RISK ASSESSMENT SUMMARY SHEET

Asian date mussel (*Arcuatula senhousia*)

- A small marine mussel that aggregates and can produce extensive mats in shallow coastal water areas.
- Native to Asia, but introduced to North America (west coast), Europe, Oceania (Australia, New Zealand) and West Africa
- Established in at least one population in GB. Present in Solent since 2011, most likely introduced with hull fouling, ballast water or aquaculture. Probably at the edge of its northern range, but climate change may facilitate expansion northwards.
- No evidence yet of impacts in GB, but it has the potential to form dense mats altering soft-sediment habitat, displacing native species and altering habitat for feeding birds. Could also impact on commercial shellfish / fisheries.

Photograph: Graham Bould, Wikimedia

History in GB

Present in the Solent area since at least 2011, where it is now widespread. Not known to be established elsewhere in GB; however, populations may be unrecorded. The largest density recorded in GB so far has been 290 per m^2, whereas elsewhere in Europe densities of >10,000 per m^2 have been recorded.

Native Distribution

Siberia to Singapore in the western Pacific including: Japan, Korea, China, and parts of Indochina.

GB Distribution

Present in the Solent

Source: NBN 2020

Impacts

In general the impacts of this species are not known with confidence and will involve complex interactions. Currently at low densities in GB, but has potential to form much larger, denser mats.

Environmental (moderate, medium confidence)

- Capable of forming dense mats, transforming soft sediment habitats and outcompeting native species for space and food.
- Large mats could alter food availability for birds.
- Has potential to impede the growth of seagrass, although this remains unclear.

Economic (moderate, medium confidence)

- A fouling organism and potential nuisance to marine vessels and aquaculture.
- Could directly compete with commercially important aquaculture species (e.g. oysters, mussels, clams, facilitate disease spread and impact on seagrass (an important nursery for commercial fish); however, there is little evidence for this yet.

Social (minor, low confidence)

- As with other bivalve molluscs this species could act as a carrier of viruses.

Introduction pathway

Hull fouling and ballast water: a fouling organism that could be moved at pelagic larval stage, for which there is evidence from Europe and New Zealand.

Aquaculture: attaches to shellfish (pacific oyster, flat oyster, blue mussels) and there is evidence of potential movements with aquaculture stocks (e.g. in North America).

Spread pathway

Natural dispersal: broadcast spawner with long dispersal distance (>100km).

Biofouling: could be spread on boats and aquaculture stock

Summary

	Response	Confidence
Entry	VERY LIKELY	VERY HIGH
Establishment	VERY LIKELY	VERY HIGH
Spread	RAPID	HIGH
Impact	MODERATE	MEDIUM
Overall risk	MEDIUM	MEDIUM

GB Non-native Species Rapid Risk Assessment (NRRA)

Rapid Risk Assessment of: *Arcuatula senhousia* (Asian date mussel)
Author: Kate Dey, University of Portsmouth

Version: Draft 1 (May 2020), Peer Review (June 2020), NNRAP 1st review (September 2020), Draft 2 (November 2020), NNRAP 2nd review (December 2020)
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Placed on NNSS website: February 2022

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.

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

Response: This species is being assessed in response to its arrival in Great Britain (GB) and research indicating that there are established populations on the south coast of England (Worsfold et al. 2020; Watson et al. 2021). Barfield et al. (2018) reported the appearance of *A. senhousia* for the first time in GB after observing it in 2017 and 2018 in the Solent region. However, it later came to light that the earliest record from this region was in fact from 2011 (Worsfold et al. 2020; Watson et al. 2021).

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:

Scientific name: *Arcuatula senhousia* (Benson in Cantor, 1842)
Common synonyms: *Modiola senhousia* (Benson, 1842) (type specimen); *Modiolus senhousei* (Benson, 1842); *Musculista senhousia* (Benson, 1842), *Brachidontes senhousia* (Kira, 1959). Full list provided by (CABI 2019).

Preferred common name: Asian date mussel
Other common names: Asian mussel, East Asian bag mussel, Japanese mussel, green mussel, bag mussel, nest mussel, cuckoo mussel, Senhouse's mussel

Willan (1985) provides a detailed explanation of nomenclature history.

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

Response: Yes.

Areas within its introduced range which have been particularly affected / widely reported in the literature include: Mission Bay and adjacent San Diego Bay in California, USA (Levin 1982; Dexter 1983; Crooks 1998;

Reusch and Williams 1998; Crooks and Khim 1999), Tamaki Estuary in Auckland, New Zealand (Willan 1985, 1987; Creese et al. 1997), Sacca di Goro lagoon in Ferrera, Italy (Turolla 1999; Mistri 2002, 2004a; Sgro et al. 2002; Munari 2008) and Taranto Seas, Italy (Mastrototaro et al. 2003, 2004). Even within its native range of Chiba in Japan. *A. senhousia* has been associated with increased mortality of the commercially important Manila clam (*Ruditapes philippinarum*), with specific reference to an "outbreak of a mussel *Brachidontes senhousia* in Urayasu shellfish rearing ground" (Sugawara et al. 1961; Uchida 1965).

Global distribution

A. senhousia has spread from its native range of Asia (stretching from Singapore to Siberia (Chuang 1961; Kulikova 1978)) to four other continents. The first introduction event was on the Pacific coast of North America in the 1920s (Dexter 1983). It has since been reported from Australia and New Zealand (Willan 1985, 1987); the Mediterranean and Adriatic Seas (Hoenselaar and Hoenselaar 1989; Mastrototaro et al. 2003; Micu 2004); the Azov-Black Sea Basin (Kovalev et al. 2017) and West Africa (Lourenço et al. 2018). Furthermore, it has been reported from the Suez Canal, Red Sea, Aden, Zanzibar, Madagascar, Mauritius, India, Indo-China and New Caledonia (Barash and Danin 1972; George and Nair 1974). The closest report preceding its arrival in GB is from the Bay of Biscay (Bachelet et al. 2009). Most recently, *A. senhousia* was reported from the Netherlands on 7th July 2018 (Faasse 2018) which, together with the UK records (Worsfold et al. 2020; Watson et al. 2021), suggests *A. senhousia* is spreading across the Greater North Sea ecoregion (as defined by ICES (2020)).

Spread within Europe

In the 1980s, Hoenselaar and Hoenselaar (1989) reported *A. senhousia* from Europe for the first time in the ecoregion of the Western Mediterranean Sea (ICES 2020). It has since been reported from nearly all ecoregions within European Waters which touch the continent, including the: Adriatic Sea (1990s) (Lizzari and Rinaldi 1994; Min and Vio 1997; Turolla 1999); Black Sea (2000s) (Micu 2004); Ionian Sea and the Central Mediterranean Sea (2000s) (Mastrototaro et al. 2003, 2004); Bay of Biscay and the Iberian Coast (2000s) (Bachelet et al. 2009); Aegean-Levantine Sea (2000s) (Uysal et al. 2008) and the Greater North Sea (2010s) (Barfield et al. 2018; Faasse 2018; Watson et al. 2021).

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

Response: So far, *A. senhousia* has only been reported in the Solent region on the south coast of England. First discovered on 11th May 2011 within the subtidal area of Southampton Water, during a Water Framework Directive (WFD) benthic survey undertaken by the Environment Agency (EA) (Worsfold et al. 2020; Watson et al. 2021). *A. senhousia* was not found during the EA's previous WFD benthic survey (in 2007), suggesting arrival between 2007 and 2011 (Watson et al. 2021). Subsequent EA surveys confirmed that *A. senhousia* was still present within Southampton Water in June 2013 and May 2016, and various other field collections have confirmed its presence in the wider Solent region up to 2019 (Holman et al. 2019; Worsfold et al. 2020; Watson et al. 2021).

A. senhousia was first officially reported in scientific literature as being present in GB after an individual shell was discovered in the intertidal area of Brownwich shore on 25th October 2017, and subsequent findings on 3rd December 2017 and 15th February 2018 (Barfield et al. 2018). Gonadosomatic index (GSI) and gonad staging analyses conducted from March to October 2019 on populations at Brownwich shore evidenced an established population in the intertidal (Watson et al. 2021). These reports, combined with the findings of small numbers of individuals from a variety of other surveys, suggest a distribution from the east to the west of the Solent (Watson et al. 2021). The intertidal locations of these surveys include Hythe, River Test (11th August 2016 and 11th December 2019), Weston Shore, River Itchen (31st March 2018), Saxon Wharf, River Itchen (22nd February 2019), Port Hamble, River Hamble (15th April 2019), Lepe (23rd March 2019), Portsmouth Harbour (13th May 2019), Chichester Harbour (2019), Shamrock Quay, River Itchen (29th November 2019) and Newtown, Isle of Wight (2019).

Although apparently extensive in the Solent, its known distribution is patchy (Watson et al. 2021) and a targeted survey of the whole region has not yet been undertaken. Moreover, the lack of reports from other parts of GB do not necessarily indicate its absence. As with many bivalve species (Strayer et al. 2017), populations can drastically fluctuate in number both temporally and spatially (Crooks 1996; Como et al. 2018). The highest density of *A. senhousia* was recorded as 290 per m^2 in the muddy subtidal sediment of Southampton Water in 2016 (Watson et al. 2021). This is a relatively low density since populations in other introduced regions have been reported to reach >10,000 per m^2 (Creese et al. 1997; Reusch and Williams 1998; Mistri 2002), with a maximum density of 190,000 per m^2 recorded in Mission Bay, San Diego, California, USA (Crooks 1998). In Auckland, New Zealand, *A. senhousia* populations increased 100-fold in just one year (6 per m^2 compared to 660 per m^2) (Willan 1987). Conversely populations can quickly decline; Mcdonald and Wells (2010) hypothesised that a high rainfall event in the Swan River Estuary (Perth, Australia) and a subsequent toxic algal bloom resulted in the complete eradication of *A. senhousia;* an introduced species that had been present for at least 20 years and had reached a maximum density of 2,600 per m^2 (Slack-Smith and Brearley 1987).

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: Watson et al. (2021) have already provided evidence for reproduction and successful establishment within the Solent region on the south coast of GB. Furthermore, *A. senhousia* is able to thrive in a variety of intertidal and subtidal habitats (Kuroda et al. 1971; Morton 1974; Crooks 1996; Creese et al. 1997; Watson et al. 2021) and has relatively broad environmental tolerances (Inoue and Yamamuro 2000; Sgro et al. 2002; CABI 2019). The majority of distribution records within Europe are from the relatively seasonal Warm Temperate climatic region, determined by the temperature of the hottest month being >10°C and the temperature of the coldest month being >0°C and <18°C (Beck et al. 2018).

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 presence of a small population within the Goese Meer, Netherlands (Faasse 2018) and an established population within the Bay of Biscay (Bachelet et al. 2009) suggest that the climate of GB is suitable for *A. senhousia* survival and reproduction. These locations all sit within a Temperate Oceanic Climate (cfb) as defined by the Köppen-Geiger climate classification (Beck et al. 2018), the same climate classification as for *A. senhousia*'s introduced range of Tamaki Estuary in Auckland, New Zealand where densities reached 16,000 per m^2 (Creese et al. 1997). Even though its extensive native range in East Asia, stretching from Siberia to Singapore (Chuang 1961; Kulikova 1978), is little classified as cfb, its climate is extremely variable, dominated by a Tropical Rainforest Climate (af) in the south, Temperate Humid Subtropical Climate (cfa) in the centre and Warm Summer Humid Continental Climate (dfb) in the north. *A. senhousia* must therefore be tolerant of a wide range of environmental conditions. Perhaps unsurprisingly, Asif and Krug (2012) have identified a warm-water lineage and cold-water lineage; the cold-water lineage from north-eastern Korea having established within the Mediterranean Sea. This cold-water lineage may well have established in GB.

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: N/A

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

Response: Yes.

A. senhousia is a broadcast spawner with high fecundity and large dispersal capability (due to a long planktonic stage) which facilitate natural spread (Sgro et al. 2002; Shanks 2009). Human-assisted spread via shipping (Carlton 1979; Willan 1985; Crooks 1996; Katsanevakis et al. 2013; Slijkerman et al. 2017), recreational boating (Clarke Murray et al. 2011; Robertson et al. 2020) and the aquaculture trade (Kincaid 1947; Hoenselaar and Hoenselaar 1989; Bachelet et al. 2009) is highly likely.

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

Response: Yes.

A. senhousia has not yet been found forming mats in GB and densities of *A. senhousia* may be currently too low to have significant environmental, economic, and social impacts. However, it can take years before *A. senhousia* reaches problematic densities (Crooks 1996) since invasive species often exhibit extended lag times from initial introduction (Crooks and Soulé 1999). If densities significantly increase, they can do so rapidly (Willan 1987). Research into diseases carried, and potentially spread, by *A. senhousia* could not be found at the time of writing, however in New Zealand native parasites have been found within *A. senhousia* (Miller et al. 2008).

A review of the literature summarising the impacts of *A. senhousia* in relation to natural capital and ecosystem services can be found in Watson et al. (2021). It is important to note that not all impacts of *A. senhousia* will be negative, for example bivalves offer nutrient remediation services (Yamamuro and Ishitobi 2000), sequester toxic pollutants (Broszeit et al. 2016) and provide habitat for native species (Crooks 1998). A balanced impact assessment is therefore imperative before implementing management and control measures.

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):

A. senhousia has already been recorded in GB (Worsfold et al. 2020; Watson et al. 2021), probably introduced via human assistance given the lack of records between the Bay of Biscay and the UK, as hypothesised by Barfield et al. (2018).

Shipping and recreational boating are likely pathways of introduction and spread since *A. senhousia* is a biofouling organism. In addition, its pelagic larval stage (lasting two to eight weeks (George and Nair 1974; Cohen 2011)) likely makes it susceptible to transport in ballast water and DNA has been detected in ballast water in Dutch harbours (Slack-Smith and Brearley 1987; Clarke Murray et al. 2011; Slijkerman et al. 2017; Robertson et al. 2020). Furthermore, the appearance of *A. senhousia* in New Zealand coincided with increased shipping movements between Auckland Harbour and a Japanese port (Willan 1985), and its arrival in southern California (USA) coincided with increased vessel traffic due to the Vietnam War (Carlton 1979).

Introduction via aquaculture is also likely since the first record of *A. senhousia* from North America was within Pacific oyster (*Crassostrea gigas*) beds in Samish Bay, Washington (Kincaid 1947). *A. senhousia* has also been found attached to European flat oysters (*Ostrea edulis*) and blue mussels (*Mytilus edulis*) (Watson et al. 2021) which, in addition to *C. gigas,* are economically important shellfish within Europe and are traded around the world (FAO 2017). Furthermore, as a biofouling organism, spread via marine litter is possible (Rech et al. 2016; Miralles et al. 2018). Also, natural dispersal of pelagic larvae on ocean currents, while not evidenced, cannot be ruled out.

At the time of writing, a predictive distribution model determining the potential spread of *A. senhousia* within GB or Europe could not be found. Such models can facilitate risk based biosecurity, surveillance and early detection which are essential for the effective management of non-native species (Srivastava et al. 2019).

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):

A. senhousia has already successfully established within the Solent region on the south coast of GB (Watson et al. 2021). It can thrive in a wide range of habitats, from the intertidal to a depth of 20 m, and from soft substrates (mud and sand) to hard substrates such as wood, cement, rock and shells (Kuroda et al. 1971; Morton 1974; Crooks 1996; Creese et al. 1997; Watson et al. 2021). Like many mytilid mussels, *A. senhousia* produces byssal threads which it uses to attach to these substrates and, when in high enough densities, to each other, forming mussel mats that can consist of thousands of individuals per m^2 (for example, Creese et al. 1997; Crooks 1998).

GSI and gonad staging analyses, in addition to the recording of juveniles (<10 mm) across multiple years strongly suggests that *A. senhousia* is reproducing within the Solent, although the presence of larvae has not yet been assessed (Watson et al. 2021). Individuals that appear to be ready for spawning have been observed in July and September, displaying thickened gonad tissue and a particularly high gonad tissue weight compared to total tissue weight ratio (Watson et al. 2021). This apparent readiness to spawn coincides with when sea temperatures are at their highest in the Solent, reaching an average of 15-16°C from July to October (World Sea Temperature 2020), and up to 21°C in shallow waters (Watson et al. 2021). Similarly, in its native range of the Sea of Okhotsk, Southern Sakhalin (Russia), the spawning period of *A. senhousia* coincides with temperatures of 15-20°C (Kulikova 1978). Temperatures <15°C may therefore limit reproduction and have indeed been proven to be lethal to *A. senhousia* embryos under laboratory conditions (Liang et al. 2009). This temperature limitation could restrict *A. senhousia* populations to more southern, warmer waters in GB, however climate change may facilitate northward population expansion (Hiscock et al. 2004; Cottier-Cook et al. 2017). It is worth noting that the temperature range required for *A. senhousia* reproduction to take place is commonly reported as 22.5-28°C (Inoue and Yamamuro 2000; Sgro et al. 2002; CABI 2019). However this temperature range may only apply to *A. senhousia* individuals originating from the warmer parts of its native region such as Tokyo Bay and South Korea (Asif and Krug 2012).

A. senhousia has a wide tolerance of both salinity (17-37 ppt) and dissolved oxygen (1-3 mg/l) (Inoue and Yamamuro 2000; Sgro et al. 2002; CABI 2019) and therefore can be found in the subtidal and intertidal, within estuaries and more open waters (Morton 1974; Kulikova 1978; Willan 1987; Creese et al. 1997; Watson et al. 2021). However, seasonal changes in mortality have been associated with anoxia, particularly during summer months (Kikuchi 1964; Yamamuro and Ishitobi 2000; Mistri 2002), and an extreme and prolonged decline in salinity can cause populations to crash (Slack-Smith and Brearley 1987). Densities of *A. senhousia* can also be limited by predation which can prevent the formation of mussel mats (Yamamuro and Jun 2010). *A. senhousia* is predated upon by shorebirds (such as diving ducks and oyster catchers) (Willan 1987; Creese et al. 1997; Yamamuro et al. 1998), boring carnivorous gastropods (Slack-Smith and Brearley 1987; Reusch 1998; Kushner and Hovel 2006), fish (Barash and Danin 1971) and crabs (Mistri 2004b). Its thin shell probably also makes it susceptible to predation by echinoderms.

Southampton Water (where *A. senhousia* is present in GB) is subject to high levels of nutrient inputs mainly from sewage discharge and river runoff, like most estuaries around GB (Maier et al. 2009). Phytoplankton levels are therefore likely to be high, providing plenty of food for *A. senhousia.* However, if nutrient levels are too high they could result in eutrophication and anoxia causing mass mortalities of *A. senhousia* (Yamamuro and Ishitobi 2000; Mistri 2002).

Spread Summary

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

Overall response: *rapid*
Confidence: *high*

Sub scores:

Natural spread only:
Response: *rapid*
Confidence**:** *high*

Human facilitated spread only:
Response: *rapid*
Confidence**:** *high*

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):

A. senhousia is a broadcast spawner with high fecundity and large dispersal capability which facilitate natural spread. Shanks (2009) determined a dispersal distance of 116 km by reviewing data from Willan (1987) and Semenikhina et al. (2008). One female can release >100,000 eggs (Sgro et al. 2002) and the larval plankton stage can last two to eight weeks (George and Nair 1974; Cohen 2011). Juveniles take about one year to sexually mature (Morton 1974) releasing gametes when about 14-20 mm in length (Sgro et al. 2002).

The drifting of settlement substrates is likely to influence local distribution. Throughout its introduced and native ranges, *A. senhousia* juveniles have been found attached to a variety of fibrous and filamentous substrates, including synthetic materials such as capron line, polyethylene film and foam plastic planes, and organic materials such as seagrass, macroalgae and even conifer tree needles (Kulikova 1978). More specifically, *A. senhousia* has been reported to settle on *Zostera* and *Ulva* spp. (Kikuchi 1964; Reusch and Williams 1998; Watson et al. 2021), *Sargassum* and *Ahnfeltia* spp. (Kulikova 1978) and *Agarophyton vermiculophyllum* (Yamamuro and Jun 2010). (As a side note, *Sargassum muticum* is an invasive species in the UK, also native to Japan and China, like *A. senhousia,* which raises the question of whether an invasive species could facilitate another.) High densities have additionally been found on pleustophytic algal felt, mainly *Chaetomorpha linum* and *Cladophora hutchinsiae,* and on *Caulerpa racemosa* beds (Mastrototaro et al. 2003).

As a hitchhiker on shells and boats (Slack-Smith and Brearley 1987; Watson et al. 2021), with a prolonged pelagic larval stage (George and Nair 1974; Cohen 2011) which could be transported in ballast water, spread human assistance is very likely. High levels of boat traffic into and out of the Solent region, and numerous shellfisheries, are likely to facilitate both local and international spread. Having probably been transported to GB from the Bay of Biscay (Barfield et al. 2018), *A. senhousia* could also be introduced to other parts of GB via further introduction from abroad. *A. senhousia*'s ability to thrive in a variety of habitats and tolerate a wide range of environmental conditions makes it likely that *A. senhousia* has only colonised a small area of its potential habitat within GB.

Impact Summary

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

Overall response: *moderate*
Confidence: *medium*

Sub-scores

Environmental impacts:
Response: *moderate*
Confidence**:** *medium*

Economic impacts:
Response: *moderate*
Confidence: *medium*

Social impacts:
Response: *minor*
Confidence: *low*

Comments (include list of impacts in your comments):

Impact scores reflect future potential impact and have been determined by reviewing case studies from elsewhere and baseline analyses within GB by Watson et al. (2021). Successful establishment of *A. senhousia* is documented, however no specific impacts of *A. senhousia* within GB have yet been recorded within scientific literature. This may be because current impacts are minimal due to low densities (maximum 290 per m^2 recorded in the Solent compared to 10,000s per m^2 in other parts of its native and introduced ranges) (Creese et al. 1997; Reusch and Williams 1998; Mistri 2002; Watson et al. 2021), or simply due to a lack of research. Predicting the future distribution and therefore impact of *A. senhousia* is particularly difficult because densities can vary so much both temporally and spatially (Willan 1987; Creese et al. 1997; Yamamuro and Ishitobi 2000). Furthermore, some impacts could even be beneficial (Watson et al. 2021). Ongoing monitoring of *A. senhousia* populations within GB and research into its potential impacts are essential to increase the certainty of impacts.

Environmental

In parts of its introduced and native ranges *A. senhousia* can form dense mussel mats that consist of thousands of individuals per m^2 which physically and chemically transform soft sediment habitats and change community composition (Creese et al. 1997; Crooks 1998; Reusch and Williams 1998; Crooks and Khim 1999). *A. senhousia* mats have been reported to increase the abundances of gastropods, polychaetes, crustaceans and amphipods (Crooks 1998; Mistri 2002; Como et al. 2018). However, they can reduce the abundances of some bivalve and polychaete species (Sugawara et al. 1961; Creese et al. 1997; Crooks 2001; Munari 2008). Probable factors leading to species declines include resource competition (i.e. space and food) (Crooks 2001) and the accumulation of fine, organic rich, anoxic sediments resulting from the faeces and pseudofaeces produced by *A. senhousia* (Takenaka et al. 2018) which may impede the feeding ability of suspension feeders (Chiba 1977; Creese et al. 1997). Furthermore, *A. senhousia* could impact the distribution of bird species; introduced molluscs such as *C. gigas* can provide feeding grounds for some shorebird species but destroy it for others (Herbert et al. 2018)

In GB, *A. senhousia* has been found within seagrass beds (*Zostera* spp.) in Portsmouth Harbour and on Brownwich beach (Watson et al. 2021). Seagrass is declining in GB due to a host of anthropogenic factors (Jones and Unsworth 2016) sparking restoration efforts such as Project Seagrass (Project Seagrass 2018). *A. senhousia* could impede such efforts since sparse and patchy populations are particularly at risk, although the interactions between *A. senhousia* and *Zostera* spp. are complex (Reusch and Williams 1998). *A. senhousia* may inhibit eelgrass (*Zostera marina*) rhizome growth via spatial interference but may also provide beneficial nutrients (Reusch and Williams 1998). Considering studies of *M. edulis, w*hether *A. senhousia* has a positive or negative impact on *Zostera* may be determined by light levels (Castorani et al. 2015; Hasler-Sheetal et al. 2016). Further, *Z. marina* can reduce the growth rate of *A. senhousia* via nutrient limitation (Reusch and Williams 1999; Albentosa 2002).

Economic

A. senhousia's ability to attach to the hulls of boats (Slack-Smith and Brearley 1987) could result in higher antifouling costs for boat owners if background levels are increased. Attachment of fouling organisms to marine infrastructure and equipment can also cause physical damage and mechanical interference (Fitridge et al. 2012; Want et al. 2017). For instance, in Northern Ireland, the freshwater zebra mussel (*Dreissena polymorpha*) blocked water intake pipes at Killyhevlin water works in Enniskillen and modifications were needed at a cost of over £100,000 (Maguire and Sykes 2004). Furthermore, *A. senhousia* has been found attached to *O. edulis, M. edulis* and *C. edule* within GB (Watson et al. 2021) and larvae can settle on synthetic materials such as capron (plastic) line (Kulikova 1978). This species could therefore become a significant biofouling organism of commercial shellfish and their settlement substrate (for example, ropes used for longline cultivation of *M. edulis*) in marine and brackish waters, potentially increasing the cost of shellfish aquaculture (biofouling is estimated to be 20-30% of shellfish production costs) (Fitridge et al. 2012; Lacoste and Gaertner-Mazouni 2015; Forrest and Atalah 2017). *A. senhousia* could also impede national *O. edulis* restoration initiatives such as the Solent Oyster Restoration Project (Harding et al. 2016). Moreover, the potential for *A. senhousia* to hybridise with, or spread disease to, commercial shellfish in the UK (such as *Mytilus* spp.) has yet to be investigated. However, in New Zealand, a native parasite *Pinnotheres novaezelandiae* has been found in both *A. senhousia* and *Mytilus galloprovincialis* (Miller et al. 2008).

In the Solent region and coastal areas across GB, species of European commercial importance, such as polychaetes (e.g. *Alitta virens* and *Arenicola marina*) collected for angling bait and oysters (*O. edulis* and *C. gigas*), clams (*Ruditapes philippinarum* and *R. decussatus*) and cockles (*C. edule*) farmed for consumption, are found within the soft sediment habitats that *A. senhousia* can colonise (CEFAS 2013; Watson et al. 2016; FAO 2017). *A. senhousia* has been reported to reduce the growth rate and survivorship of commercially important clams, such as the manila clam (*R. philippinarum*) and *Chione* spp., by competing for space and food (Sugawara et al. 1961; Uchida 1965; Crooks 2001; Mistri 2002) and indirectly increasing predation (Castorani and Hovel 2015). Furthermore, high *A. senhousia* densities can alter sediment conditions causing changes in community composition (Crooks 1998; Crooks and Khim 1999).

If *A. senhousia* causes seagrass to decline in GB then this could have a negative impact on commercial fish species. Significant numbers of juvenile plaice, pollock and herring have been recorded within *Z. marina* beds in the UK (Bertelli and Unsworth 2014). These fish have substantial commercial value in Europe; in 2018, 55,300 tonnes were landed in UK waters by UK vessels, valued at £30.7 million (Elliott and Holden 2019).

Social

Wild and cultured bivalve molluscs can contain human enteric viruses (Vilariño et al. 2009). *A. senhousia* could spread such viruses to other shellfish species consumed in GB, or to humans directly (*A. senhousia* is consumed by humans in China (Morton 1974; Carlton 1979)). However, as of the time of writing, no investigations into diseases carried by *A. senhousia* could be found. The formation of dense *A. senhousia* mats may also have a negative aesthetic impact in the intertidal, both in terms of the visual aspect of the mats themselves and the resulting changes in community composition. In New Zealand, *A. senhousia* mats provide habitat and food for a toxic sea slug (*Pleurobranchaea maculata*) which is harmful to dogs, however there are currently no records of *A. senhousia* facilitating other species that could be harmful to humans and animals in the UK.

Climate Change

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

Response: *high*
Confidence: *medium*

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):

In GB, *A. senhousia* has been recorded at 50.91° North (Solent region, south coast of England) (Watson et al. 2021); the most northerly distribution of an established population within its introduced range so far reported. Barfield et al. (2018) investigated the northern edge of its native distribution, concluding that the literature strongly suggests it is just north of Japan, at the southern end of the Kuril Islands and Sakhalin Island (approximately N46.87°; the location of Izmenchivoye Lake on Sakhalin (Labay 2009)). It is therefore likely that *A. senhousia* is at the edge of its potential introduced range on the south coast of GB. However the warming of our seas will almost certainly allow the northwards extension of that range, as it probably will (and probably already has) for many southerly distributed benthic species (Hiscock et al. 2004; Cottier-Cook et al. 2017), and potentially improve the environmental conditions required for reproduction and therefore higher densities (Liang et al. 2009). On the other hand, warmer waters could prolong periods of anoxia (Danise et al. 2013) which can significantly increase *A. senhousia* mortality (Yamamuro and Ishitobi 2000; Mistri 2002). The timescale over which potential climate-induced spread and density increases may occur is dependent on the environmental tolerances of the *A. senhousia* population which has established in the Solent region; these are yet to be determined.

Conclusion

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

Response: *medium*
Confidence: *medium*

Comments:

At the time of writing (2020), densities of *A. senhousia* are currently low in GB (maximum 290 per m^2 recorded) and there is no evidence that individuals are forming mats (Watson et al. 2021). However, comprehensive survey data for *A. senhousia* in GB is currently limited and *A. senhousia* populations have been known to rapidly increase after an initial lag phase (Crooks 1996). The likelihood that problematic *A. senhousia* mats could form in the future could be considered high, based on the knowledge that an established population is already successfully reproducing on the south coast and a wide variety of habitats have been colonised (Watson et al. 2021). Furthermore, warming seas may increase reproduction success and decrease mortality events since *A. senhousia* appears to be at its northern limit of distribution in GB. If rapid expansion happens and high densities form, *A. senhousia* will transform soft sediment habitats and so alter their associated species communities. More specifically, *A. senhousia* could have a negative impact on *Zostera* and *O. edulis* restoration and may present a significant threat to GB's fisheries and shell fisheries.

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

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