elsewhere in the world) (Aldridge *et al* 2006). This control agent acts selectively on some filter feeding bivalves such as *R. cuneata,* but does not kill all other non-target species such as *Anodonta anatina, A. cygnea* and *Unio pictorum* which are present in the SFFD. .

Treatment of the South Forty Foot Drain with BioBullets or other non-selective molluscicides would present immense practical and environmental difficulties, not least the escape of treated waters into the tidal Witham system and the potential (even if diluted) to cause some damage to populations of certain native bivalves there (although it is not known how susceptible various native marine bivalves are to this treatment).

If the threat of *Rangia cuneata* was judged to be sufficiently great and if the population of this bivalve was found (after further surveys of the Witham and Nene systems) to be restricted to the a section of the South Forty Foot Drain, then it might be worth considering the temporary draining of this channel to allow sufficient time for populations of the clam to be killed by desiccation and/or by other means. Clearly the practical difficulties of undertaking such a scheme would be immense and extremely costly.

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

Response: Complete eradication of *Rangia* from the South Forty Foot Drain would pose considerable practical difficulties. The most realistic option to limit *R. cuneata* colonisation seems to be the development of containment and spread-reduction procedures. If larval transport in boat ballast water is the primary cause of *R. cuneata* spread then measures should be developed to avoid any boats entering the infected drain from taking up ballast waters from it. The relatively small size of the SFFD may mean that few ballast-carrying ships and boats are likely to use the channel. In the case of small craft it maybe that anchors and their chains contaminated with infected sediments pose the greater risk. In any event boats leaving the channel should undergo standard cleaning including the hosing of anchors and chains to remove sediments contain young live mussels. Regulation and monitoring of other water sport and leisure activities (e.g. angling, canoeing) using the South Forty Foot Drain (SFFD) should be developed. It maybe that angling actvites present the greatest risk of transfer of the clam to completely new waters although *Rangia*'s ability to survive out of water both as larvae or adults is not known. Public access sites such as for boat and canoe launching and also angling should be provided with suitable wash-down facilities. Education signage has already been posted by the Environment Agency at access and other points warning of the risks of contamination, dangers posed by the spread of the bivalve and an explanation of the 'Check Clean, Dry' procedures for all users of the channel.

As part of the Fen Waterways Link the navigable status of the SFFD is being improved by the Environment Agency including a future connecting link to the River Glen in the south. Whilst recruiting *R. cuneata* populations exist in the SFFD such a link might help to assist the spread of the clam into river systems to the south (e.g. River Nene) both by natural and artificial spread, especially by boats. Creation of the link is also likely to greatly increase boat traffic from the drain and into the tidal Witham from where potentially contaminated boats could spread the clam to other estuarine systems, especially on the East Coast. Further surveillance for new *Rangia* colonisation is necessary in order to locate new populations at an early stage. Recent work in Lithuania is trialling an eDNA procedure to allow the early detection of *Rangia* in a water body

(Ardura *et al* 2015). If successful this might usefully be employed in the UK to allow surveyors to quickly assess if a water course contains *Rangia* but without the need for sediment removal or the skill to identify this clam.

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

Response: An initial assessment of the *Rangia* distribution in the Witham and lower Nene systems has been completed demonstrating that the clam appears to be currently restricted to a section of the SFFD.. As *Rangia* is estimated to have been living in the South Forty Foot Drain for at least 6 years then it has shown a weak ability to spread in the Lincolnshire area. Having had 'good' opportunity to spread by a mixture of natural and artificial means.. The apparent restriction of the clam to only one relatively short length of the SFFD provides an opportunity (if the potential damage caused by its spread is considered sufficiently great) to remove this non-native from Britain at a stage when it does not appear to have developed into an invasive pest. If control measures are to be considered then the speed of action might need to be based upon these considerations. Control over the winter months would come at a time when probable lower water temperatures would mean that the clam is not breeding.

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

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