Name of organism:

*Boccardia proboscidea* Hartman, 1940

Author(s) of the assessment:

- Marika Galanidi, Dr, Dokuz Eylul University, Institute of Marine Sciences and Technology, Izmir, Turkey
- Argyro Zenetos, Dr, Research Director, Hellenic Centre for Marine Research, Greece
- Björn Beckmann, Dr, Centre for Ecology & Hydrology, Edinburgh, UK

**Risk Assessment Area:** The risk assessment area is the territory of the European Union (excluding the outermost regions) and the United Kingdom.

**Peer review 1:** Vasily Radashevsky, National Scientific Center of Marine Biology, Far Eastern Branch of the Russian Academy of Sciences, Russia

**Peer review 2:** Jack Sewell, The Marine Biological Association, UK

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SECTION A – Organism Information and Screening

A1. Identify the organism. Is it clearly a single taxonomic entity and can it be adequately distinguished from other entities of the same rank?

including the following elements:

- the taxonomic family, order and class to which the species belongs;
- the scientific name and author of the species, as well as a list of the most common synonym names;
- names used in commerce (if any)
- a list of the most common subspecies, lower taxa, varieties, breeds or hybrids

As a general rule, one risk assessment should be developed for a single species. However, there may be cases where it may be justified to develop one risk assessment covering more than one species (e.g. species belonging to the same genus with comparable or identical features and impact). It shall be clearly stated if the risk assessment covers more than one species, or if it excludes or only includes certain subspecies, lower taxa, hybrids, varieties or breeds (and if so, which subspecies, lower taxa, hybrids, varieties or breeds). Any such choice must be properly justified.

Response:

**Phylum:** Annelida, **Class:** Polychaeta, **Order:** Spionida, **Family:** Spionidae

*Boccardia proboscidea* Hartman, 1940

A burrowing spionid worm

Synonym: *Polydora californica* (Treadwell, 1914)

*Spio californica* (Fewkes, 1889)

*Polydora californica* (Treadwell, 1914) and *Spio californica* (Fewkes, 1889) were both suppressed in 2012 by the International Commission on Zoological Nomenclature (ICZN, case 3520). The widely cited and used name, *Boccardia proboscidea* (Hartman, 1940) was conserved (ICZN, 2012).

The species is clearly a single taxonomic entity, however its similarity with other spionid species and the use of European identification keys, not including non-native species, has led to misidentifications in the past in the RA area (see Qu A2 below for details).

A2. Provide information on the existence of other species that look very similar [that may be detected in the risk assessment area, either in the environment, in confinement or associated with a pathway of introduction]

Include both native and non-native species that could be confused with the species being assessed, including the following elements:

- other alien species with similar invasive characteristics, to be avoided as substitute species (in this case preparing a risk assessment for more than one species together may be considered);
- other alien species without similar invasive characteristics, potential substitute species;
- native species, potential misidentification and mis-targeting

Response: Spionid polychaete worms are common shellfish pests throughout the world, especially species of *Polydora* and *Boccardia* which are commonly referred to as "mudworm" (Handley, 1995). Among the most widespread spionid species in Europe worth mentioning are *Polydora ciliata* (native in NW Europe) and *Polydora cornuta* (cosmopolitan, alien). For differences among the spionid species see Rainer (1973). There are three *Boccardia* species in European waters (*Boccardia polybranchia* (Haswell, 1885), *Boccardia proboscidea* and *Boccardia semibranchiata* Guérin, 1990) which can be misidentified with the two *Boccardiella* species (*Boccardiella hamata* (Webster, 1879) and *Boccardiella ligera* (Ferroniere, 1898)). The genera *Boccardia* and *Boccardiella* differ in the kinds of modified setae on the fifth setiger, *Boccardiella* species have heavy falcate spines alternating with bilimbate-tipped companion chaetae while in *Boccardia* the notopodia have heavy falcate spines and brush-topped spines (Radashevsky, 2012).

Identification of this species with a recent regional polychaete identification manual (Hartmann-Schroder, 1996) readily points to *Boccardiella ligera* due to the gills on chaetigers 2, 3 and 4. Identification with the older and more southerly-oriented manual of Fauvel (1927) points to *Boccardia polybranchia* (Kerckhof & Faasse, 2014). Martinez et al. (2006) provide a key to *Boccardia* species recorded from the Atlantic, including *B. proboscidea*, which highlights the short notopodial chaetae on the first chaetiger of *B. proboscidea* that are lacking in *B. polybranchia*. *Boccardia proboscidea* further differs from other *Boccardia* species recorded from the Atlantic, in the bristle-tipped special chaetae of chaetiger 5 without subdistal bosses and the undivided prostomium. *Boccardia proboscidea* has a robust, thick body reaching 45 mm length (Radashevsky et al., 2019).

*Boccardia polybranchia* is green to reddish-yellow in color and has a notched prostomium. Its first setiger lacks notosetae, it has only 60–80 segments and a pygidium that is a thick ring. *Boccardia polybranchia* is a cosmopolitan species that lives in estuarine mud and is reported in France (Ruellet, 2004), UK, Spain and Portugal (Martinez et al, 2006 and references therein) yet with reservations about its correct identification.
In fact, Radashevsky (2015) notes for *B. polybranchia* that the characters of the material from type locality are poorly known and that the insufficient original description could have led to reports from worldwide locations. Therefore, records of *B. polybranchia* in Europe may be misidentifications of what could be *B. proboscidea* (Radashevsky, pers. comm, January 2021).

*Boccardia semibranchiata* is a recently described species from the Mediterranean Sea. It is reported from the Atlantic France (Goulletquer *et al.*, 2002) and Spain (Martínez *et al.*, 2006).

*Boccardiella hamata* has recurved spines, rather than straight bifid uncini, on its posterior parapodia and the pygidium has two lappets (Hartman 1969). It is common in oyster beds and builds tubes in mudflats or bores holes into hermit crab and bivalve shells and is reported from the Netherlands (Kerckhof & Faasse, 2014). *Boccardiella hamata* can be easily confused and has been misidentified as *Boccardiella ligerica*, a cryptogenic species reported from the Baltic Sea and North Sea (Jansson, 1994).

In conclusion, there is definitely scope for misidentification of *Boccardia* specimens; correct identification requires a high level of taxonomic expertise and an awareness that one should look beyond regional/generic identification guides.

A3. Does a relevant earlier risk assessment exist? Give details of any previous risk assessment, including the final scores and its validity in relation to the risk assessment area.

Response: No full risk assessment is available. However David *et al* (2016) have studied its dispersal potential is South Africa. Results obtained from David *et al* (2016) genetic study and dispersal simulations have shown that *B. proboscidea* can disperse and become established along a large section of the South Africa coast irrespective of biogeographic boundaries. Its success will be due in part to its versatile reproductive strategy and wide thermal tolerance. However, it appears that anthropogenic movement will most likely be the critical factor governing both the spread and long-term establishment of this species in southern Africa.

Garaffo *et al* (2016) have povided predictive models for variations in the density of *B. proboscidea* around sewage discharges of Mar del Plata, Argentina, using environmental variables.

A4. Where is the organism native?

including the following elements:

- an indication of the continent or part of a continent, climatic zone and habitat where the species is naturally occurring
- if applicable, indicate whether the species could naturally spread into the risk assessment area
Response:

*Boccardia proboscidea* is a eurythermal and euryhaline species (Hartmann, 1940) with a cosmopolitan distribution in temperate seas.

*Boccardia proboscidea* Hartman, 1940 was originally described from northern California (see Radashevsky & Harris, 2010; Fauchald *et al*., 2011). It is widely reported from the E. Pacific (coast of North America from British Columbia, Canada, south to southern California), and also from the NW Pacific (Japan, Korea and China).

The native distribution of *B. proboscidea* had been uncertain. Based on the type locality only, the species was assumed to be native to California and introduced from British Columbia to Baja California and all other locations (Jaubet *et al*., 2018), or native to the Pacific coast of North America and Japan (Spilmont *et al*., 2018)

The high 16S haplotype diversity of *B. proboscidea* from the Pacific USA suggests a native distribution for the species in the northern Pacific and subsequent introductions through human activities to other parts of the world (Radashevsky *et al*., 2019).

Its presence in the Asian North-Pacific is of questionable origin (Sato-Okoshi *et al*., 2000; Abe *et al*., 2019a) and assumptions that it is native in Japan are not substantiated by concrete evidence (Radashevsky *et al*., 2019).

**A5. What is the global non-native distribution of the organism outside the risk assessment area?**

Response: Review of previous reports and our new records of *B. proboscidea* show a wide spread of the species in temperate waters across the globe. A phylogenetic analysis revealed the occurrence of single haplotypes in Europe (haplotype K) and in South Africa, Australia and South America (haplotype A), which suggests a recent foundation event for each. The exclusive occurrence of one or the other of these haplotypes suggests at least two distinct routes of colonization from the original distribution zone (Norh Pacific): one for European locations, and one for the Southern Hemisphere ((Radashevsky *et al*., 2019).

The genetic diversity of *B. proboscidea* in Japan, Korea and China, has not been studied. Its common occurrence along the Chinese coast (Yang & Sun, 1988; Zhou *et al*., 2010) may be indicative of a wider distribution (East and west North Pacific). However the absence of a continous distribution along the North East Pacific may be due to a recent introduction.

Outside of the North Pacific, *B. proboscidea* was first reported from Australia by Blake & Kudenov (1978). Based on this, *B. proboscidea* was suggested to be introduced to Australia with ballast waters discharged in Port Phillip Bay, which hosts the largest seaport in Australia (Pollard & Hutchings, 1990). In 1979, *B. proboscidea* was collected in Elliston, South Australia 1,000 km west of Port Phillip Bay (Hutchings & Turvey, 1984). Therefore, either there were multiple introductions of *B. proboscidea* to southern Australia, or *B. proboscidea* was introduced much earlier and dispersed locally but remained undetected until the first major environmental surveys occurred in the 1970s (Radashevsky *et al*., 2019).

The species is widely established, in Argentina (Jaubet *et al*., 2011, 2013, 2015). Jaubet *et al*. (2018) suggested that the species might have been introduced into Argentina from Australia with shipments of Australian bauxite to the aluminum plant in Puerto Madryn that was installed in 1974.

In South Africa, *B. proboscidea* occurs in south-west coasts, indicating establishment in the wild (Simon *et al*., 2009, 2010b; Boonzaaier *et al*., 2014; David *et al*., 2016).
Boccardia proboscidea was also introduced to an oyster farm at Keahole, Hawaii, with a shipment of Ostrea edulis Linnaeus, 1758 (Bailey-Brock, 2000) from Maine, although no population of the species has been reported there. However, individuals of B. proboscidea have not been recorded to date in the wild in Hawaii, even though the species is within its physiological limits there (see Annexes VII & VIII).

Record of B. proboscidea from Panama by Fauchald (1977), Mexico (de León-González et al., 1993), Chile, by Carrasco (1974, 1976) and Costa Rica (Sibaja-Cordero & Echeverría-Sáenz, 2015) have been refuted by Radashevsky et al. (2019) as misidentifications. In most cases (Panama, Mexico, Costa Rica) the records were outside the known thermal tolerance of the species.

In detail sources of distribution with confirmed id.

**Australia**: Blake & Kudenov, 1978; Hutchings & Turvey, 1984; Pollard & Hutchings, 1990; Thresher & Martin, 1995; Petch, 1995; Hewitt et al., 2004

**Argentina** (Diez et al., 2011; Jaubet et al., 2011, 2013, 2015, 2018; Radashevsky, 2011)

**South Africa**: Simon et al., 2009; 2010b; David & Simon, 2014; Simon & Booth, 2007; Mead et al., 2011

**New Zealand**: Read, 2004

**Tasmania**: Leonart, 2002

**Brazil**: Jaubet et al., 2018


?China: Yang & Sun, 1988; Sun, 1994; Zhou et al., 2010

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**A6. In which biogeographic region(s) or marine subregion(s) in the risk assessment area has the species been recorded and where is it established? The information needs be given separately for recorded and established occurrences.**

**A6a. Recorded: List regions**

**A6b. Established: List regions**

Freshwater / terrestrial biogeographic regions:

- Alpine, Atlantic, Black Sea, Boreal, Continental, Mediterranean, Pannonian, Steppic

Marine regions:

- Baltic Sea, North-east Atlantic Ocean, Mediterranean Sea, Black Sea

Marine subregions:

- Greater North Sea, incl. the Kattegat and the English Channel, Celtic Seas, Bay of Biscay and the Iberian Coast, Western Mediterranean Sea, Adriatic Sea, Ionian Sea, Central Mediterranean Sea, Aegean-Levantine Sea.

Comment on the sources of information on which the response is based and discuss any uncertainty in the response.


Response (6a): Greater North Sea, incl. the Kattegat and the English Channel, Celtic Seas, Bay of Biscay and the Iberian Coast, Western Mediterranean Sea, Bay of Biscay and the Iberian Coast- established see response 6b
Greater North Sea, incl. the Kattegat and the English Channel: established see response 6b
Celtic Sea: established see response 6b
Western Mediterranean Sea: the discovery of the species in an oyster, purportedly originating in Leucate Lagoon, France (see question mark in the map above) raises concerns for this major aquaculture facility in Mediterranean France. However, there was high uncertainty associated with the origins of the oyster specimen, such that this finding requires confirmation and further investigation (Radashevsky et al., 2019).

Response (6b):
Bay of Biscay and the Iberian Coast: established
*B. proboscidea* was first discovered in 1996 on the rocky intertidal near a sewage outfall at San Sebastián, Bay of Biscay, Spain (Martínez et al., 2006) Additional records of the species based on specimens collected in northern Spain during environmental monitoring programs and Studies for Public administrations after 1997. In 2014, *B. proboscidea* was collected from several rocky shores surrounding La Rochelle on the French coast of the Bay of Biscay (Spilmont et al., 2018).

Greater North Sea, incl. the Kattegat and the English Channel
In the UK, *B. proboscidea* was first collected in August 1998 on Horsey Island, Essex, south-eastern England. In 2000, worms were found at Shotley, Suffolk, near the ports of Felixstowe, Suffolk, and Harwich, Essex (recorded at generic level in an unpublished report. In 2004 and 2005, it was found in the Tees Estuary, north-eastern England; in 2006, it was found in the Clyde Sea, Scotland and in 2008 in King Edwards Bay, Tynemouth, and Cullercoats Bay, north-eastern England. In 2011, the species was found on rocky intertidal shores in Looe, Cornwall, near Plymouth, and in 2016 it was present in Kent and Sussex, all of which are along the English Channel (full details in Radashevsky *et al.*, 2019). In 1999, *B. proboscidea* was collected near Roscoff, Brittany, France (museum specimen #USNM 186423, Radashevsky *et al.*, 2019) and in 2014 it was found on an intertidal rocky reef near Wimereux, Hauts-de-France (Spilmont *et al.*, 2018). In the Southern Bight of the North Sea (Belgium), the species was first recorded in 2013 but its presence is suspected since 2001 (Kerckhof & Faasse, 2014 – see also Qu. A8). In the German Bight (Helgoland Island), the first report of *B. proboscidea* (2016) appears in Lackschewitz *et al.* 2017 (in WGITMO, 2017), however the presence of the species backdates to 2008, observed by Ralph Kuhlenkamp and confirmed by Vasily Radashevsky (Radashvsky *et al.*, 2019). According to existing information, the species has neither established nor been recorded in the Skagerrak and the Kattegat.

**Celtic Seas: established**

In 2011 and 2013, worms were found intertidally on the Isle of Skye, north-west Scotland (Hatton & Pierce, 2013), and in 2016 we collected them in Great Cumbrae Island, western Scotland (MIMB 33681). Full details in Radashevsky *et al.* (2019)

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**A7. In which biogeographic region(s) or marine subregion(s) in the risk assessment area could the species establish in the future under current climate and under foreseeable climate change? The information needs be given separately for current climate and under foreseeable climate change conditions.**

**A7a. Current climate: List regions**

**A7b. Future climate: List regions**

With regard to EU biogeographic and marine (sub)regions, see above.

With regard to climate change, provide information on

- the applied timeframe (e.g. 2050/2070)
- the applied scenario (e.g. RCP 4.5)
- what aspects of climate change are most likely to affect the risk assessment (e.g. increase in average winter temperature, increase in drought periods)

The assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4-1.6°C global warming increase by 2065) and RCP 4.5
(likely range of 0.9-2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

Response (7a): **Combining physiological tolerances and distribution modeling** (see Qu 3.1, Qu 3.13 and Annex VII & VIII for details)

- **Baltic Sea**: unlikely, high confidence
- **Greater North Sea**: very likely, high confidence (not in the Skagerrak or Kattegat)
- **Celtic Seas**: very likely, high confidence
- **Bay of Biscay and the Iberian coast**: very likely, high confidence
- **Mediterranean Sea**: likely, medium confidence
- **Black Sea**: unlikely, low confidence

Response (7b): **Combining physiological tolerances and distribution modeling** – Estimates in Annex VII refer to a maximum increase in seawater temperatures of 0.8 °C by 2065, according to the medium time frame RCP 4.5 scenario. Aspects of climate change most likely to affect future distribution were considered as an increase in minimum and maximum Sea Surface Temperatures (SST). The methodology for the developed models is described in Annex VIII.

- **Baltic Sea**: unlikely, high confidence
- **Greater North Sea**: very likely, high confidence (not in the Kattegat)
- **Celtic Seas**: very likely, high confidence
- **Bay of Biscay and the Iberian coast**: very likely, high confidence
- **Mediterranean Sea**: moderately likely, medium confidence
- **Black Sea**: unlikely, low confidence

A8. In which EU Member States has the species been recorded and in which EU Member States has it established? List them with an indication of the timeline of observations and include the United Kingdom when relevant. The information needs be given separately for recorded and established occurrences.

A8a. Recorded: List Member States

A8b. Established: List Member States

Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom
The description of the invasion history of the species shall include information on countries invaded and an indication of the timeline of the first observations, establishment and spread.

Response (8a): Ireland, in Galway Bay on the west coast of Ireland in 2001 and 2014 (see Radashevsky et al., 2019)

Response (8b):
Belgium: since 2011: Kerckhof & Faasse, 2014, however its presence is suspected since 2001, based on the re-examination of old material that was misidentified by Volckaert et al. (2003) as Boccardiella ligerica (Kerckhof & Faasse, 2014).
Ireland: since 2001 (Radashevsky et al., 2019).
Germany: 2016: Helgoland Island (Lackschewitz et al., 2017 in WGITMO, 2017) and backdated record from 2008, established (Kind & Kuhlenkamp, 2017; Radashevsky et al., 2019).
Netherlands: since 2013 (Kerckhof & Faasse, 2014) established by 2017 (Wijnhoven et al., 2017)
Spain: Atlantic coast since 1996 (Martínez et al., 2006).

A9. In which EU Member States could the species establish in the future under current climate and under foreseeable climate change? Include the United Kingdom when relevant. The information needs be given separately for current climate and under foreseeable climate change conditions.

A9a. Current climate: List Member States
A9b. Future climate: List Member States

With regard to EU Member States, see above.

With regard to climate change, provide information on

- the applied timeframe (e.g. 2050/2070)
- the applied scenario (e.g. RCP 4.5)
- what aspects of climate change are most likely to affect the risk assessment (e.g. increase in average winter temperature, increase in drought periods)

The assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4-1.6°C global warming increase by 2065) and RCP 4.5
(likely range of 0.9-2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

Response (9a): In addition to the countries where it is already established (Belgium, France, Germany, Ireland, Netherlands, Spain, United Kingdom) it may be established in Croatia, Denmark, Greece, Italy, Portugal, Slovenia. The current maps indicate that in Malta and Cyprus the species will be constrained by high summer temperatures both now and in the future, and in Sweden by low salinity in the Baltic and by low winter temperatures along the Skagerrak. - See Annex VII, VIII

Response (9b): Belgium, France, Germany, Ireland, Netherlands, Spain, United Kingdom, Croatia, Denmark, Greece, Italy, Portugal, Slovenia and Sweden (an increase in winter temperatures will offer suitable climatic conditions along the Skagerrak).

A10. Is the organism known to be invasive (i.e. to threaten or adversely impact upon biodiversity and related ecosystem services) anywhere outside the risk assessment area?

Response: for details and references please see Q5.1

In summary: In sewage impacted sites in Argentina, Boccardia proboscidea creates epilithic biogenic reefs, smothers and displaces native species (most importantly native engineering species) and greatly alters the structure and function of the associated communities. The species is also known to bore into friable sedimentary rocks and soft sand/mudstone where, at high densities, it destroys the substrate. As a tube dweller in soft sediments, it can also create dense populations (examples from Australia, California and South Africa), which consolidate the sediments with their “tube mats”, impacts on the associated benthic communities however have not been reported.

A11. In which biogeographic region(s) or marine subregion(s) in the risk assessment area has the species shown signs of invasiveness? Indicate the area endangered by the organism as detailed as possible.

Freshwater / terrestrial biogeographic regions:
- Alpine, Atlantic, Black Sea, Boreal, Continental, Mediterranean, Pannonian, Steppic

Marine regions:
- Baltic Sea, North-east Atlantic Ocean, Mediterranean Sea, Black Sea

Marine subregions:
Response: *Boccardia proboscidea* has been generally reported in low/medium densities in the RA area (see Qu. 5.2) with the exception of the island of Helgoland in the Greater North Sea (German Bight) and in North Tyneside, England, UK. In these locations the species is observed in high densities, boring into soft mudstone and concerns are expressed about potential erosion of the invaded habitat and the possible displacement of the native polychaete *Polydora ciliata* (Kind & Kuhlenkamp, 2017; Radashevsky *et al.*, 2019).

**A12. In which EU Member States has the species shown signs of invasiveness? Indicate the area endangered by the organism as detailed as possible and include the United Kingdom as relevant.**

Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom

Response: In Germany and the United Kingdom, see details above

**A13. Describe any known socio-economic benefits of the organism.**

including the following elements:

- Description of known uses for the species, including a list and description of known uses in the Union and third countries, if relevant.
- Description of social and economic benefits deriving from those uses, including a description of the environmental, social and economic relevance of each of those uses and an indication of associated beneficiaries, quantitatively and/or qualitatively depending on what information is available.

If the information available is not sufficient to provide a description of those benefits for the entire risk assessment area, qualitative data or different case studies from across the Union or third countries shall be used, if available.

Response: None
SECTION B – Detailed assessment

Important instructions:
- In the case of lack of information the assessors are requested to use a standardized answer: “No information has been found.”
- With regard to the scoring of the likelihood of events or the magnitude of impacts see Annexes I and II.
- With regard to the confidence levels, see Annex III.
- Highlight the selected response score and confidence level in **bold** but keep the other scores in normal text (so that the selected score is evident in the final document).

1 PROBABILITY OF INTRODUCTION

Important instructions:
- **Introduction** is the movement of the species into the risk assessment area (it may be either in captive conditions and/or in the environment, depending on the relevant pathways).
- **Entry** is the release/escape/arrival in the environment, i.e. occurrence in the wild and is treated in the next section (N.B. introduction and entry may coincide for species entering through pathways such as “corridor” or “unaided”).
- The classification of pathways developed by the Convention of Biological Diversity (CBD) should be used. For detailed explanations of the CBD pathway classification scheme consult the IUCN/CEH guidance document\(^2\) and the provided key to pathways\(^3\).
- For organisms which are already present in the risk assessment area, only complete this section for current active pathways and, if relevant, potential future pathways.

Qu. 1.1. List relevant pathways through which the organism could be introduced. Where possible give details about the specific origins and end points of the pathways as well as a description of any associated commodities.

For each pathway answer questions 1.2 to 1.7 (copy and paste additional rows at the end of this section as necessary). Please attribute unique identifiers to each question if you consider more than one pathway, e.g. 1.2a, 1.3a, etc. and then 1.2b, 1.3b etc. for the next pathway.

In this context a pathway is the route or mechanism of introduction of the species.

The description of commodities with which the introduction of the species is generally associated shall include a list and description of commodities with an indication of associated risks (e.g. the volume of trade; the likelihood of a commodity being contaminated or acting as vector).

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\(^2\) [https://circabc.europa.eu/sd/a/738e82a8-f0a6-47c6-8f3b-aeddb535b83b/TSSR-2016-010%20CBD%20categories%20on%20pathways%20Final.pdf](https://circabc.europa.eu/sd/a/738e82a8-f0a6-47c6-8f3b-aeddb535b83b/TSSR-2016-010%20CBD%20categories%20on%20pathways%20Final.pdf)

\(^3\) [https://circabc.europa.eu/sd/a/0aeba7f1-c8c2-45a1-9ba3-bcb91a9f039d/TSSR-2016-010%20CBD%20pathways%20key%20full%20only.pdf](https://circabc.europa.eu/sd/a/0aeba7f1-c8c2-45a1-9ba3-bcb91a9f039d/TSSR-2016-010%20CBD%20pathways%20key%20full%20only.pdf)
If there are no active pathways or potential future pathways this should be stated explicitly here, and there is no need to answer the questions 1.2-1.9

Pathway name:

TRANSPORT-STOWAWAY (ship/boat ballast water)

TRANSPORT-STOWAWAY (ship/boat hull fouling)

TRANSPORT-CONTAMINANT Contaminant on animals (except parasites, species transported by host/vector) mariculture

a. TRANSPORT-STOWAWAY (ship/boat ballast water)

| Qu. 1.2a. Is introduction along this pathway intentional (e.g. the organism is imported for trade) or unintentional (e.g. the organism is a contaminant of imported goods)? |
| --- | --- | --- |
| RESPONSE | Unintentional | CONFIDENCE | high |

Response: In Argentina, Australia, the French English channel and the Netherlands, the discovery and proliferation of *Boccardia proboscidea* at locations close to ports and harbours has led to the hypothesis that ship-borne transport was the most likely pathway of introduction (Jaubet *et al*., 2018; Spilmont *et al*., 2018; Wijnhoven *et al*., 2017; Radashevsky *et al*., 2019).

On the other hand, on identifying and ranking introduced marine species found within Australian waters Hayes *et al*. (2005) ranked *B. proboscidea* as a low priority species to be introduced with ballast waters. The invasion potential of a species was expressed as the weighted sum of ship movements, and ballast discharge, from ‘infected’ bioregions to ‘uninfected’ bioregions.

<table>
<thead>
<tr>
<th>Qu. 1.3a. How likely is it that large numbers of the organism will be introduced through this pathway from the point(s) of origin over the course of one year?</th>
</tr>
</thead>
<tbody>
<tr>
<td>including the following elements:</td>
</tr>
<tr>
<td>• discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.</td>
</tr>
<tr>
<td>• an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication</td>
</tr>
</tbody>
</table>
if relevant, comment on the likelihood of introduction based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in introduction whereas for others high propagule pressure (many thousands of individuals) may not.

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>moderately likely</th>
<th>CONFIDENCE</th>
<th>high</th>
</tr>
</thead>
</table>

Response: *Boccardia proboscidea* is capable of producing planktotrophic (free swimming) larvae, whose survivorship is favoured in cold-temperate waters (see Qu. 3.1, 3.10 and Annex VII). Each female can produce up to $10^2 - 10^3$ larvae per brood and up to 8 broods per year (for details on reproductive traits please see Qu. 3.9). It should be noted that the species achieves its highest densities (upwards of $10^5$ individuals/m$^2$) in deteriorated and sheltered habitats (impacted by organic pollution) as for example in Australia, in Port Phillip Bay (Petch, 1989) which hosts the largest seaport in Australia.

The lowest estimates of the volumes of ballast water taken-up, transferred and discharged into world oceans each year are around 10 billion tonnes (Interwies & Khuchua, 2017), whereas just one cubic metre of ballast water may contain from 21 up to 50,000 zooplankton specimens (Locke *et al.*, 1991, 1993; Gollasch, 1997) and a heavy bulk carrier can carry up to more than 130,000 tonnes of ballast water (GloBallast, 2009). While data on ballasts discharges are not available from EU organizations (EMSA, ECSA, ESPO) or other international relevant organisations, it is evident from the above information that the potential for sufficiently high numbers of *B. proboscidea* larvae to travel along this pathway is high.

**Qu. 1.4a. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?**

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>likely</th>
<th>CONFIDENCE</th>
<th>medium</th>
</tr>
</thead>
</table>

Response: *Boccardia proboscidea* is capable of producing free-swimming, planktotrophic larvae, which spend 15-30 days in the water column before settling and whose survivorship is favoured at relatively low temperatures (12-17 °C) but is severely reduced at 24 °C (for more details and references, see Qu 3.1, 3.9, 3.10). Reproduction is clearly not an issue during ballast transport of larvae, however they are very likely to survive, as indicated by the detection and establishment of *B. proboscidea* populations in areas close to ports/harbors. Additionally, species of the Spionidae family are well known and often abundant constituents of both ballast waters and ballast sediments (e.g. Carlton, 1993; NRC, 1996; Gollasch, 1997).
Qu. 1.5a. How likely is the organism to survive existing management practices during transport and storage along the pathway?

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>CONFIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 2024 (with full compliance to the IMO D2): unlikely</td>
<td>medium</td>
</tr>
<tr>
<td>until 2024 (with current BWE): likely</td>
<td></td>
</tr>
</tbody>
</table>

Response: The International Maritime Organization (IMO) Ballast Water Management Convention (BWMC) entered into force in September 2017. It requires ships in international traffic to apply ballast water management measures, in particular:

- ballast water exchange in open seas, away from coastal areas (D-1 standard for an interim period)
- fulfil a certain discharge standard (D-2 standard according to the ship specific application schedule phased in up to 8 September 2024).

D-2 standard requires the installation of a certified ballast water treatment device, which enables sterilization to avoid transfers of ballast water mediated species.

Ballast Water Exchange (BWE) is currently practiced and requires ships to exchange a minimum of 95% ballast water volume whenever possible at least 200 nautical miles (nm) from the nearest land and in water depths of at least 200 metres. When this is not possible, the BWE shall be conducted at least 50 nm from the nearest land and in waters at least 200 metres in depth (David et al., 2007 and BWMC Guideline 6). Even though BWE can reduce the concentration of live organisms in ballast by 80–95% (Ruiz & Reid 2007), its application has severe limitations, primarily dependant on shipping patterns of a port (e.g., shipping routes, length of voyages) and local specifics i.e., distance from nearest shore, water depth (David et al., 2007), particularly for EU Seas where these conditions are often not met. Also, organisms may still remain in the volume of ballast not exchanged, or BWE may not be possible due to weather conditions or other safety restrictions. The survival of zooplanktonic organisms (including *B. proboscidea*) is thus not unlikely when only BWE measure are implemented.

As a result, ballast water treatment has been deemed necessary, such that ships shall discharge (in relation to the organism size range of interest for *B. proboscidea*): less than 10 viable organisms per cubic metre greater than or equal to 50 micrometres in minimum dimension (IMO D-2 standard).

Ballast water treatment options include mechanical (filtration, separation), physical (heat treatment, ozone, UV light) and chemical methods (biocides). Efficiencies of various technologies utilised for ballast water treatment are reviewed in Tsolaki & Diamadopoulos (2010) and can vary with treatment method but the application of many combined methods (e.g. Filtration+UV or Hydroclone+chemical disinfectant) can decrease live zooplankton to undetectable levels, practically diminishing propagule pressure. As such, the
survival of *B. proboscidea* larvae in ballast water with full implementation of the D-2 standard is considered unlikely.

**Qu. 1.6a. How likely is the organism to be introduced into the risk assessment area undetected?**

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>likely</th>
<th>CONFIDENCE</th>
<th>high</th>
</tr>
</thead>
</table>

Response: After September 2017, with the BWMC coming into effect and gradually being implemented, detection of larval stages in ballast water during Port State Control inspections may be possible. According to Resolution MEPC.252(67), if initial inspections of ballast water samples indicate non-compliance with the D-2 standard, detailed inspections will be carried out. eDNA methodologies are rapidly becoming one of the fastest and most cost-efficient tools for the detection of NIS\(^4\) in introduction water samples (Darling *et al.*, 2017; Borrell *et al.*, 2017; Koziol *et al.*, 2019) and have proven suitable for the detection of *B. proboscidea* larvae specifically in bilge water samples from vessels (Fletcher *et al.*, 2017). However, full implementation of the BWMC is not anticipated until 2024. Until then, the likelihood that *B. proboscidea* will enter the RA area undetected in ballast waters remains high.

**Qu. 1.7a. Estimate the overall likelihood of introduction into the risk assessment area based on this pathway?**

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>After 2024 unlikely (IMO D2 is fully implemented)</th>
<th>CONFIDENCE</th>
<th>medium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Until 2024 likely</td>
<td></td>
<td></td>
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</table>

Response: Regarding existing populations of the organism in the RA area (but also elsewhere in the invaded range), ballast water transport is considered one of the most likely pathways of introduction. Management measures implemented so far (i.e. BWE) have not proven adequate to prevent the introduction of this and other marine invasive species in EU marine waters. With the recent ratification of the BWMC (September 2017), compliance with the D2 standard is expected to greatly reduce the likelihood of secondary introductions of *B. proboscidea* in Europe with ballast water. However, this is not expected before 2024 and there may be difficulties in fully implementing it. For example, there are already some early reports of operational problems with the currently installed Ballast Water Management Systems, presumably due to

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\(^4\) NIS: non-indigenous species, term used in the Marine Strategy Framework Directive, synonym of “alien species” as used in the framework of Regulation (EU) 1143/2014

A concrete protocol for the verification of ballast water compliance monitoring devices has been proposed by IOC-UNESCO, ICES and ISO to IMO (IOC-UNESCO, ICES, ISO, 2019). This protocol builds on the method presented in documents PPR 6/4 and MEPC 74/4/11 (Denmark) (First et al., 2018) and suggests a protocol for verifying ballast water compliance monitoring devices using laboratory and shipboard tests. The intention is that the protocol can be the basis for the development of a standard for such devices, which may be used during commissioning testing, data gathering during the experience-building phase, compliance testing by port State control or self-monitoring.

End of pathway assessment, repeat Qu. 1.3 to 1.7 as necessary using separate identifier.

b. TRANSPORT-STOWAWAY (ship/boat hull fouling)

| Qu. 1.2b. Is introduction along this pathway intentional (e.g. the organism is imported for trade) or unintentional (e.g. the organism is a contaminant of imported goods)? |
| RESPONSE | Unintentional | CONFIDENCE | high |

Response: It has been hypothesized but never documented. In most publications shipping traffic is reported as a potential pathway but the vector is not specified, it can be envisaged however that the organism can travel as part of a mature fouling assemblage, boring or hiding in/amongst attached bivalves, barnacles and other fouling organisms. The closely related, and also shell infesting species *Boccardia columbiana* Berkeley, 1927 was found in macrofouling of sea-chests of two commercial vessels in Canada (Frey et al., 2014).

| Qu. 1.3b. How likely is it that large numbers of the organism will be introduced through this pathway from the point(s) of origin over the course of one year? |
| RESPONSE | Moderately likely | CONFIDENCE | low |

Response: For the reproductive biology of the species please see Qu 3.9. Considering the biological characteristics of the organism (ability to hide in crevices and burrows on/in bivalves, withstand desiccation and wide temperature range), it is considered possible that *B. proboscidea* can maintain a viable population within the fouling communities on ships hulls, sufficient for a new introduction.
Qu. 1.4b. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?

**RESPONSE** | likely | **CONFIDENCE** | medium

Response: In a relatively wide range of temperatures, *B. proboscidea* is able to produce directly developing (adelphophagic) larvae that hatch at an advanced stage and settle close to the parent (see Qu 3.1, 3.9, 3.10). As such, it is possible that it can reproduce and maintain its fouling population during transport, and its cryptic lifestyle will protect it from the drag at high speeds of moving vessels.

Qu. 1.5b. How likely is the organism to survive existing management practices during transport and storage along the pathway?

**RESPONSE** | Likely | **CONFIDENCE** | medium

Response: Fouling organisms such as *B. proboscidea* can be transported for weeks or months in or amongst other elements of the fouling assemblage (e.g. bivalve shells). Implementing practices to control and manage biofouling can greatly assist in reducing the risk of the transfer of invasive marine species.

While the International Convention on the Control of Harmful Anti-Fouling Systems on Ships, 2001 (AFS Convention) addresses anti-fouling systems on ships, its focus is on the prevention of adverse impacts from the use of anti-fouling systems and the biocides they may contain, rather than preventing the transfer of invasive aquatic species.

Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species were adopted on 15 July 2011 [RESOLUTION MEPC.207(62)] The Biofouling Guidelines represent a decisive step towards reducing the transfer of invasive aquatic species by ships. Especially vessel cleaning during dry-docking in a shipyard generates a very low biosecurity risk because the debris is sent to local deposit and residue water from cleaning is collected (Bohn *et al*., 2016). Moreover, maintenance during dry-docking involves the re-application of anti-fouling paint, which seems to be efficient for up to 1-1.5 years – thereafter heavy fouling can start occurring (Sylvester *et al*., 2011; Frey *et al*., 2014).

On the other hand, in-water cleaning (IWC) of hulls (used as an additional tool, in-between dry-dock cleaning), especially without capturing the biofouling debris, might represent a higher risk of introducing NIS relative to land based cleaning in dry-docks with land based waste disposal because physical
disturbance of the fouling communities may trigger the release of propagules or viable gametes (Hopkins & Forrest, 2008). The Resolution identifies this risk and consultations are in progress for more efficient management methods (e.g. Zabin et al., 2016). There has been a proliferation of new IWC technologies in the past decade (e.g. https://www.ecosubsea.com/, http://econetsaustralia.com/) that capture debris and render it non-viable through e.g. UV treatment, although such systems sometimes fail to contain all of the removed debris (for reviews see Zabin et al., 2016; Scianni & Georgiades, 2019).

Commercial ship-owners have a strong interest in having their vessels cleaned in order to decrease their fuel consumption but dry-docking frequency is determined by performance (fuel consumption below a certain threshold) and can range from 0.5-5 years (Bohn et al., 2016).

The suite of measures described above can prove effective against *B. proboscidea* and other fouling organisms, if fully implemented, although sea-chests would still remain higher risk areas and may require more frequent in-water treatment. However, anti-fouling practices are not legally required, and can be financially costly, making it likely that a number of vessels traveling between contaminated and uncontaminated marinas and ports will not have been treated, motivating a likely score for this question. Even though there does not appear to be any comprehensive analysis of the compliance levels to the MEPC 2011 biofouling guidelines, a considerable reduction in the arrival of high-risk vessels was observed in New Zealand, after biofouling management measures became mandatory (Hayes et al., 2019).

Although (as with physical hull cleaning), antifouling is not currently a legal requirement, there is potential that treatments with biocidal compounds may prove an effective method of controlling fouling and reduce the likelihood of introduction and spread.

**Qu. 1.6b. How likely is the organism to be introduced into the risk assessment area undetected?**

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>Very likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONFIDENCE</td>
<td>High</td>
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</table>

Response: The species is unlikely to be detected upon introduction, unless thorough inspections of hull fouling communities are carried out, which is currently not a routine practice. Even then, because, as part of the fouling community, it is most likely to be hidden within other fouling macro-organisms, the likelihood of detection via visual inspections is very low. Additionally, due to its similarity with other spionid species (see section A2), even upon detailed examination, the species may be confused with other species such as with *B. polybranchia* (Haswell, 1885), previously recorded in the English Channel (Dauvin et al. 2003).

In order to reach GES targets with reference to Descriptor D2, most EU states are already designing or implementing national/regional NIS-targeted monitoring programmes. Monitoring should focus on introduction hotspots (e.g. ports, marinas, aquaculture plots) and this will increase the detectability of *B. proboscidea* entering the RA area through hull fouling. Indeed one record of the burrowing worm *Boccardia proboscidea* was made from the regular monitoring programme in Orkney, UK (Kakkonen et al. 2019).
Qu. 1.7b. Estimate the overall likelihood of introduction into the risk assessment area based on this pathway?

| RESPONSE | Moderately likely | CONFIDENCE | low |

Response: It has been hypothesized but never documented. In most publications shipping traffic is reported as a potential pathway but the vector is not specified, it is however considered possible that the species can survive as part of the fouling community on ships hulls and release propagules upon arrival to new locations.

c. TRANSPORT-CONTAMINANT Contaminant on animals (except parasites, species transported by host/vector) mariculture

Qu. 1.2c. Is introduction along this pathway intentional (e.g. the organism is imported for trade) or unintentional (e.g. the organism is a contaminant of imported goods)?

| RESPONSE | Unintentional | CONFIDENCE | high |

Response: B. proboscidea is a nuisance fouling species in aquaculture facilities thus aquaculture has been considered as the most probable pathway of its introduction in many parts of the invaded range. In fact, the species has been reported to heavily infest a shipment of oysters imported in Hawaii from Maine, USA (Bailey-Brock, 2000). Abalone farms were infested in New Zealand (Read, 2004), Tasmania (Lleonart, 2002) and South Africa (Boonzaaier et al., 2014). In South Africa, its introduction is almost certainly linked with shellfish transfers, either abalone from California or spat of the oyster Crassostrea gigas from Europe (Simon et al., 2009). In Belgium its presence may also be related to mariculture, since it was detected among the Pacific oyster Crassostrea gigas (Kerckhof & Faasse, 2014).

Qu. 1.3c. How likely is it that large numbers of the organism will be introduced through this pathway from the point(s) of origin over the course of one year?

| RESPONSE | unlikely | CONFIDENCE | medium |
Response: *B. proboscidea* on cultured molluscs can display high infestation rates, in the order of tens of individuals per shell (for rates of infestation, see Qu 5.9), shellfish imports however from countries outside the EU are not very common and prohibited in many cases, if not requiring strict quarantine procedures.

Available information in the peer reviewed literature suggests that bivalve culture in Europe is largely dependent on harvesting/collecting wild seed from nearby locations to aquaculture plots, bivalve seed from hatcheries to a smaller extent and, when necessary, imports of seed from other EU countries (Muehlbauer et al., 2014, Robert et al., 2013; Occhipinti-Ambrogi et al., 2016; Marchini et al., 2016). Small quantities of bivalves and other cultured molluscs may still be imported from non-EU countries (e.g. small quantities of oysters *C. gigas*, up to 3-4 tonnes per year, were directly imported from Japan and Korea into the Netherlands between 2004 and 2008 – Haydar & Wolff, 2011), but more extensive information on bivalve imports from countries outside the EU could not be found. The non-native abalone species *Haliotis discus hannai*, originally imported from Japan, is cultivated in Ireland (Hannon et al., 2013) and Spain (http://abalonbygma.com/en/abalone-exclusive-seafood/, see also Cook, 2014), where current production takes place in closed systems and relies on local hatcheries for seed. If more stock was imported from the native range, it would be subjected to the stringent controls of COUNCIL REGULATION (EC) No 708/2007 (see Qu.1.5c), such that this species is not considered to pose additional risks for new introductions of *B. proboscidea* into the RA area.

**Qu. 1.4c. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?**

| RESPONSE | Very likely | CONFIDENCE | high |

Response: Spionids, or “mudworms“ have been regularly associated with shellfish consignments, as the shellfish themselves and the methods used to contain the shellfish during transport may actually enhance the likelihood of survival of contaminant species as well by providing moisture and protection from harsher conditions (Minchin, 2007). For example, the *Ostrea edulis* shipment that was imported to Hawaii in 2000 was heavily infested with adult *B. proboscidea*, whose burrows contained egg capsules with late-stage larvae, leading Bailey-Brock (2000) to conclude that reproduction had recently occurred, either before collection at the facility of origin or after placing the oysters in the recipient grow-out facility.

**Qu. 1.5c. How likely is the organism to survive existing management practices during transport and storage along the pathway?**
**RESPONSE**  | moderately likely (overall; local variations may apply) | **CONFIDENCE** | medium
---|---|---|---

Response: COUNCIL REGULATION (EC) No 708/2007 concerning use of alien and locally absent species in aquaculture defines the procedures to be followed that minimise the risk of introducing non-target alien species accompanying commercial shellfish spat and stocks. It requires a permit procedure, involving risk assessment for the non-target species and a quarantine period for the translocated stock.

The bivalve *C. gigas* listed in Annex IV constitutes an exception and can be moved without any risk assessment or quarantine; however local/national legislation exists that can limit the translocation possibilities of species like *C. gigas*, e.g. see WG-AS & Gittenberger (2018) for the trilateral Wadden Sea area. Additionally, if the import region is a Natura2000 area regulations can be much stricter as they aim to protect the conservation objectives of the protected area first.

Other initiatives have produced codes of conduct for the transfer of bivalve seed/stock at the national/regional level, such as the ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2005, the Code of practice for mussel seed movements (Wilson & Smith, 2008) Wales, etc.

The implementation of EC regulation 708/2007 (EC 2007) introduces a high biosecurity level for most bivalve transfers from areas outside the EU, that has already proven to be effective in preventing new introductions of marine alien species (Katsanevakis et al., 2013; Zenetos, 2019). However, the exemption of *C. gigas*, one of the main bivalve hosts of *B. proboscidea*, means that *C. gigas* consignments potentially infested with *B. proboscidea* would not be subjected to stringent control before being released into the wild, unless stricter national/regional regulations apply, thus increasing the risk of introduction of the species.

**Qu. 1.6c. How likely is the organism to be introduced into the risk assessment area undetected?**

| RESPONSE | likely | **CONFIDENCE** | high
---|---|---|---

Response: Due to its size, cryptic nature and similarity with other spionid species (see section A2) and the frequent use of local (European) identification manuals, the species may be confused and remain unidentified/misidentified or go unreported (see also Qu. 1.6a, 1.6b). Moreover, *B. proboscidea* can deposit its eggs and larvae in the burrows created by other boring spionid pests (e.g. *Polydora hoplura*) or the calcareous tubes created by fouling spirorbid worms on the shells (Lleonart, 2002; Simon et al., 2009, 2010b), such that eggs/larvae can easily go undetected by perfunctory visual inspections.
**Qu. 1.7c. Estimate the overall likelihood of introduction into the risk assessment area based on this pathway?**

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>unlikely</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONFIDENCE</td>
<td>low</td>
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</table>

Response: The species may be introduced as pest, primarily on imported oysters *C. gigas* from the North East Pacific. Available literature suggests that shellfish imports from countries outside the EU are generally limited in the past couple of decades and well regulated. The risk of introduction is associated with a few species listed in Annex IV of Council Regulation (EC) No 708/2007 if stricter local/regional regulations are not in place (see Qu. 1.5d) and with illegal/unreported transfers. Even for the exempted species of Annex IV however (particularly *C. gigas* in Atlantic Europe, where establishment of *B. proboscidea* is more likely), the amount imported from outside the EU is at low enough levels to render this pathway unlikely.

**Qu. 1.8. Estimate the overall likelihood of introduction into the risk assessment area based on all pathways and specify if different in relevant biogeographical regions in current conditions.**

Provide a thorough assessment of the risk of introduction in relevant biogeographical regions in current conditions: providing insight in to the risk of introduction into the Union.

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONFIDENCE</td>
<td>high</td>
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</table>

Response: Occurrence of *Boccardia proboscidea* at locations in the vicinity of ports and harbours has led to the hypothesis that vessels (either in ballasts or as fouling) is the most plausible pathway of its introduction. Management measures implemented so far (i.e. BWE) have not proven adequate to prevent its introduction in EU marine waters and this will partly continue until full implementation of the BWMC in 2024.

On the other hand, and based on its invasion history worldwide, aquaculture (i.e. contaminant on shellfish imported from outside the RA area) could be a very likely mode of its introduction but existing management measures scale down this probability significantly. Conclusively, vessels are a likely pathway of *B. proboscidea* introduction, mostly in the North East Atlantic, where prevailing temperatures favour the survival of planktotrophic larvae likely to be carried by ballast waters (see Risk of Establishment section).

**Qu. 1.9. Estimate the overall likelihood of introduction into the risk assessment area based on all pathways in foreseeable climate change conditions?**
Thorough assessment of the risk of introduction in relevant biogeographical regions in foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk.

With regard to climate change, provide information on

- the applied timeframe (e.g. 2050/2070)
- the applied scenario (e.g. RCP 4.5)
- what aspects of climate change are most likely to affect the likelihood of introduction (e.g. change in trade or user preferences)

The thorough assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment of likely introduction within a medium timeframe scenario (e.g. 30-50 years) with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4-1.6°C global warming increase by 2065) and RCP 4.5 (likely range of 0.9-2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>likely</th>
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<tbody>
<tr>
<td>CONFIDENCE</td>
<td>high</td>
</tr>
</tbody>
</table>

Response: as in Qu. 1.9. Future climate change conditions are not anticipated to significantly change the likelihood of introduction of B. proboscidea through the above-mentioned pathways. Potential donor areas are not predicted to greatly expand/contract (see modelling results – global projected distribution – RCP 4.5).
2 PROBABILITY OF ENTRY

Important instructions:

- Entry is the release/escape/arrival in the environment, i.e. occurrence in the wild. Entry is not to be confused with spread, the movement of an organism within the risk assessment area.

- The classification of pathways developed by the Convention of Biological Diversity (CBD) should be used. For detailed explanations of the CBD pathway classification scheme consult the IUCN/CEH guidance document and the provided key to pathways.

- For organisms which are already present in the risk assessment area, only complete this section for current active or if relevant potential future pathways. This section need not be completed for organisms which have entered in the past and have no current pathway of entry.

Qu. 2.1. List relevant pathways through which the organism could enter into the environment.

For each pathway answer questions 2.2 to 2.7 (copy and paste additional rows at the end of this section as necessary). Please attribute unique identifiers to each question if you consider more than one pathway, e.g. 2.2a, 2.3a, etc. and then 2.2b, 2.3b etc. for the next pathway.

In this context a pathway is the route or mechanism of entry of the species into the environment.

If there are no active pathways or potential future pathways this should be stated explicitly here, and there is no need to answer the questions 2.2-2.8

Pathway name:

TRANSPORT-STOWAWAY (ship/boat ballast water)

TRANSPORT-STOWAWAY (ship/boat hull fouling)

TRANSPORT-CONTAMINANT Contaminant on animals (except parasites, species transported by host/vector) mariculture

a. TRANSPORT-STOWAWAY (ship/boat ballast water)

Qu. 2.2a. Is entry into the environment intentional (e.g. the organism is released for a specific purpose) or unintentional (e.g. the organism escapes from a confinement)?

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5 https://circabc.europa.eu/sd/a/738e82a8-0a6-47c6-8f3b-aeddb535b83b/TSSR-2016-010%20CBD%20categories%20on%20pathways%20Final.pdf
6 https://circabc.europa.eu/sd/a/0aeb4c2-45a1-9ba3-bcb91a9f039d/TSSR-2016-010%20CBD%20pathways%20key%20full%20only.pdf
On identifying and ranking introduced marine species found within Australian waters Hayes et al. (2005) ranked *B. proboscidea* as a low priority species to be introduced with ballast waters. The invasion potential of a species was expressed as the weighted sum of ship movements, and ballast discharge, from ‘infected’ bioregions to ‘uninfected’ bioregions.

**Qu. 2.3a. How likely is it that large numbers of the organism will enter into the environment along this pathway from the point(s) of origin over the course of one year?**

including the following elements:

- discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.
- an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if relevant, comment on the likelihood of entry into the environment based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in entry whereas for others high propagule pressure (many thousands of individuals) may not).

**RESPONSE**  
unintentional  
**CONFIDENCE**  
high

Response: The organism will enter into the environment during the de-ballasting process. See questions 1.3a and 1.5a for quantitative information on ballast volumes, propagule pressure and management practices that will affect entry of viable propagules.

**Qu. 2.4a. How likely is the organism to enter into the environment within the risk assessment area undetected?**

**RESPONSE**  
likely  
**CONFIDENCE**  
high
Response: The organism has already entered Europe and it was detected when it had already established (Martínez et al., 2006). In Belgium, its presence is suspected since 2001, based on the re-examination of old material that was misidentified by Volckaert et al. (2003) as Boccardiella ligerica (Kerckhof & Faasse, 2014).

The probability of observing the initial introduction event is minimal, particularly at the larval or early life stages but monitoring with settlement panels at introduction hotspots (Andersen et al., 2014) and DNA barcoding in port water samples can increase the likelihood of early detection.

**Qu. 2.5a. How likely is the organism to enter into the environment during the months of the year most appropriate for establishment?**

| RESPONSE | likely | CONFIDENCE | medium |

Response: For details on the reproductive biology of the species, see Qu. 3.9.

In summary, the reproductive period lasts from March to September in the northern hemisphere (Oyarzun, 2010) with multiple broods per year (up to 8). Considering that B. proboscidea reaches sexual maturity approximately 2.5 months after settlement (Simon & Booth, 2007) and maritime transport is carried out throughout the year, larvae picked up at locations with high B. proboscidea populations (occurring primarily in areas with mean summer temperatures higher or equal to 15 °C) have a high likelihood of arriving at a recipient area at a time appropriate for establishment – which is December to June, according to the information above.

**Qu. 2.6a. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host in the environment?**

| RESPONSE | likely | CONFIDENCE | high |

Response: Boccardia proboscidea occupies a wide range of habitats, one or all of which are widely distributed in the RAA. It has proved very capable of colonising and dominating natural and man-made habitats

If ballast water exchange occurs in open seas rather than in coastal areas, transfer of planktonic larvae to suitable substrate will be hampered. If, however, untreated ballast water is released in ports, estuaries or other coastal areas, then establishment will be dependent on availability of suitable habitat. Considering a) the breadth of habitat that characterizes the species; b) the wide distribution of such habitats in the RAA and c) the documented records inside/near harbours (e.g. Spilmont et al., 2018; Wijnhoven et al., 2017;
Radashevsky et al., 2019), there is a high likelihood that *B. proboscidea* can transfer to a suitable habitat after release with ballast water.

### Qu. 2.7a. Estimate the overall likelihood of entry into the environment within the risk assessment area based on this pathway?

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>CONFIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 2024 unlikely (with full compliance to the IMO D2, i.e. not until 2024)</td>
<td>medium</td>
</tr>
<tr>
<td>Until 2024 likely</td>
<td></td>
</tr>
</tbody>
</table>

Response: Regarding existing populations of the organism in the RA area (but also elsewhere in the invaded range), ballast water transport is considered one of the most likely pathways of introduction. Management measures implemented so far (i.e. BWE) have not proven adequate to prevent the introduction and entry of this and other marine invasive species in EU marine waters. With the recent ratification of the BWMC (September 2017) and full implementation anticipated until 2024, compliance with the D2 standard is expected to greatly reduce the likelihood of additional introductions of *B. proboscidea* in Europe with ballast water.

*End of pathway assessment, repeat Qu. 2.2 to 2.7. as necessary using separate identifier.*

### b. TRANSPORT-STOWAWAY (ship/boat hull fouling)

#### Qu. 2.2b. Is entry into the environment intentional (e.g. the organism is released for a specific purpose) or unintentional (e.g. the organism escapes from a confinement)?

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>CONFIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>unintentional</td>
<td>high</td>
</tr>
</tbody>
</table>

Response: *B. proboscidea* can transfer from a vessel’s fouling assemblage through release of free-swimming larvae or as adult individuals, following the dislodgement of fouling material into the environment where the vessel is moored/berthed (MAF, 2011). Such vector has been hypothesized but never documented. In most publications shipping traffic is reported as a potential pathway but the vector is not specified, it can be envisaged however that the organism can travel as part of a mature fouling assemblage, boring or hiding
in/amongst attached bivalves, barnacles and other fouling organisms. The closely related, and also shell infesting species *Boccardia columbiana* Berkeley, 1927 was found in macrofouling of sea-chests of two commercial vessels in Canada (Frey *et al*., 2014).

Global shipping and recreational boat travel take place between areas from which the species is known and ports, harbours and marinas within the RAA. The current concentration of records in and in close proximity to structures associated with recreational and commercial shipping suggest it is a potential vector of entry.

**Qu. 2.3b. How likely is it that large numbers of the organism will enter into the environment along this pathway from the point(s) of origin over the course of one year?**

including the following elements:

- discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.
- an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if relevant, comment on the likelihood of entry into the environment based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in entry whereas for others high propagule pressure (many thousands of individuals) may not).

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>moderately likely</th>
<th>CONFIDENCE</th>
<th>low</th>
</tr>
</thead>
</table>

Response: *B. proboscidea* can transfer from a vessel’s fouling assemblage through release of free-swimming larvae or as adult individuals, following the dislodgement of fouling material into the environment where the vessel is moored/berthed (MAF, 2011). Both polychaetes and bivalves (in this case as potential hosts) are known to be translocated via hull fouling and remain viable (MAF, 2011 and references therein).

Global shipping and recreational boat travel take place between areas from which the species is known and ports, harbours and marinas within the RAA on a regular basis. The current concentration of records in and in close proximity to structures associated with recreational and commercial shipping suggest a potential source of propagules. *Boccardia* reproduces year-round and can produce up to eight broods throughout its reproductive period (Gibson 1997). Despite the reproductive output per individual not being particularly high per se, *B. proboscidea* regularly occurs in high densities both in the wild and in aquaculture systems, thus increasing the total number of propagules likely to be moved along the relevant pathways. Reports of population densities of tens to hundreds of thousands of individuals per m² and even higher are not uncommon in the literature (e.g. Oyarzun, 2010; Petch, 1995; see Impacts section for more details).
**Qu. 2.4b. How likely is the organism to enter into the environment within the risk assessment area undetected?**

**RESPONSE**  very likely  
**CONFIDENCE**  high

Response: The organism has already entered Europe and it was detected when it had already established (Martínez et al., 2006). In Belgium, its presence is suspected since 2001, based on the re-examination of old material that was misidentified by Volckaert et al. (2003) as Boccardiella ligerica (Kerckhof & Faasse, 2014).

Due to its size, cryptic nature and similarity with other spionid species (see section A2) and the frequent use of local (European) identification manuals, the species may be confused and remain unidentified/misidentified or go unreported (see also Qu. 1.6a, 1.6b). Boccardia proboscidea larvae released from ships fouling communities are highly unlikely to be detected early, considering the frequency of monitoring activities (especially in relation to larval stages). Furthermore, adults dislodged along with biofouling material will likely be hidden among/within other organisms, such as bivalves and barnacles. Adults can then deposit their eggs and larvae in the burrows created by other boring spionid pests (e.g. Polydora hoplura) or the calcareous tubes created by fouling spirorbid worms on the shells (Lleonart, 2002; Simon et al., 2009, 2010b), such that eggs/larvae can easily go undetected by perfunctory visual inspections.

**Qu. 2.5b. How likely is the organism to enter into the environment during the months of the year most appropriate for establishment?**

**RESPONSE**  likely  
**CONFIDENCE**  medium

*Boccardia proboscidea* reproduces for about 6 months per year (March to September in the northern hemisphere – see Qu. 3.9) and can produce up to eight broods throughout its reproductive period (Gibson 1997), thus it has high chances of arriving during the months of the year most appropriate to establishment.

**Qu. 2.6b. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host in the environment?**

**RESPONSE**  likely  
**CONFIDENCE**  medium

Response: *Boccardia proboscidea* occupies a wide range of habitats, one or all of which are widely distributed in the RAA. It has proved very capable of colonising and dominating natural and man-made...
habitats. Suitable habitats abound, especially in ports and marinas; indicatively at least two European records of *B. proboscidea* come from various substrates within harbours, i.e. one scraped off Scapa Pier, Orkney (Kakkonen *et al.*, 2019) and one from mud deposits under sandstone ledges in Staffin Harbour, Isle of Skye (Hatton & Pearce, 2013).

Considering a) the breadth of habitat that characterizes the species; b) the wide distribution of such habitats in the RAA and c) the documented records inside/near harbours (e.g. Spilmont *et al.*, 2018; Wijnhoven *et al.*, 2017; Radashevsky *et al.*, 2019), there is a high likelihood that *B. proboscidea* can be deposited to a suitable habitat after release from fouling structures. In some cases, recreational vessels might moor in natural areas, adjacent to suitable natural substrate where propagules might be deposited.

**Qu. 2.7b.** Estimate the overall likelihood of entry into the environment within the risk assessment area based on this pathway?

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>moderately likely</th>
<th>CONFIDENCE</th>
<th>medium</th>
</tr>
</thead>
</table>

Response: Although not formally documented, it remains plausible that *B. proboscidea* can be introduced and enter the RA area as a member of mature fouling communities on ships’/boats’ hulls (see also Wijnhoven *et al.*, 2017 for an assessment of likely pathways of introduction and spread), through the release of either larvae or adult individuals. As the BWMC is gradually implemented and until management measures for hull fouling become mandatory and/or widespread, this pathway will likely remain relevant for the introduction/entry of the species.

*End of pathway assessment, repeat Qu. 2.2 to 2.7. as necessary using separate identifier.*

c. **TRANSPORT-CONTAMINANT** Contaminant on animals (except parasites, species transported by host/vector) mariculture

**Qu. 2.2c.** Is entry into the environment intentional (e.g. the organism is released for a specific purpose) or unintentional (e.g. the organism escapes from a confinement)?

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>unintentional</th>
<th>CONFIDENCE</th>
<th>high</th>
</tr>
</thead>
</table>

Response: as in Qu 1.2c
Qu. 2.3c. How likely is it that large numbers of the organism will enter into the environment along this pathway from the point(s) of origin over the course of one year?

including the following elements:

- discuss how likely the organism is to get onto the pathway in the first place. Also comment on the volume of movement along this pathway.
- an indication of the propagule pressure (e.g. estimated volume or number of individuals / propagules, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if relevant, comment on the likelihood of entry into the environment based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in entry whereas for others high propagule pressure (many thousands of individuals) may not).

| RESPONSE | unlikely | CONFIDENCE | medium |

Response: as in Qu. 1.3c and based on the well-regulated and limited imports of potential hosts from countries outside the EU.

Qu. 2.4c. How likely is the organism to enter into the environment within the risk assessment area undetected?

| RESPONSE | likely | CONFIDENCE | high |

Response: as in Qu. 1.6c.

Qu. 2.5c. How likely is the organism to enter into the environment during the months of the year most appropriate for establishment?

| RESPONSE | likely | CONFIDENCE | medium |

Response: as in Qu. 2.5a
**Qu. 2.6c. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host in the environment?**

| RESPONSE | very likely | CONFIDENCE | high |

Response: If *B. proboscidea* infested bivalve seed/stock is relayed on cultivation plots without any prior management measure, as may be the case for *C. gigas* stock, the likelihood of transfer to other suitable habitats (the cultivation plots themselves are suitable habitats) is very high. These plots are often situated in coastal areas in close proximity to suitable natural habitat to which individuals may spread.

**Qu. 2.7c. Estimate the overall likelihood of entry into the environment within the risk assessment area based on this pathway?**

| RESPONSE | unlikely | CONFIDENCE | low |

Response: as in Qu. 1.7c and based on the well-regulated and limited imports of potential hosts from countries outside the EU. Unreported/illega transfers are still a possibility, hence the low confidence rating.

*End of pathway assessment.*

**Qu. 2.8. Estimate the overall likelihood of entry into the environment within the risk assessment area based on all pathways in current conditions and specify if different in relevant biogeographical regions.**

Provide a thorough assessment of the risk of entry into the environment in relevant biogeographical regions in current conditions.

| RESPONSE | likely | CONFIDENCE | medium |

Response: Occurrence of *Boccardia proboscidea* at locations in the vicinity of ports and harbours has led to the hypothesis that vessels (either in ballasts or as fouling) is the most plausible pathway of its introduction and entry. Management measures implemented so far (i.e. BWE) have not proven adequate to
prevent its introduction in EU marine waters and this will partly continue until full implementation of the BWMC in 2024.

On the other hand, and based on its invasion history worldwide, aquaculture (i.e. contaminant on shellfish imported from outside the RA area) could be a very likely mode of its introduction but existing management measures scale down this probability significantly. Bilge waters as a vector of movement has been documented but the distances from the source areas are rather prohibitive. Conclusively, vessels are a likely pathway of *B. proboscidea* introduction and entry, mostly in the North East Atlantic, where prevailing temperatures favour the survival of planktotrophic larvae likely to be carried by ballast waters (see Risk of Establishment section).

**Qu. 2.9. Estimate the overall likelihood of entry into the environment within the risk assessment area based on all pathways in foreseeable climate change conditions and specify if different in relevant biogeographical regions.**

Thorough assessment of the risk of entry in relevant biogeographical regions in foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk, specifically if likelihood of entry is likely to increase or decrease for specific pathways.

| RESPONSE | likely    | CONFIDENCE | medium |

Response: as in Qu. 2.8. Future climate change conditions are not anticipated to significantly change the likelihood of introduction and entry of *B. proboscidea* through the above-mentioned pathways. Potential donor areas are not predicted to greatly expand/contract (see modelling results – global projected distribution – RCP4.5).
3 PROBABILITY OF ESTABLISHMENT

Important instructions:
- For organisms which are already established in parts of the risk assessment area, answer the questions with regard to those areas, where the species is not yet established.

Qu. 3.1. How likely is it that the organism will be able to establish in the risk assessment area based on the history of invasion by this organism elsewhere in the world (including similarity between other abiotic conditions within it and the organism’s current distribution)?

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>very likely</th>
<th>CONFIDENCE</th>
<th>high</th>
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</table>

Response: *Boccardia proboscidea* is a eurythermal and euryhaline species (Hartmann, 1940) with a cosmopolitan distribution in temperate seas. It is considered an introduced species in Australia, New Zealand, South Africa, Argentina and Hawaii (for details and references, see Qu. A5). Its presence in the Asian North-Pacific is of questionable origin (Sato-Okoshi *et al.*, 2000; Abe *et al.*, 2019a) and assumptions that it is native in Japan are not substantiated by concrete evidence (Radashevsky *et al.*, 2019).

The organism is already established in the RA area (Bay of Biscay and the Iberian coast, Celtic Seas, Greater North Sea) and further establishment in these MSFD marine subregions is considered very likely (see also Qu.A6, Qu.A7 and Annex VII, VIII). *B. proboscidea* has been recorded from locations with minimum yearly temperatures as low as 1.15 °C in northern China (Radashevsky *et al.*, 2019) and 2.6 °C in Japan (Imajima & Hartmann, 1964), it is more regularly encountered however in places where temperatures drop to 5-7 °C (Argentina, Canada) and in European waters between 3.7-6 °C (i.e. around the UK and the French, Belgian and Dutch North Sea coasts. Low winter temperatures in the Baltic (besides the salinity limitations – see below), as well as the Skagerrak and Kattegat, in the Greater North Sea, will hamper establishment in the region.

With regards to high temperature thresholds, the species can be found in Japan, at locations where the average temperature of the warmest month is in the region of ≈26.5 °C (species records from Abe *et al.*, 2019a; 2019b – temperature values according to BIO-ORACLE data layers, Assis *et al.*, 2018, (http://www.bio-oracle.org/downloads-to-email.php). Additionally, it is known that in laboratory conditions, water temperatures of 24 °C and 28 °C severely reduce the survivorship of planktotrophic and adelphophagic larvae respectively (David & Simon, 2014 - see also Qu 3.9), while at 30 °C embryos do not develop at all (Oyarzun, 2010). The two types of larvae achieve survival optima at different temperatures (see also Qu. 3.10). Accordingly, high summer temperatures in the Levantine and large parts of the Ionian and the Central Mediterranean are expected to limit its distribution in the Mediterranean Sea to the relatively cooler regions of the basin (for details see Annexes VII & VIII).
With respect to salinity, in Australia, the species is established in conditions that range from brackish to fully marine (21 to 34.8 psu) (Coleman & Sinclair, 1996) but in laboratory experiments it has been shown to thrive at high salinities of up to 39-40 psu (Hillyard, 1979). Additionally, peak densities in Argentina were observed at salinities between 15-20 psu (Garaffo et al., 2016), associated with increased organic matter conditions at untreated sewage outflows with high freshwater input. Thus, salinity would not be expected to pose limitations to survival and establishment at the range of values encountered in the Black Sea (SSS of 14-19 psu) but is very likely to become a prohibitive factor in most of the Baltic. In the Black Sea however, B. proboscidea would find itself at the edge of its physiological tolerance both in terms of temperature and salinity simultaneously, facing challenging conditions. The species distribution model predicts a low likelihood of establishment in this marine subregion (see Qu. 3.13 and Annex VII & VIII for more details).

**Qu. 3.2. How widespread are habitats or species necessary for the survival, development and multiplication of the organism in the risk assessment area?**

**RESPONSE** ubiquitous  
**CONFIDENCE** high

Response: Boccardia proboscidea occupies a wide range of habitats, one or all of which are widely distributed in the RA area. Populations of B. proboscidea have been reported from different habitats including mudflats, sandy harbours, seagrass beds, among barnacles and mussels, in coralline algae, sandstone or sedimentary rocks, limestone reefs, artificial groynes, abrasion platforms, sewage outfalls and gastropod shells inhabited by hermit crabs (Hartman 1940; Woodwick 1963; Imajima & Hartman 1964; Petch 1989; Gibson 1997; Martinez, 2006; Kerckhof & Faasse, 2014; Jaubet et al., 2015). The species has been found boring into sponge (David, 2015; Abe et al., 2019a) and infesting bivalve (primarily oyster) and gastropod (abalone) shells (Simon et al., 2010b; Simon & Sato-Okoshi, 2015; Radashevsky et al., 2019). It is most commonly encountered in the intertidal but has also been reported from subtidal locations in the wild at depths down to 100m (Imajima & Hartman, 1964), and in association with cultivated molluscs (Lleonart, 2002).

**Qu. 3.3. If the organism requires another species for critical stages in its life cycle then how likely is the organism to become associated with such species in the risk assessment area?**

**RESPONSE** N/A  
**CONFIDENCE** high

Response: The organism does not require another species for critical stages in its life cycle.
Qu. 3.4. How likely is it that establishment will occur despite competition from existing species in the risk assessment area?

**RESPONSE** very likely **CONFIDENCE** high

Response: In sewage impacted locations in Argentina, *B. proboscidea* outcompetes local intertidal species, and displaces the ecosystem engineering mussel *Brachidontes rodriguezii* as a structuring species within the intertidal due to competitive exclusion for space (Jaubet *et al.*, 2015). In non-impacted sites, *B. proboscidea* and *B. rodriguezii* coexist in patches of variable size (Jaubet *et al.*, 2013). Again in Argentina, the invasion by *B. proboscidea* has been implicated in an apparent decline of its close relative, *Boccardia claparedei* (Kinberg, 1866) which occupies the same ecological niche (Radashevsky *et al.*, 2013 – abstract) and the smothering of the barnacle *Balanus glandula* (Diez *et al.*, 2011 – abstract). In European waters, the species has already established on rocky shores and intertidal areas among mussel beds (Martinez *et al.*, 2006; Spilmont *et al.*, 2018), thus further establishment is not expected to be prevented by competition with native species.

Qu. 3.5. How likely is it that establishment will occur despite predators, parasites or pathogens already present in the risk assessment area?

**RESPONSE** very likely **CONFIDENCE** medium

Response: Polychaetes constitute an important part of the food chain and are eaten by a variety of infaunal as well as by epifaunal and pelagic species such as fish, molluscs and crustaceans (Hutchings, 1998). As an example, flatfish species have a documented preference for polychaetes in their diet, especially at the juvenile stage (Hinz *et al.*, 2006) and *B. proboscidea* in particular is reported to dominate the diet of juvenile English sole *Parophrys vetulus* in its native range (Toole, 1980). Information on selective predation on *B. proboscidea* by native predators in the RA area could not be found, the species however is expected to play a similar role as elsewhere in the native and invaded range, where natural control by predation does not appear to be the critical factor for establishment.

Thus, based on its invasion history in the RA area, further establishment in suitable areas is not expected to be hampered by predation.

Qu. 3.6. How likely is the organism to establish despite existing management practices in the risk assessment area?
RESPONSE | very likely | CONFIDENCE | high
---|---|---|---

Response: The organism is already established in Europe, thus existing management practices related to introduction pathways/vectors could not prevent the entry into the environment of sufficient propagules for establishment.

Intensified monitoring for NIS, especially in hotspot areas, such as ports and marinas has resulted in the recent detection of new (or previously missed) populations in Europe (e.g. Hatton & Pearce, 2013; Wijnhoven et al., 2017; Kakkonen et al., 2019). Considering, however, the detection history of the species with repeated misidentifications, the established populations in Europe and the length of the EU coastline that would need to be monitored, further establishment is considered very likely.

Qu. 3.7. How likely are existing management practices in the risk assessment area to facilitate establishment?

RESPONSE | likely | CONFIDENCE | medium
---|---|---|---

Response: While Ballast Water Exchange (BWE) and Ballast Water Treatment (BWT) can reduce propagule pressure and, consequently, the rate of establishment (see Q1.6a for details), these management practices are not always possible or yet in effect. On the other hand, bivalve transportations for aquaculture purposes (which constitute a pathway of introduction and spread) offer suitable habitats to *B. proboscidea* in the form of the aquaculture plots themselves and, thus, facilitate establishment. Moreover, the exemption of *Crassostrea gigas* from Council Regulation (EC) No 708/2007 concerning use of alien and locally absent species in aquaculture means that *C. gigas* spat/stocks can be moved without any risk assessment or quarantine (unless stricter local/regional regulations apply – see Qu. 1.5d concerning e.g. the Wadden Sea or Natura2000 areas), potentially exacerbating the risk of importing infested oysters. Coastal defenses, other man-made structures and reefs of escaped *Crassostrea gigas* will provide suitable habitat to facilitate the establishment of the species.

Qu. 3.8. How likely is it that biological properties of the organism would allow it to survive eradication campaigns in the risk assessment area?

RESPONSE | likely | CONFIDENCE | medium
---|---|---|---
Response: In protected conditions (i.e. aquaculture) eradication may be attempted, depending on the cultivated species, with freshwater or heated seawater immersion, the application of chemical agents or natural products, such as phyco-derived compounds, etc (Lleonart, 2002; Handliger et al., 2004; Haupt et al., 2012; Simon et al., 2010a). In such cases, the protection afforded by the burrow for adults/juveniles and by the capsule for the eggs and larvae can compromise the effectiveness of the treatment (compared with exposed worms/larvae in laboratory tanks) but this is dose/time/species specific.

Even though specific information on similar management efforts in the wild was not found, it is expected that the same biological properties of the organism would enhance its chances of survival following eradication campaigns in the wild. Additionally, the species has the ability to recover rapidly from disturbance, both at the small (Garaffo et al., 2016) and the large scale (Jaubet et al., 2011), presumably due to its breadth of habitat and reproductive strategy. In any case, eradication methods are not available for the planktonic larval stage, which, if already released, can travel long distances before settling on a suitable habitat.

**Qu. 3.9. How likely are the biological characteristics of the organism to facilitate its establishment in the risk assessment area?**

including the following elements:

- a list and description of the reproduction mechanisms of the species in relation to the environmental conditions in the Union
- an indication of the propagule pressure of the species (e.g. number of gametes, seeds, eggs or propagules, number of reproductive cycles per year) of each of those reproduction mechanisms in relation to the environmental conditions in the Union.

If relevant, comment on the likelihood of establishment based on propagule pressure (i.e. for some species low propagule pressure (1-2 individuals) could result in establishment whereas for others high propagule pressure (many thousands of individuals) may not.

**RESPONSE** very likely **CONFIDENCE** high

Response:

_Boccardia proboscidea_ lives for approximately 12 months, and reaches sexual maturity approximately 2.5 months after settlement (Simon & Booth, 2007). In the laboratory it reproduces year-round and can produce up to eight broods throughout its reproductive period (Gibson 1997). In the wild, the reproductive period last around 6 months, between March and September in the northern hemisphere (Oyarzun, 2010; Gibson 1997) and the respective spring and summer months in Argentina (Jaubet et al., 2015). Its reproduction is a well-documented case of poecilogony with two developmental modes (planktotrophic, adelphophagic), and three reproductive modes: Type I, egg capsules with only planktotrophic larvae; Type II, egg capsules with planktotrophic larvae and 15% nurse eggs (rare); and Type III, egg capsules with 90% nurse eggs and a mixture of planktotrophic larvae and adelphophagic larvae that feed on nurse eggs and hatch as advanced larvae or juveniles (Hartman 1940; Woodwick 1977; Gibson et al. 1999). Females can produce 30-60 capsules in a clutch, each of which contains an average of 60 larvae in Type I reproduction,
and an average of 6 larvae plus nurse eggs in Type III reproduction (Gibson et al. 1999). Brooding time varies considerably with temperature; from 26 days at 12 °C to 9 days at 28 °C (David & Simon, 2014). Planktotrophs need to feed on the plankton after hatching (Pelagic Larval Duration PLD is ≈ 30 days for Type I and ≈ 15 days for Type III (Gibson, 1997)), whereas adelphophages eat nurse eggs and cannibalize small planktotroph siblings inside the capsule, hatching as juveniles that directly settle close to the adult (Gibson, 1997) or spend up to 4 days in the water column before settling (David, 2015). Optimal conditions for rearing in the lab are reported as 21 °C and 33 psu (David, 2015), while the range of temperatures under which spawning and development can be completed is very common along large parts of the RA area (Qu 3.1 and Annex VII).

Despite the reproductive output per individual not being particularly high per se, B. proboscidea regularly occurs in high densities both in the wild and in aquaculture systems, thus increasing the total number of propagules likely to be moved along the relevant pathways. Reports of population densities of tens to hundreds of thousands of individuals per m² and even higher are not uncommon in the literature (e.g. Oyarzun, 2010; Petch, 1995; see Impacts section for more details). Intensity of infestation of abalone in South Africa was up to ≈ 90 worms/shell in late winter, of which 1-8 were brooders and more than 50% were juveniles (Simon & Booth, 2007). Abalone farms rear tens of thousands of individuals per season, at high densities (Lleonart, 2002; Simon & Booth, 2007).

**Qu. 3.10. How likely is the adaptability of the organism to facilitate its establishment?**

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>very likely</th>
<th>CONFIDENCE</th>
<th>high</th>
</tr>
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</table>

Response: Tolerance of a relatively wide range of temperatures and salinities and the habitat breadth of this species will very likely facilitate its establishment, particularly in Northern European waters. This will be further enhanced by the maternal control over the time of release of developing larvae from their capsules (Oyarzun and Strathmann, 2011), and the two types of larvae achieving survival optima at different temperatures. At relatively low temperatures (12-17 °C), females release larvae at an earlier stage of development, favouring the survivorship of planktotrophic larvae which manage to escape predation by their adelphophagous siblings (David & Simon, 2014). At higher temperatures, increased developmental rates result in shorter brooding times, increased adelphophagia and higher survivorship of directly developing larvae, potentially leading to strong local populations. In either case, the decision of when to rupture the capsules and release the larvae belongs to the mother, which, based on environmental cues, determines the optimal reproductive strategy for the population (Oyarzun and Strathmann, 2011; David, 2015).

**Qu. 3.11. How likely is it that the organism could establish despite low genetic diversity in the founder population?**
Response: Molecular studies with the 16S rRNA gene detected a single haplotype (haplotype A of Oyarzun, 2010, i.e. the second most widespread haplotype in the native range) for South African B. proboscidea populations (Simon et al., 2009), which is shared among all south hemisphere populations (Radashevsky et al., 2019). Radashevsky et al. (2019) also found a single 16S rDNA haplotype (haplotype K of Oyarzun, 2010, i.e. the most common and widespread haplotype in the native range) from UK and French populations. On the other hand, when examining the more variable cytochrome b mtDNA, which is considered more suitable for intraspecific studies (Simon et al., 2009; Williams et al., 2017), Simon et al. (2009) detected 7 haplotypes in South Africa. The most common of these was also detected in Vancouver, Washington and California, while the remaining 6 haplotypes were unique to South Africa. Based on these finding, Simon et al. (2009) suggested that B. proboscidea in South African abalone farms were ultimately derived from the same source, initially towards the central south coast abalone farms. The authors postulated that these populations were either subjected to more than one introduction or had the greatest haplotype diversity at the time of introduction.

Qu. 3.12. If the organism does not establish, then how likely is it that casual populations will continue to occur?

Consider, for example, a species which cannot reproduce in the risk assessment area, because of unsuitable climatic conditions or host plants, but is present because of recurring introduction, entry and release events. This may also apply for long-living organisms.

Response: Multiple introductions have been hypothesized through shellfish transports in South Africa (Simon et al., 2009) and via ballast water transport for Australia (Radashevsky et al., 2019). The Hawaiian record of B. proboscidea on an oyster farm, caused by an Ostrea edulis shipment from Maine-USA (Bailey-Brock, 2000) has not been followed by any subsequent records in culture or in the wild (Radashevsky et al., 2019). Considering the volume of shellfish transports in the RA area, as well as the shipping traffic intensity, casual populations are likely to occur, particularly in areas of the Mediterranean and the Black Sea where environmental conditions do not favour establishment (see Qu.A6, Qu.A7 and Qu.3.1).

Qu. 3.13. Estimate the overall likelihood of establishment in the risk assessment area based on the similarity between climatic conditions within it and the organism’s current distribution under current climatic conditions. In addition, details of the likelihood of establishment in relevant biogeographical regions under current climatic conditions should be provided.
Thorough assessment of the risk of establishment in relevant biogeographical regions in current conditions: providing insight in the risk of establishment in (new areas in) the Union.

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Response: Based on its invasion history in Atlantic Europe, the abiotic requirements, existence of similar conditions and availability of preferred habitats, the establishment of *Boccardia proboscidea* in the risk assessment area is considered very likely in the Celtic Seas, the Greater North Sea, the Bay of Biscay and the Iberian Coast. In the Baltic Sea, the species will be limited by low winter temperatures and low salinities and is considered unlikely to establish. This assessment is corroborated by the results of a newly developed species distribution model, presented in Annex VIII.

With respect to the Mediterranean Sea, high summer temperatures in the Levantine and in large parts of the Ionian and the Central Mediterranean are expected to limit *B. proboscidea’s* distribution in this marine region to its relatively cooler areas (see relevant maps Annexes VII & VIII). Even in these areas, maximum water temperatures above 24 °C are likely to reduce the survivorship of planktotrophic larvae and instead favour the development of adelphophagic larvae, for which the main pathway of introduction is anticipated to be shellfish transport. Thus, likelihood of establishment is predicted to be higher in areas of shellfish cultivation (oysters and mussels) and associated with high organic matter input and sheltered conditions. In the Black Sea, *B. proboscidea’s* salinity requirements are met but temperatures are similarly likely to favour directly developing larvae. Considering that bivalve cultivation in the Black Sea is not as developed/widespread as in the Mediterranean, introduction events are considered less likely to occur, resulting in an overall low probability of establishment. The species distribution model predicts low likelihood of occurrence in the Black Sea, presumably reflecting the fact that the species will find itself at the edge of its physiological tolerance both in terms of salinity and maximum temperature. At the same time, the low salinity tolerance is not likely to be picked up by the model due to limitations associated with the coarse resolution of global data layers (see Annex VIII for details), such that there is high uncertainty associated with this prediction.

**Combining physiological tolerances and distribution modelling**

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Greater North Sea, Celtic Seas, Bay of Biscay and the Iberian coast

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Mediterranean Sea

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Black Sea

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Baltic Sea
Qu. 3.14 Estimate the overall likelihood of establishment in the risk assessment area under foreseeable climate change conditions. In addition, details of the likelihood of establishment in relevant biogeographical regions under foreseeable climate change conditions should be provided.

Thorough assessment of the risk of establishment in relevant biogeographical regions in foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk.

With regard to climate change, provide information on

- the applied timeframe (e.g. 2050/2070)
- the applied scenario (e.g. RCP 4.5)
- what aspects of climate change are most likely to affect the likelihood of establishment (e.g. increase in average winter temperature, increase in drought periods)

The thorough assessment does not have to include a full range of simulations on the basis of different climate change scenarios, as long as an assessment of likely establishment within a medium timeframe scenario (e.g. 30-50 years) with a clear explanation of the assumptions is provided. However, if new, original models are executed for this risk assessment, the following RCP pathways shall be applied: RCP 2.6 (likely range of 0.4-1.6°C global warming increase by 2065) and RCP 4.5 (likely range of 0.9-2.0°C global warming increase by 2065). Otherwise, the choice of the assessed scenario has to be explained.

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Response: Estimates in Annex VII refer to a maximum increase in seawater temperatures of 0.8 °C by 2065, according to the medium timeframe RCP 4.5 scenario. The SDM, presented in Annex VIII employed modelled future conditions for the 2070s under two different scenarios, RCP 2.6 and RCP 4.5.

Foreseeable climate change conditions are anticipated to lead to a slightly northward expansion of the species. In the Mediterranean Sea, increased maximum summer temperatures will restrict even more the areas with climatic conditions suitable for establishment to the north-eastern Aegean, small parts of the Adriatic and the cooler areas of the West Mediterranean. The development of localized populations is still possible under the circumstances mentioned above. Low likelihood of establishment is again predicted for the Black Sea, subject to the same limitations as mentioned above. An increase in minimum winter temperatures will offer suitable climatic conditions in parts of the Baltic Sea, low salinities however will continue to limit *B. proboscidea* in this marine region. Atlantic Europe will still offer highly suitable climatic conditions for the establishment of the species, for longer periods throughout the year at northern latitudes. A northward shift of the species is predicted by the model.

very likely high confidence

*Greater North Sea, Celtic Seas, Bay of Biscay and the Iberian coast*
moderately likely medium confidence
*Mediterranean Sea*

unlikely low confidence
*Black Sea*

unlikely high confidence
*Baltic Sea*
4 PROBABILITY OF SPREAD

Important instructions:

- Spread is defined as the expansion of the geographical distribution of an alien species within the risk assessment area.
- Repeated releases at separate locations do not represent continuous spread and should be considered in the probability of entry section. In other words, intentional anthropogenic “spread” via release or escape (“jump-dispersal”), should be dealt within the entry section. However, as repeated releases contribute to the spread of the target organism in the risk assessment area, the relevant pathway(s) should be briefly discussed here too, with an explicit reference to the entry section for additional details.

Qu. 4.1. How important is the expected spread of this organism within the risk assessment area by natural means? (List and comment on each of the mechanisms for natural spread.)

including the following elements:

- a list and description of the natural spread mechanisms of the species in relation to the environmental conditions in the risk assessment area.
- an indication of the rate of each of those spread mechanisms in relation to the environmental conditions in the Union.

The description of spread patterns should include elements of the species life history and behavioural traits able to explain its ability to spread, including: reproduction or growth strategy, dispersal capacity, longevity, dietary requirements, environmental and climatic requirements, specialist or generalist characteristics.

UNAIDED

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Response:

Pathway Name: UNAIDED (Natural dispersal across borders from neighbouring countries, where the species has been introduced, (i.e. Spain, France, Belgium, Netherlands, UK, Ireland) by

- a) planktotrophic larvae dispersed with oceanic currents
- b) rafting on natural (e.g. logs, algae) debris

*Boccardia proboscidea* lives for approximately 12 months and reaches sexual maturity approximately 2.5 months after settlement (Simon & Booth, 2007). It can produce multiple broods throughout its 6 month reproductive period, which lasts between March and September in the northern hemisphere. It is capable of producing free-swimming, planktotrophic larvae, which spend 15-30 days in the water column before settling and whose survivorship is favoured at relatively low temperatures (12-17 °C) but is severely reduced at 24 °C (for more details and references, see Qu 3.1, 3.9, 3.10). The reproductive traits of the European populations have not been studied but it is expected that spring and summer temperatures prevalent throughout north-western European waters favour the development of naturally dispersing planktotrophic
larvae, which is further supported by the expansion of the species along the French English channel and the Southern Bight of the North Sea near locations which constitute introduction hotspots, i.e. the port of Boulogne in France (Spilmont et al., 2018) and the Belgian and Dutch coast near ports and oyster culture plots (Kerckhof & Faasse, 2104; Wijhoven et al., 2017). The rate of spread due to natural dispersal cannot be teased apart from the rate of human-mediated spread (Qu. 4.2), especially since the species has very likely been overlooked, misidentified or not officially reported in the past in Europe (Radashevsky et al., 2019; Kerckhof & Faasse, 2014; Hatton and Pearce, 2013) and it is very difficult to reconstruct an accurate timeline of spread, particularly without genetic data.

Rafting has been assumed as a means of dispersal of B. proboscidea from its original source populations in the south of Pacific USA northwards along the Pacific coast until Canada, as the species frequently establishes its tubes in logs, burrowing into the wood (Oyarzun, 2010). Debris such as drift-wood can travel great distances on ocean currents and would be capable of transporting and spreading reproductively viable worms within the RA area. Females store sperm such that adults boring into logs could continue reproducing, assuming they could find enough food resources to sustain them, with the ensuing larvae either directly settling next to the parent or freely dispersing. For information on propagule pressure, see Qu 3.9.

See also Qu 3.1, 3.9 and Annex VII.

| RESPONSE | major | CONFIDENCE | medium |

**Qu. 4.2. How important is the expected spread of this organism within the risk assessment area by human assistance?** (List and comment on each of the mechanisms for human-assisted spread and provide a description of the associated commodities.)

including the following elements:

- a list and description of the anthropogenic spread mechanisms of the species in relation to the environmental conditions in the Union.
- an indication of the rate of each of those spread mechanisms in relation to the environmental conditions in the Union.

Response: Pathway name:

TRANSPORT-STOWAWAY (ship/boat ballast water)

TRANSPORT-STOWAWAY (ship/boat hull fouling)

TRANSPORT-STOWAWAY (other – Ship/boat bilge water)

TRANSPORT-CONTAMINANT Contaminant on animals (except parasites, species transported by host/vector) mariculture

According to the recent re-examination of older material and the tentative reconstruction of the invasion and spread timeline of the species (Radashevsky et al., 2019, Qu. A6, A8), within 5 years of the first European record in Spain in 1996 (Martinez et al., 2006), B. proboscidea was present in Brittany (1999), western
Ireland (2001), south-eastern UK (1998) and most likely Belgium by 2001, whereas Helgoland in Germany was already colonized by 2008 (Kind & Kuhlenkamp, 2017; Radashevsky et al., 2019). While discoveries of *B. proboscidea* in relatively distant parts of northern Europe within a short period of time (late 1990s – early 2000s) may have arisen from several introduction incidents, it is considered likely that secondary spread through human assisted pathways has almost certainly played a role in its current distribution (Radashevsky et al., 2019).

**Qu. 4.2a. List and describe relevant pathways of spread. Where possible give detail about the specific origins and end points of the pathways. For each pathway answer questions 4.3 to 4.9 (copy and paste additional rows at the end of this section as necessary). Please attribute unique identifiers to each question if you consider more than one pathway, e.g. 4.3a, 4.4a, etc. and then 4.3b, 4.4b etc. for the next pathway.**

including the following elements:

- a list and description of pathways with an indication of their importance and associated risks (e.g. the likelihood of spread in the Union, based on these pathways; likelihood of survival, or reproduction, or increase during transport and storage; ability and likelihood of transfer from the pathway to a suitable habitat or host). Where possible details about the specific origins and end points of the pathways shall be included.
- an indication of the propagule pressure (e.g. estimated volume or number of specimens, or frequency of passage through pathway), including the likelihood of reinvasion after eradication.
- All relevant pathways should be considered. The classification of pathways developed by the Convention of Biological Diversity shall be used.

Pathway name:

UNAIDED (Natural dispersal across borders from neighbouring countries)

TRANSPORT-STOWAWAY (ship/boat ballast water)

TRANSPORT-STOWAWAY (ship/boat hull fouling)

TRANSPORT-STOWAWAY (other – Ship/boat bilge water)

TRANSPORT-CONTAMINANT Contaminant on animals (except parasites, species transported by host/vector) mariculture

Assuming eradication is highly unlikely throughout the European invaded range (see Qu 3.8), even if local populations were detected early and eradicated at specific locations, reinvasion and spread with natural dispersal from persistent populations is considered very likely.
a. TRANSPORT-STOWAWAY (ship/boat ballast water)

Qu. 4.3a. Is spread along this pathway intentional or unintentional (e.g. the organism is a contaminant of translocated goods within the risk assessment area)?

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Response. As in Qu.1.2.a

Qu. 4.4a. How likely is it that a number of individuals sufficient to originate a viable population will spread along this pathway from the point(s) of origin over the course of one year? including the following elements:

- an indication of the propagule pressure (e.g. estimated volume or number of specimens, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if appropriate, indicate the rate of spread along this pathway
- if appropriate, include an explanation of the relevance of the number of individuals for spread with regard to the biology of species (e.g. some species may not necessarily rely on large numbers of individuals).

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Response: For reproductive output and ship ballast volume & potential larval concentration, see Qu. 1.3a. With respect to spread of the organism within the EU, transshipment operations constitute the main maritime traffic that will act as the vector for spread. Important transshipment hubs are situated along the southern Mediterranean (serving the rest of the Mediterranean and the Black Sea) and the Le Havre-Hamburg range, serving the UK, the Baltic and Scandinavia (Notteboom et al., 2013). Considering that planktotrophic *B. proboscidea* larvae are favoured by water temperatures encountered throughout northern European Seas, it is considered likely that sufficient numbers can be transferred with ballast water along this pathway. See also Qu. 4.2. Higher water temperatures and the lack of established populations in the Mediterranean Sea, render this pathway of lesser importance for the spread of *B. proboscidea* in this marine region.

Qu. 4.5a. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?
Response: As in Qu.1.4.a. Additionally, the smaller duration of short sea shipping routes between EU ports further increases the likelihood of survival within ballast waters, compared with international shipping routes.

**Qu. 4.6a. How likely is the organism to survive existing management practices during spread?**

| RESPONSE | unlikely (with full compliance to the IMO D2) | likely (otherwise) | CONFIDENCE | medium |

Response: See Q1.5a. BWE for EU short sea shipping routes is usually restricted to the second criterion of at least 50 nm from the nearest land and in waters at least 200 metres in depth in the Mediterranean Sea and is often not even feasible within these limits in northern European Seas (David et al., 2007), such that ballast water exchange is not likely to be effective in preventing the spread of *B. proboscidea* (and other organisms potentially transferred in ballast water) within European Seas. Regarding the IMO D2 standard, compliance can practically diminish propagule pressure of zooplankton, but full implementation of the BWMC is not expected to happen before 2024.

**Qu. 4.7a. How likely is the organism to spread in the risk assessment area undetected?**

| RESPONSE | likely | CONFIDENCE | high |

Response: as in Qu. 1.6a
Qu. 4.8a. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host during spread? (including, where possible, details about the specific origins and end points of the pathway)

**RESPONSE**  likely  **CONFIDENCE**  high

Response: as in Qu. 2.6a

Qu. 4.9a. Estimate the overall potential rate of spread within the Union based on this pathway? (please provide quantitative data where possible).

**RESPONSE**  rapidly  **CONFIDENCE**  medium

Response: While it is not possible to assign separate rates of spread to the different pathways, discoveries of *B. proboscidea* in relatively distant parts of northern Europe within a short period of time (late 1990s – early 2000s) point to a relatively rapid rate of spread via human assisted pathways, of which ballast water transport is considered a likely vector within the RA area. See also Qu. 4.2

*End of pathway assessment, repeat Qu. 4.3 to 4.9. as necessary using separate identifiers.*

**b. TRANSPORT-STOWAWAY (ship/boat hull fouling)**

Qu. 4.3b. Is spread along this pathway intentional or unintentional (e.g. the organism is a contaminant of translocated goods within the risk assessment area)?

**RESPONSE**  unintentional  **CONFIDENCE**  high

Response: as in Qu.1.2b

Qu. 4.4b. How likely is it that a number of individuals sufficient to originate a viable population will spread along this pathway from the point(s) of origin over the course of one year?
including the following elements:

- an indication of the propagule pressure (e.g. estimated volume or number of specimens, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if appropriate, indicate the rate of spread along this pathway
- if appropriate, include an explanation of the relevance of the number of individuals for spread with regard to the biology of species (e.g. some species may not necessarily rely on large numbers of individuals).

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Response: Females of *Boccardia proboscidea* can produce 30-60 egg capsules in a clutch, each of which contains an average of 60 larvae in Type I reproduction, and an average of 6 larvae plus nurse eggs in Type III reproduction (Gibson et al. 1999); it is considered possible that *B. proboscidea* can spread within the RA area as a member of mature fouling communities on ships’/boats’ hulls (see also Wijnhoven et al., 2017 for an assessment of likely pathways of introduction and spread), through the release of either larvae or adult individuals. — see also Qu 3.9 and 1.3b. Besides large vessels, particular mention is warranted of the role played by small leisure craft in the spread of marine NIS via hull fouling. Gittenberger *et al.* (2017), in a study focusing on non-native species in Dutch pleasure craft harbours between 2009-2016, demonstrated that, on average, 59% of all pleasure crafts studied (n=2055) in Dutch marine harbours had fouling on their hulls, with up to 25% of them carrying “heavy fouling” in the summer, i.e. abundant and often diverse fouling assemblages, covering >16% of the visible submerged surfaces. Even though *B. proboscidea* was not detected in these surveys, hull fouling communities included oysters *C. gigas* and barnacle species (Gittenberger *et al.*, 2017), that could serve as hosts of *B. proboscidea*, which would be overlooked unless fouling material is collected and carefully examined. Additionally, the closely related boring spionid *Polydora ciliata* was found on floating docks and settlement plates within the harbours.

**Qu. 4.5b. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?**

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Response: In a relatively wide range of temperatures, *B. proboscidea* is able to produce directly developing (adelphophagic) larvae that hatch at an advanced stage and settle close to the parent (see Qu 3.1, 3.9, 3.10). As such, it is possible that it can reproduce and maintain its fouling population during transport, and its cryptic lifestyle will protect it from the drag at high speeds of moving vessels.
Regarding intra-European voyages, and within EU marine regions in particular, recreational vessels are less likely to travel at high speeds and fouling species less likely to face as big changes in environmental conditions as those experienced during oceanic voyages (Ashton et al., 2006), such that their likelihood of survival increases. Moreover, leisure craft tend to remain at a single port for longer periods, which increases their chances of accumulating fouling species.

**Qu. 4.6b. How likely is the organism to survive existing management practices during spread?**

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Response: Hull cleaning is an often practiced method of defouling ship hulls and has the potential to physically remove *B. proboscidea*, which would in turn reduce the risk of spread. Regarding large vessels, the suite of measures available for the management of biofouling (see Qu. 1.5b) can prove effective against *B. proboscidea* and other fouling organisms, if fully implemented, although sea-chests would still remain higher risk areas and may require more frequent in-water treatment. However, anti-fouling practices are not legally required, and can be financially costly, making it likely that a number of vessels traveling between contaminated and uncontaminated marinas and ports will not have been treated, motivating a high likelihood score for this question.

With respect to small leisure craft, Gittenberger et al. (2017) found that, although the majority (64%) of boat owners in the Netherlands haul their boats out of the water and clean them at least once a year, practices vary widely from harbor to harbor, with dry-docking/cleaning prevalence varying between 6% and 95%. This level of compliance still leaves plenty of opportunities for the spread of *B. proboscidea* within EU waters through fouling on recreational craft.

**Qu. 4.7b. How likely is the organism to spread in the risk assessment area undetected?**

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Response: see Q1.6b

**Qu. 4.8b. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host during spread?** (including, where possible, details about the specific origins and end points of the pathway)
Response: as in Qu. 2.3b, 2.6b

**Qu. 4.9b. Estimate the overall potential rate of spread within the Union based on this pathway? (please provide quantitative data where possible).**

| RESPONSE     | moderately rapidly | CONFIDENCE | medium |

Response: Transport of *B. proboscidea* on ships hulls has been hypothesized but never documented. In most publications shipping traffic is reported as a potential pathway but the vector is not specified, it is however considered possible that the species can survive as part of the fouling community on ships hulls and release propagules upon arrival to new locations. It is not possible to assign separate rates of spread to the different pathways, but, considering the higher uncertainty associated with this pathway, its contribution to the overall potential for human assisted spread is assessed as relatively lower than ballast water (see Qu. 4.9a).

*End of pathway assessment, repeat Qu. 4.3 to 4.9. as necessary using separate identifiers.*

c. TRANSPORT-STOWAWAY (Bilge waters)

**Qu. 4.3c. Is spread along this pathway intentional or unintentional (e.g. the organism is a contaminant of translocated goods within the risk assessment area)?**

| RESPONSE     | unintentional | CONFIDENCE | high |

Response: as in Qu 1.2c

**Qu. 4.4c. How likely is it that a number of individuals sufficient to originate a viable population will spread along this pathway from the point(s) of origin over the course of one year?**

including the following elements:

- an indication of the propagule pressure (e.g. estimated volume or number of specimens, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if appropriate, indicate the rate of spread along this pathway
• if appropriate, include an explanation of the relevance of the number of individuals for spread with regard to the biology of species (e.g. some species may not necessarily rely on large numbers of individuals).

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Response: It depends on a) the number of yachts and vessels arriving in a hub, b) theoretical distance and time to first discharge (assuming constant and linear travel) c) survival of the species and d) volume of bilge water.

See Qu 1.3c for bilge water volumes. An indication of the number of recreational vessels in the RA area is given by the European Boating Industry (2016), which estimates that over 6 million boats are kept in European waters while 4,500 marinas provide 1.75 million berths both inland and in coastal areas. Extrapolating from Gittenberger et al. (2017), approximately 30% of these vessels travel distances >100km from their home port. Assuming travel speeds of 5 knots (Fletcher et al., 2017), considerable distances can be travelled within the RA area within a matter of days, which significantly increases the likelihood that sufficient viable propagules of *B. proboscidea* can spread along this pathway from already established populations in the RA area.

**Qu. 4.5c. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?**

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Response: It is related to propagule survival and typical distances travelled by yachts. The metabarcoding analysis of 23 bilge samples collected from yachts and motorboats operating commercially and recreationally in two boating hubs in New Zealand’s South Island, lead to the identification of 5 NIS among which the polychaete *Boccardia proboscidea* (Fletcher et al., 2017). Considering the pelagic larval duration of *B. proboscidea* planktotrophic larvae (up to 30 days), the relatively short travel times of small vessels within the RA area and the tolerance of the organism to salinities down to approximately 15 psu, the likelihood of survival along this pathway is assessed as high.

**Qu. 4.6c. How likely is the organism to survive existing management practices during spread?**

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Response: see Qu. 1.5c

**Qu. 4.7c. How likely is the organism to spread in the risk assessment area undetected?**

| RESPONSE | likely | CONFIDENCE | medium |

Response: see Qu.1.6c

**Qu. 4.8c. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host during spread? (including, where possible, details about the specific origins and end points of the pathway)**

| RESPONSE | likely | CONFIDENCE | high |

Response: If viable propagules are discharged with untreated bilge water, they are likely to transfer to a suitable habitat or host, see Qu 2.3a, 2.3b, 2.6c.

**Qu. 4.9c. Estimate the overall potential rate of spread within the Union based on this pathway? (please provide quantitative data where possible).**

| RESPONSE | moderately rapidly | CONFIDENCE | medium |

Response: If present in a hub, which is not an uncommon occurrence for *B. proboscidea* (see e.g. Kakkonen *et al.*, 2019; Hatton & Pearce, 2013; Radashevsky *et al.*, 2019), the organism can easily spread to the next destination of a leisure craft or other type of small vessel. Considering the much lower volumes of bilge water transported (compared to ballast water), and the generally smaller distances covered by recreational boats compared to large vessels, the contribution of this pathway to the overall potential for human assisted spread is assessed as relatively lower than ballast water (see Qu. 4.9a)

*End of pathway assessment, repeat Qu. 4.3 to 4.9 as necessary using separate identifiers.*
d. TRANSPORT-CONTAMINANT Contaminant on animals (except parasites, species transported by host/vector) mariculture

**Qu. 4.3d. Is spread along this pathway intentional or unintentional (e.g. the organism is a contaminant of translocated goods within the risk assessment area)?**

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>Unintentional</th>
<th>CONFIDENCE</th>
<th>high</th>
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Response: All countries along the European Atlantic and the Mediterranean coasts involved in the cultivation of bivalves are currently conducting transfer activities (Muehlbauer et al., 2014; Occhipinti-Ambrogi et al., 2016; Marchini et al., 2014; Rodrigues et al., 2015). These activities include transfers at all life stages, from field sites to wild fishery sites or from field to culture sites, from shore to onshore facilities or from nearshore wild bottom beds to offshore hanging cultivation devices (Muehlbauer et al., 2014). Based on its invasion history in South Africa, where *B. proboscidea* worms were spread among farms in South Africa primarily through the transport of infested abalone (Simon et al., 2009), and its well known history of bivalve infestation (particularly oysters – Simon & Sato-Okoshi, 2015), the species is considered likely to spread within the RA area as an aquaculture pest. Particularly noteworthy is the danger of spread through this pathway to the Mediterranean Sea, where the species is not currently present/established (e.g. both Spain and France transfer bivalve seed/stock between Atlantic and Mediterranean cultivations sites - Muehlbauer et al., 2014). In fact, the discovery of the species in an oyster, purportedly originating in Leucate Lagoon, France (Radshevsky et al., 2019) raises concerns about the role of aquaculture on the potential spread of *B. proboscidea*.

**Qu. 4.4d. How likely is it that a number of individuals sufficient to originate a viable population will spread along this pathway from the point(s) of origin over the course of one year?**

including the following elements:

- an indication of the propagule pressure (e.g. estimated volume or number of specimens, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if appropriate, indicate the rate of spread along this pathway
- if appropriate, include an explanation of the relevance of the number of individuals for spread with regard to the biology of species (e.g. some species may not necessarily rely on large numbers of individuals).

| RESPONSE | likely to very likely | CONFIDENCE | medium |
Response: *B. proboscidea* on cultured mollusks can display high infestation rates, in the order of tens of individuals per shell (for rates of infestation, see Qu 5.9). The species has already been recorded among oysters (Wijnhoven et al., 2017) and intertidal mussel reefs (Martinez et al., 2006; Spilmont et al., 2018) as an interstitial organism in small to medium densities (See Qu. 5.2), which are considered likely to act as sources of infestation. Given the large volume of shellfish transfers within the RA area, the potential for sufficient individuals of *B. proboscidea* spreading along this pathway is high.

for more details see also Qu.1.3d

<table>
<thead>
<tr>
<th>Qu. 4.5d. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?</th>
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<td>RESPONSE</td>
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</table>

Response: Spionids, or „mudworms“, have been regularly associated with shellfish consignments, as the shellfish themselves and the methods used to contain them during transport may actually enhance the likelihood of survival of contaminant species as well by providing moisture and protection from harsher conditions (Minchin, 2007). For example, the *Ostrea edulis* shipment that was imported to Hawaii in 2000 was heavily infested with adult *B. proboscidea*, whose burrows contained egg capsules with late-stage larvae, leading Bailey-Brock (2000) to conclude that reproduction had recently occurred, either before collection at the facility of origin or after placing the oysters in the recipient grow-out facility.

<table>
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<tr>
<th>Qu. 4.6d. How likely is the organism to survive existing management practices during spread?</th>
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<td>RESPONSE</td>
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Response: Response: COUNCIL REGULATION (EC) No 708/2007 concerning use of alien and locally absent species in aquaculture defines the procedures to be followed that minimise the risk of introducing non-target alien species accompanying commercial shellfish spat and stocks. It requires a permit procedure, involving risk assessment for the non-target species and a quarantine period for the translocated stock. Importantly, in relation to spread within the RA area, the regulation does not apply to movements of locally absent species within the Member States “except for cases where, on the basis of scientific advice, there are grounds for foreseeing environmental threats due to the translocation, Art. 2 para. 2.”

Additionally, the bivalve *C. gigas* listed in Annex IV, which is one of the main bivalve hosts of *B. proboscidea* both in cultivation and in the wild, constitutes an exception and can be moved without any risk assessment or quarantine. However local/national legislation exists that can limit the translocation
possibilities of species like *C. gigas*, e.g. see WG-AS & Gittenberger (2018) for the trilateral Wadden Sea area. Moreover, if the import region is a Natura2000 area regulations can be much stricter as they aim to protect the conservation objectives of the protected area first.

Other initiatives have produced codes of conduct for the transfer of bivalve seed/stock at the national/regional level, such as the ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2005, the Code of practice for mussel seed movements (Wilson & Smith, 2008) Wales, etc. In general, restrictions on transfers based on the risk associated with the source areas is an effective management method, as long as extensive and up-to-date data on the distribution of the high-risk NIS are available; for *B. proboscidea*, difficulties in detection and identification can hamper such efforts.

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<tr>
<th>Qu. 4.7d. How likely is the organism to spread in the risk assessment area undetected?</th>
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<td><strong>RESPONSE</strong></td>
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<tr>
<td><strong>CONFIDENCE</strong></td>
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Response: Eggs/larvae can easily go undetected by perfunctory visual inspections. Mature individuals can be misidentified.

<table>
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<tr>
<th>Qu. 4.8d. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host during spread? (including, where possible, details about the specific origins and end points of the pathway)</th>
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<td><strong>RESPONSE</strong></td>
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<td><strong>CONFIDENCE</strong></td>
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Response: If *B. proboscidea* infested bivalve seed/stock is relayed on cultivation plots without any prior management measure, the likelihood of transfer to other suitable habitats (the cultivation plots themselves are suitable habitats) is very high. These plots are often situated in coastal areas in close proximity to suitable natural habitat to-which individuals may spread. Regarding abalone cultivation practices, these species are grown in land-based facilities, from which *B. proboscidea* can escape through the farms’ outflow waters, as it happened in South Africa (David, 2014 and references therein).

<table>
<thead>
<tr>
<th>Qu. 4.9d. Estimate the overall potential rate of spread within the Union based on this pathway? (please provide quantitative data where possible).</th>
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<tbody>
<tr>
<td><strong>RESPONSE</strong></td>
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<td><strong>CONFIDENCE</strong></td>
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</table>
Response: see Qu. 4.9a. Bivalve transfers are a likely mechanism of spread in the RA area, although, considering the degree of regulation of the industry and the fact that in many cases transfers are predominantly conducted within Member States, spread to distant locations through this pathway may be less important than spread through ship-mediated pathways.

*End of pathway assessment, repeat Qu. 4.3 to 4.9. as necessary using separate identifiers.*

**Pathway Name:** UNAIDED

**Qu. 4.3e. Is spread along this pathway intentional or unintentional (e.g. the organism is a contaminant of translocated goods within the risk assessment area)?**

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<tr>
<th>RESPONSE</th>
<th>unintentional</th>
<th>CONFIDENCE</th>
<th>high</th>
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</table>

Response: By definition unintentional

**Qu. 4.4e. How likely is it that a number of individuals sufficient to originate a viable population will spread along this pathway from the point(s) of origin over the course of one year?**

including the following elements:

- an indication of the propagule pressure (e.g. estimated volume or number of specimens, or frequency of passage through pathway), including the likelihood of reinvasion after eradication
- if appropriate, indicate the rate of spread along this pathway
- if appropriate, include an explanation of the relevance of the number of individuals for spread with regard to the biology of species (e.g. some species may not necessarily rely on large numbers of individuals).

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<th>RESPONSE</th>
<th>likely</th>
<th>CONFIDENCE</th>
<th>high</th>
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Response: Females of *Boccardia proboscidea* can produce 30-60 egg capsules in a clutch, each of which contains an average of 60 larvae in Type I reproduction, and an average of 6 larvae plus nurse eggs in Type III reproduction (Gibson et al. 1999) – see also Qu 3.9. Despite the reproductive output per individual not being particularly high per se, and the current densities of *B. proboscidea* in the RA area not being very high, the relatively wide spread of the species in the RA area, particularly near introduction hotspots, indicates that the number of individuals (be it free swimming larvae or rafting adults) spreading unaided has been sufficient to originate viable populations in new locations.

**Qu. 4.5e. How likely is the organism to survive, reproduce, or increase during transport and storage along the pathway (excluding management practices that would kill the organism)?
**Qu. 4.6e. How likely is the organism to survive existing management practices during spread?**

**RESPONSE** very likely  
**CONFIDENCE** high

Response: No management practices are in place concerning natural dispersal that can affect the organism’s ability to survive along this pathway.

**Qu. 4.7e. How likely is the organism to spread in the risk assessment area undetected?**

**RESPONSE** likely  
**CONFIDENCE** high

Response: The species has very likely been overlooked, misidentified or not officially reported in the past in Europe (Hatton & Pearce, 2013; Kerckhof & Faasse, 2014; Radashevsky et al., 2019). *Boccardia proboscidea* is easily missed by many routine survey methods because its preference for intertidal firm or hard substrata excludes it from most routine grab and core samples (Radashevsky et al., 2019). Intertidal rocky shore or artificial hard substrates have not been the focus of regular monitoring schemes (Spilmont et al., 2018; Kerckhof & Faasse, 2014); additionally, the use of European identification keys that may not include non-native species can lead to misidentifications.

**Qu. 4.8e. How likely is the organism to be able to transfer from the pathway to a suitable habitat or host during spread? (including, where possible, details about the specific origins and end points of the pathway)**

**RESPONSE** very likely  
**CONFIDENCE** high
Response: During natural dispersal, organisms usually arrive and settle in suitable habitats or move on. *Boccardia proboscidea* larvae settle on a variety of habitats, including sand, broken mollusk shells, alive mollusks (Gibson, 1997; Simon and Booth, 2007; Oyaruzun, 2010); settlement habitats are widely available throughout the RA. Similarly, individuals traveling on floating debris can easily find settlement habitats both on hard and soft substrates once the rafting material reaches the shore.

**Qu. 4.9e.** Estimate the overall potential rate of spread within the Union based on this pathway? (please provide quantitative data where possible).

<table>
<thead>
<tr>
<th>RESPONSE</th>
<th>moderately rapidly</th>
<th>CONFIDENCE</th>
<th>medium</th>
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Natural dispersal has almost certainly played (and will keep playing) an important role in the spread of *B. proboscidea* within the RA area, particularly in Atlantic Europe, however it is rather unlikely that it is the mechanism responsible for the appearance of the species at locations as distant as northern Spain, western Ireland, south-eastern UK and Belgium within a period of approximately 5 years (see QU. A6, A8). While larval dispersal will proceed at different rates depending on local/regional hydrodynamic conditions and topography, on average a moderate rate of spread is expected. In the Mediterranean Sea, where high temperatures will favour the survival of directly developing larvae, natural spread may be even slower and of lesser importance at the regional scale. Directly developing larvae (also called adelphophagic) hatch as juveniles that directly settle close to the adult (Gibson, 1997) or spend up to 4 days in the water column before settling (David, 2015), thus having reduced natural dispersal by currents.

*End of pathway assessment*

**Qu. 4.10.** Within the risk assessment area, how difficult would it be to contain the organism in relation to these pathways of spread?

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<thead>
<tr>
<th>RESPONSE</th>
<th>very difficult</th>
<th>CONFIDENCE</th>
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Response:

Naturally dispersing organisms are very difficult to contain. However, early detection, rapid response and control in aquaculture sites is feasible (Grosholz & Ruiz, 2002), if the species is correctly identified and restrictions based on the risk associated with the source areas are rapidly adopted by the industry. The current legal instruments and levels of implementation of voluntary measures are not sufficient to ensure containment of the organism, when transferred by ballast water (but this can change with full
implementation of the D-2 Standard), fouling assemblages on ships’ hulls, or bilge water. See also responses to Qu 4.6a-d.

Qu. 4.11. Estimate the overall potential rate of spread in relevant biogeographical regions under current conditions for this organism in the risk assessment area (indicate any key issues and provide quantitative data where possible).

Thorough assessment of the risk of spread in relevant biogeographical regions in current conditions, providing insight in the risk of spread into (new areas in) the Union.

**RESPONSE** | rapidly | **CONFIDENCE** | high

Response: Unaided dispersal and multiple pathways of human-aided spread create a considerable potential for rapid spread, in the order of $10^3$ km within 5 years. Among the ship-mediated pathways, ballast transport is considered more likely to have been responsible for the already manifested rapid rate of spread along Atlantic Europe and will continue to play the same role until the BWMC is fully implemented. Hull fouling and bilge waters, especially of leisure and other small craft may have also contributed to the current spread of *B. proboscidea* in northern European waters; bilge waters in particular is a vector that has been overlooked until recently and it appears to be able to transport viable propagules of the species in the relatively short duration of intra-European journeys. Finally, bivalve transfers are another likely mechanism of spread in the RA area, especially within Member States but potentially also between marine regions/subregions. Particular attention is needed when transferring oyster consignments between Atlantic Europe and the Mediterranean.

Qu. 4.12. Estimate the overall potential rate of spread in relevant biogeographical regions in foreseeable climate change conditions (provide quantitative data where possible).

Thorough assessment of the risk of spread in relevant biogeographical regions in foreseeable climate change conditions: explaining how foreseeable climate change conditions will influence this risk, specifically if rates of spread are likely slowed down or accelerated.

**RESPONSE** | rapidly | **CONFIDENCE** | high

Response: Foreseeable climate change conditions are anticipated to lead to a slightly northward expansion of the species (see model results in ANNEX VIII). Natural dispersal may be slightly accelerated, as Atlantic Europe will offer highly suitable climatic conditions for the establishment of the species for longer periods throughout the year at northern latitudes (but still within the 12-17 °C bracket optimal for planktotrophic larvae), increasing brood frequency and production. In the Mediterranean Sea on the contrary, elevated maximum temperatures will make bivalve transport the dominant potential spread mechanism for *B.*
proboscidea and may further enhance its importance. For example, heat waves can cause mass mortality of aquaculture bivalves, leading to increased shellfish transfers to replete the stocks (Rodrigues et al., 2015). Finally, higher frequency and severity of storms and hurricanes can increase the amount of large floating debris, further enhancing natural dispersal. Higher frequency of inclement weather may also lead to higher port residence times for vessels, increasing the likelihood of development of fouling communities and of releasing propagules (Galil et al., 2019).
5 MAGNITUDE OF IMPACT

Important instructions:

- Questions 5.1-5.5 relate to biodiversity and ecosystem impacts, 5.6-5.8 to impacts on ecosystem services, 5.9-5.13 to economic impact, 5.14-5.15 to social and human health impact, and 5.16-5.18 to other impacts. These impacts can be interlinked, for example a disease may cause impacts on biodiversity and/or ecosystem functioning that leads to impacts on ecosystem services and finally economic impacts. In such cases the assessor should try to note the different impacts where most appropriate, cross-referencing between questions when needed.

- Each set of questions starts with the impact elsewhere in the world, then considers impacts in the risk assessment area (=EU excluding outermost regions) separating known impacts to date (i.e. past and current impacts) from potential future impacts (including foreseeable climate change).

- Only negative impacts are considered in this section (socio-economic benefits are considered in Qu. A.7)

Biodiversity and ecosystem impacts

**Qu. 5.1. How important is the impact of the organism on biodiversity at all levels of organisation caused by the organism in its non-native range excluding the risk assessment area?**

including the following elements:

- Biodiversity means the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems

- impacted chemical, physical or structural characteristics and functioning of ecosystems

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<th>RESPONSE</th>
<th>major</th>
<th>CONFIDENCE</th>
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Comment: *Boccardia proboscidea* is considered an introduced species in Australia, New Zealand, South Africa, Argentina, Hawaii and of uncertain origin in Japan, China, Korea (see Qu A5), it is only in Argentina however that severe environmental impacts have been documented.

At sewage impacted sites, *B. proboscidea* displaces the native ecosystem engineering mussel *Brachidontes rodriguezii* from the rocky intertidal, forming solid epilithic biogenic structures termed “reefs” (Jaubet et al., 2011, 2013). At sites heavily impacted by untreated sewage effluent, these reefs covered up to 70-100% of the substrates from 50 to 1200 m south of the sewage outfall (Jaubet et al., 2013; Elías et al., 2015), with worm densities upwards of $10^6$ individuals/m² (Garaffo et al., 2012). The dominance of *B. proboscidea* significantly reduced the species as well as the functional richness and diversity of the rocky intertidal flora and fauna (Elías et al., 2015; Garaffo et al., 2018). The explosive population increase of *B. proboscidea* and
the competitive exclusion of *B. rodriguezii* was attributed to a combination of increased organic input with the weakened condition of the native mussel due to sewage contamination. In Mar del Plata, Argentina, *B. proboscidea* is considered primarily a boring species, boring into coastal abrasion platforms and building massive aggregations of tubes over them, and secondarily a tube-dwelling species, where increased sedimentation in areas of sewage discharge is forcing the construction of tubes (Jaubet *et al.*, 2014). Major impacts on rocky intertidal habitats have also been documented in northern Patagonia, where *B. proboscidea* populations bore into friable sedimentary rocks where they destroy the substrate (see images below, depicting the scale and intensity of the boring activity and ensuing damage) and greatly alter the native communities (Radashevsky *et al.*, 2013). The species is now distributed along most of the Argentinean coastline (Jaubet *et al.*, 2018), where it has become a dominant and permanent fixture in the successional dynamics of the intertidal benthic communities, both on hard and on soft substrates (Llanos *et al.*, 2019), aided by its large capacity to rapidly recover after disturbance (Becherucci *et al.*, 2016). Additionally, *B. proboscidea* in high densities on man-made and natural hard substrates smothered populations of native [to Argentina] mussels *Brachidontes* spp. and of the alien barnacle *Balanus glandula* (Diez *et al.*, 2011).

To summarise, *Boccardia proboscidea*, like other opportunistic polychaete species, is generally favoured and proliferates under conditions of organic enrichment, whether anthropogenic or naturally occurring (see Qu. 5.2). The magnitude of the population and the severity of impacts relates as much to organic inputs as to specific local conditions. In Argentina, the introduction of *B. proboscidea* probably occurred several years before the formation of reefs, without severe ecological consequences, with the invader coexisting with other spionids species and the mussels in the intertidal community, and moderately affecting community structure (Elias *et al.*, 2003; 2006 as *B. polybranchia*). The massive increase of the *B. proboscidea* population was probably caused by the increase of the sewage-contamination. The organic matter content in sewage-impacted sites increased from 0.5% to 1% (previous to 2008) to more than 2% in 2008, in agreement with the development of *B. proboscidea* reefs (Sanchez *et al.* 2011; Jaubet *et al.*, 2013). Furthermore, the grease in the untreated sewage was hypothesized to promote binding of the sediment grains and subsequent reef formation (Jaubet, 2013). At the same time, the species was present in reference sites, away from the direct influence of sewage contamination, with a low percent cover and density, primarily as companion species of mussel beds (Jaubet *et al.*, 2011).

On the other hand, the dense populations boring into vertical rock surfaces (see images below), were observed under near pristine conditions (Radashevsky, pers.comm., January 2021), although quantitative data to document this are lacking.
Outside Argentina, structural impacts of *B. proboscidea* on soft-sediment habitats have also been observed in South Africa at the outflow path of an abalone farm (David, 2015) and in Australia, Port Phillip Bay, in areas of secondary treated sewage discharge (Petch, 1989). In both cases, high densities (e.g. Petch, 1989 reported densities of 350000 ind./m²) of the organism from “tube mats” and consolidate the sediments, impacts on the associated benthic communities however were not reported, neither was the formation of reefs, similar to those that developed in Argentina (Carol Simon, pers. comm, May 2019). In South Africa, the species was initially associated with onshore abalone farms (Simon *et al*, 2007; 2009; 2010b) and took several years to establish in the wild (David, 2015), primarily around the farms’ outflow paths. The lack of severe impacts was attributed to the fact that abalone farms are usually in high energy areas, where high wave action quickly distributes effluents (Carol Simon, pers. comm, May 2019).

**Qu. 5.2. How important is the current known impact of the organism on biodiversity at all levels of organisation (e.g. decline in native species, changes in native species communities, hybridisation) in the risk assessment area (include any past impact in your response)?**

Discuss impacts that are currently occurring or are likely occurring or have occurred in the past in the risk assessment area. Where there is no direct evidence of impact in the risk assessment area (for example no studies have been conducted), evidence from outside of the risk assessment area can be used to infer impacts within the risk assessment area.

| RESPONSE | moderate | CONFIDENCE | low |

Comment: In the Risk Assessment area, *Boccardia proboscidea* is relatively widespread along the North East Atlantic (see Qu.A6, Qu.A8) but, to date, only low to moderately high densities have been recorded,
with the exception of the island of Helgoland and one location in the UK. **Spain:** The highest densities of the species were obtained in the spring of 1997, with more than 5000 individuals/m², next to a sewage outfall and on the calcareous rhodophyte *Corallina elongata* and alongside the bivalves *Mytilaster minimus* (Poli, 1795) and *Mytilus galloprovincialis* (Martínez *et al*., 2006). This observation confirms that, under conditions of organic enrichment, *B. proboscidea* can start proliferating and dominating intertidal communities in the RA area.

**France:** English Channel (Opal coast) highest density of 263 ind./m² (Spilmont *et al*., 2018) on intertidal mussel reefs. The sampling location, considered a site not impacted by pollution (Spilmont *et al*., 2018). **Belgium:** Densities on groynes (mainly among *Polydora ciliata* turf) varied between 100 ind./m² (Koksijde 2012) and 1250 ind./m² (Oostende 2013) (Kerckhof & Faasse, 2014). In the sampled locations it was often the dominating, or only, spionid.

**Germany:** On the island of Helgoland in the German Bight *Boccardia proboscidea* is observed in high densities, boring into soft mudstone (in the order of at least 20000 ind/m², roughly estimated from Kind & Kuhlenkamp, 2017). Concerns are expressed about potential erosion of the invaded habitat and the possible displacement of the native polychaete *Polydora ciliata* (Kind & Kuhlenkamp, 2017; Radashevsky *et al*., 2019). Increased erosion of the invaded abrasion platforms may affect the fucoid and mytilid communities developing on them (Bartch & Tittley, 2004; Kuhlenkamp *et al*., 2011).

In Helgoland, the development of dense populations is most likely associated with nutrient enrichment attributed to large bird colonies on the island (Ralph Kuhlenkamp, pers. comm., January 2021). Helgoland is slightly affected by the plume of the river Elbe which carries quite a load of nutrients but has no major source of organic pollution since it has only a small population, even with tourism, and a functioning sewage plant. However, the impacted site in the north coast of Helgoland is close to major seabird colonies which nest in the cliffs; there are approximately 1000 pairs of gannets, 3000 of guillemots and 5000 of kittiwakes (Dierschke *et al*., 2018). Thus, the input of nitrogen (as ammonia) can be quite high which is also seen in a permanent band of *Enteromorpha* (*Ulva*) in the upper intertidal and high growth rate of *Fucus*. Additionally, in the intertidal there can be a high deposit of detritus together with silt and sand from abrasion of the soft sandstone, which constitutes another input of nutrients especially when there are also drift algae decomposing when they have been washed onshore after stormy weather (Ralph Kuhlenkamp, pers. comm., January 2021). Thus, naturally occurring high nutrient loads are equally sufficient to trigger a population boom of *B. proboscidea*, and such pressures are not likely to be mitigated.

**United Kingdom:** another dense population has been observed in Tyneside, Northeast England, however no quantitative data are available for this location. Worms were in silty tubes in algal mats on sandstone and also in crevices and boring into sandstone (Radashevsky *et al*., 2019 and personal communication).

Regarding other European locations, the species has been recorded from hard substrata, natural (intertidal rocky shores, boring into rocks) and artificial (piers, groynes, etc), intertidal soft sediment on hard substrata (Radashevsky *et al*., 2019), interstitially among oysters (Wijnhoven *et al*., 2017), and turf but no additional reports of densities or demonstrated impacts were found.

Based on reported values elsewhere in the world, it is estimated that densities in the order of $10^4$-$10^5$ and above may start seriously affecting local biodiversity. Currently, this seems to be the case in Helgoland,
Germany, where there are signs of possible displacement of _P. ciliata_ by high densities of _B. proboscidea_. Based on qualitative observations, it is possible that community impacts as well as structural impacts on soft rock substrates have also occurred in the UK but there is currently no sufficient evidence to quantify their extent and severity. At organically enriched locations, _B. proboscidea_ at moderate densities (e.g. San Sebastian, Spain) may be in competition for space with native mytilids, oysters and barnacles and possibly structuring algae, however no negative effects have been studied or documented to date. _Mytilaster minimus_, a species that rarely occurs outside the Mediterranean (Morton & Puljas, 2018), and is already under competitive pressure by the native _Mytilus galloprovincialis_ and the alien _Brachidontes pharaonis_ (Cinar et al., 2017 and references therein), may be particularly vulnerable to population increases of _B. proboscidea_.

**Qu. 5.3. How important is the potential future impact of the organism on biodiversity at all levels of organisation likely to be in the risk assessment area?**

See comment above. The potential future impact shall be assessed only for the risk assessment area.

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<th>RESPONSE</th>
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Comment: This depends entirely on the densities the species attains in the RA and it is rather difficult to predict with any certainty, especially because incidents of population explosions are linked with localized sources of organic enrichment, even though the species can establish outside polluted sites. Areas where untreated sewage effluents (and even treated wastewater, see Qu 5.1) are discharged into the sea, as well as the immediate vicinity of aquaculture facilities could provide such hot-spots for _B. proboscidea_ proliferation. Intertidal mussel and oyster beds/reefs are important habitats, both ecologically and commercially, and are potentially at risk as they constitute hotspots of introduction. Areas of naturally occurring high nutrient loads, such as rocky shores and cliffs with bird colonies, are also susceptible to the development of invasive populations of _B. proboscidea_, and this can potentially put sensitive habitats at risk (see Qu. 5.5). The fact that, more than 20 years after the first record (1996, documented in Martinez et al., 2006), high population densities have been reported in only two locations, could be due to misidentification with other spionid species or understudied habitats. However, as the species continues spreading in European Seas, particularly the North East Atlantic, and awareness among experts is rising, the likelihood of population explosions occurring and becoming detected is bound to increase (e.g. the recent case of Helgoland, where the species has been present since at least 2008 but high densities and impacts were only reported after 2017). Additionally, under foreseeable climate change conditions, increased frequency and intensity of storms associated with increased coastal erosion and terrigenous inputs, has the potential to create conditions suitable for spionid outbreaks both on cultured and wild populations of bivalves, i.e. high siltation rates and organic matter inputs that can reduce the fitness of the bivalves and promote both infestations and tube-building and smothering by the worms (Ogburn et al., 2007; Clements et al., 2017 and references therein; Jaubet et al., 2018). In this case, population declines of native intertidal species may be evidenced, associated with changes in community structure, as well as structural impacts on both hard and soft substrates. Importantly, the species’ boring activity has the potential to permanently alter soft rock habitats in the RA area, similarly to what was observed in Patagonia, causing irreversible damage to the
substrate with a very high density of burrows, and potentially enhancing erosion processes. See also Qu 5.4-5.5.

The potential future impact on native biodiversity is therefore assessed as major.

**Qu. 5.4. How important is decline in conservation value with regard to European and national nature conservation legislation caused by the organism currently in the risk assessment area?**

including the following elements:

- native species impacted, including red list species, endemic species and species listed in the Birds and Habitats directives
- protected sites impacted, in particular Natura 2000
- habitats impacted, in particular habitats listed in the Habitats Directive, or red list habitats
- the ecological status of water bodies according to the Water Framework Directive and environmental status of the marine environment according to the Marine Strategy Framework Directive

**RESPONSE** moderate  | **CONFIDENCE** low

Comment:

At present, impacts on the conservation value of habitats and species in the RA area have not been quantified, it should be noted however that the rocky littoral of Helgoland is a marine protected area since 1981 and a reference site for ecological comparisons of European rocky shore biotopes (Reichert & Buchholz, 2006). The abrasion platforms of the island, assigned to EUNIS Biotope A4.23 Communities on soft circalittoral rock, are already invaded by high densities of *B. proboscidea*, which is displacing the native spionid *P. ciliata* (see Qu 5.2) and are under an increased risk of bioerosion due to the larger size of the invader (up to 45mm long compared to 1-3mm for the native).

See potentially threatened habitats in the following question

**Qu. 5.5. How important is decline in conservation value with regard to European and national nature conservation legislation caused by the organism likely to be in the future in the risk assessment area?**

including the following elements:

- native species impacted, including red list species and species listed in the Birds and Habitats directives
- protected sites impacted, in particular Natura 2000
- habitats impacted, in particular habitats listed in the Habitats Directive, or red list habitats
the ecological status of water bodies according to the Water Framework Directive and environmental status of the marine environment according to the Marine Strategy Framework Directive

| RESPONSE | major | CONFIDENCE | low |

Comment: The following biotopes and habitats are suitable for colonization by *Boccardia proboscidea* and may be endangered:

• Mussel beds on infralittoral rock are part of the wider Reef NATURA-1170 habitat type (Annex I of the Habitats Directive). The habitat is also part of the Sublittoral rocky seabeds and kelp forests (code 11.24), listed as endangered in the Resolution no. 4 of the Council of Bern Convention (1996) (Salomidi *et al.*, 2012).
• In addition to A4.23 described in the previous question, other biotopes and habitats on infralittoral and circalittoral rock (under EUNIS code A.3 and A.4 respectively), and especially reefs made from soft rock (e.g. chalk reefs along the SE English coast) may be at particular risk of erosion and alteration of the associated communities. Vertical cliffs and gently-sloping intertidal platforms made from chalk support a range of micro-habitats of biological importance and unique faunal communities (OSPAR 2008). Such coastal exposures of chalk are rare in Europe; littoral chalk communities are on the OSPAR List of Threatened and/or Declining Species and Habitats (Fletcher *et al.*, 2012).
• *Ostrea edulis* beds on shallow sublittoral muddy mixed sediment are part of the wider Reef NATURA-1170 habitat type (Annex I of the Habitats Directive). They are included in the European Red List of Habitats as Critically Endangered (EU 2016).
• Infralittoral mussel beds are of conservation concern (Near Threatened to Critically Endangered) across the regional seas.
• In the Mediterranean Sea, both mussel beds A5.6v (*M. galloprovincialis*) and native oyster beds A5.6y (*Ostrea edulis*) are included in the European Red List of Habitats as Vulnerable (EU, 2016).
• In the Black Sea, Pontic *Ostrea edulis* biogenic reefs on mixed and rocky sea bottom qualify for NATURA 2000 habitat type 1170 (Reefs).

Moderate impacts may be expected in mussel and oyster habitats due to the primarily interstitial lifestyle of *B. proboscidea* in the former and its limited boring activity on the latter (see Qu 5.1, 5.2 and 5.9). On the other hand, littoral soft rock (chalk) habitats and their associated communities may be at higher risk of severe damage if infested by high densities of *B. proboscidea*, hence the major score.

Other endangered habitats under the Habitats Directive include: Estuaries-1130, Coastal lagoons-1150, Large shallow inlets-1160 (Natural England 2016).
Ecosystem Services impacts

Qu. 5.6. How important is the impact of the organism on provisioning, regulating, and cultural services in its non-native range excluding the risk assessment area?

- For a list of relevant services use the CICES classification V5.1 provided as an annex.
- Impacts on ecosystem services build on the observed impacts on biodiversity (habitat, species, genetic, functional) but focus exclusively on reflecting these changes in relation to their links with socio-economic well-being.
- Quantitative data should be provided whenever available and references duly reported.
- In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer “No information has been found on the issue”. This is necessary to avoid confusion between “no information found” and “no impact found”.

<table>
<thead>
<tr>
<th>RESPONSE</th>
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<td>CONFIDENCE</td>
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Comment: Boccardia proboscidea infests molluscs (bivalves and gastropods) both in aquaculture systems and in the wild and can thus affect food provisioning services. In Argentina, the native mussel Brachidontes rodriguezii, which is displaced by B. proboscidea, is reportedly subjected to artisanal and recreational hand harvesting (Carranza et al., 2009), however, no impacts on related provisioning services were reported in the series of articles documenting the ecological impact of B. proboscidea on B. rodriguezii communities (Jaubet et al., 2011, 2013, 2015; Garaffo et al., 2012, 2016, 2018; Elías et al., 2015, etc.). This could be attributed to the fact that population explosions of the invasive polychaete occurred at sewage impacted sites that would be unsuitable for mussel harvesting or to the fact that artisanal harvesting of the mussel may not be a widespread activity of high importance. Similarly, infestations of wild oyster populations in Asia and Australia have not been accompanied by ecosystem services impact reports (e.g. Sato-Okoshi, 2000), thus, if food provisioning services are affected, impacts are assumed to be minor. Additionally, the destruction of sedimentary rock and abrasion platforms by the boring activity of B. proboscidea (see Qu 5.1) could have implications for coastal erosion processes in the affected areas.

Impacts on cultivated mollusc populations are addressed in the Economic Impacts section.

Qu. 5.7. How important is the impact of the organism on provisioning, regulating, and cultural services currently in the different biogeographic regions or marine sub-regions where the species has established in the risk assessment area (include any past impact in your response)?

- See guidance to Qu. 5.6.

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<th>RESPONSE</th>
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<td>CONFIDENCE</td>
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Comment: Although no information was found on the issue, at the current reported densities, it is possible that the organism may have caused some impact on regulating ecosystem services (coastal erosion rates) through structural effects on abrasion platforms on Helgoland, Germany. Impacts on food provisioning ecosystem services (i.e. shellfish biomass) through mollusk infestations are not known.

Qu. 5.8. How important is the impact of the organism on provisioning, regulating, and cultural services likely to be in the different biogeographic regions or marine sub-regions where the species can establish in the risk assessment area in the future?

- See guidance to Qu. 5.6.

RESPONSE | moderate | CONFIDENCE | low

Comment: Although no information has been found on the issue, it can be hypothesized that *B. proboscidea* may impact food provisioning services by reducing shellfish biomass harvested from wild populations for direct consumption or use in aquaculture (mussel and oyster seed, to a lesser extent native abalone, juveniles and adults). Coastal erosion processes may also be intensified (Qu 5.6) in high population density areas. The recreational and aesthetical value of rare, rocky intertidal habitats (e.g. see chalk cliffs) may also be impacted, although there are currently no studies quantifying such services or documenting such impacts (Fletcher et al., 2012). In a worst-case scenario, moderate ecosystem services impacts may be envisaged.

See also Economic impacts below

Economic impacts

Qu. 5.9. How great is the overall economic cost caused by the organism within its current area of distribution (excluding the risk assessment area), including both costs of / loss due to damage and the cost of current management.

- Where economic costs of / loss due to the organism have been quantified for a species anywhere in the world these should be reported here. The assessment of the potential costs of / loss due to damage shall describe those costs quantitatively and/or qualitatively depending on what information is available. Cost of / loss due to damage within different economic sectors can be a direct or indirect consequence of the earlier-noted impacts on ecosystem services. In such case, please provide an indication of the interlinkage.

RESPONSE | moderate | CONFIDENCE | low

Comment:
As regards the “low” score for confidence, *B. proboscidea* has been associated with shellfish, both cultivated and in the wild, in various locations around the world. In the literature, *B. proboscidea* in association with molluscs is primarily described as an interstitial species inhabiting burrows in the spaces between bivalves
(e.g. in Argentina, Jaubet et al., 2011) but has also been observed as a secondary borer, inhabiting burrows and blisters of other spionid pests, such as Polydora hoplura and Dipolydora capensis on abalone (works of Simon and colleagues in South Africa; Read, 2004 in New Zealand). It has also been described by Bailey-Brock (2000) as “forming shallow burrows under the lamina of oyster [Ostrea edulis] shell valves” but not penetrating the shell all the way to the interior side of the valve. A similar description was offered by Sato-Okoshi (2000) for B. proboscidea infesting wild Crassostrea gigas from Japan. On the other hand, the species’ ability to bore into soft rock is well documented (Radashevsky et al., 2013); additionally, some spionids behave differently across various regions, boring in shells in one region and not boring, but tube-building, in another, with B. proboscidea suspected to be one of them (Radashevsky & Pankova, 2013). Since the evidence for shell boring behavior of the species is scant (Radashevsky et al., 2019 & personal communication), for the purposes of this RA, it is assumed that B. proboscidea does not currently display this trait on a wide scale, the possibility however remains that this may change in the future.

In South Africa, B. proboscidea is one of the most problematic spionid pests for abalone Haliotis midae aquaculture, infesting most abalone farms, mostly concentrated along the west coast of the country at a mean prevalence of ≈ 61% infested abalone per farm, reaching 100% in some of the farms (Boonzaaier et al., 2014). Intensity of infestation per shell was up to ≈ 90 worms/shell (Simon & Booth, 2007). The species may form burrows on the surface of the shell, in crevices on the shell surface or it may occur in the burrows and blisters of other spionid boring pests. In extreme cases it forms ‘mudpacks’ which are covered with a thin layer of nacreous shell in the region of the respiratory pores. These packs usually contain several worms of different sizes and often cause the shell to break along the respiratory pores.

In New Zealand, it was recorded from living shells of commercial shellfish (abalone Haliotis iris), in shell blisters together with P. hoplura, debri packed, or in shell crevices (Read, 2004).

In Australia, it was found infesting cultured abalone species Haliotis rubra & Haliotis laevigata but was uncommon (Lleonart, 2002).

Monetary values or estimates for the associated damages/losses were not found, however in 2013 South Africa produced 1470 tonnes of H. midae, valued at US$36.31 million (Britz & Venter, 2016), with production projected to increase to 3000 tonnes by 2019 (Britz & Raemaekers, 2015).

Reports of economical losses/damages to cultivated oysters or wild oyster populations due to B. proboscidea were not found.

Monetary values for possible management measures of B. proboscidea (i.e. management of mudworm infestations on cultivated mollusks) could not be found.

**Qu. 5.10. How great is the economic cost of / loss due to damage (excluding costs of management) of the organism currently in the risk assessment area (include any past costs in your response)?**

- Where economic costs of / loss due to the organism have been quantified for a species anywhere in the EU these should be reported here. Assessment of the potential costs of damage on human health, safety, and the economy, including the cost of non-action. A full economic assessment at EU scale might not be possible, but qualitative data or different case studies from across the EU
(or third countries if relevant) may provide useful information to inform decision making. In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer “No information has been found on the issue”. This is necessary to avoid confusion between “no information found” and “no impact found”. Cost of / loss due to damage within different economic sectors can be a direct or indirect consequence of the earlier-noted impacts on ecosystem services. In such case, please provide an indication of the interlinkage.

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<th>RESPONSE</th>
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Comments: Economic impacts in the RA area are anticipated to occur primarily in association with cultivated and/or harvested from the wild populations of oysters *Crassostrea gigas* and *Ostrea edulis*, mussels *Mytilus edulis* and *Mytilus galloprovincialis* and to a lesser extent with the abalone species *Haliotis tuberculata*, which supports both a wild fishery in France and small-scale aquaculture in France and Ireland (Robert *et al*., 2013). Aquaculture production of European abalone *H. tuberculata* is based on hatchery produced spat, however transport of juvenile abalone for on-growing takes place between EU countries (Hannon *et al*., 2013).

Even though *B. proboscidea* has already been recorded from intertidal mussel and oyster beds (e.g. Martinez *et al*., 2006; Wijnhoven *et al*., 2017) and from a cultured oyster shell (Radashevsky *et al*., 2019) in the RA area, no economic impacts are reported to date or are expected to have occurred due to low densities. However, it is important to acknowledge that difficulties in the identification of *Boccardia* species have repeatedly led to misidentifications (e.g. Kerckhof & Faasse, 2014; Radashevsky *et al*., 2019) or delayed identification of spionid worms in the case of commercial shellfish infestations (e.g. Simon *et al*., 2006; Simon & Booth, 2007), such that the species may have been overlooked when evaluating impacts of spionid infestations on cultivated oysters. Even if it does not actively burrow into mollusk shells itself, *B. proboscidea* as a secondary occupant of burrows and blisters of other spionid pests can exacerbate the negative impacts of these infestations which include reduced commercial value, growth rate, meat yield and heavy mortality (Royer *et al*., 2006; Sato-Okoshi *et al*., 2012 and references therein).

**Qu. 5.11. How great is the economic cost of / loss due to damage (excluding costs of management) of the organism likely to be in the future in the risk assessment area?**

- See guidance to Qu. 5.10.

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<th>RESPONSE</th>
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Comments:

With respect to shellfish aquaculture, if *B. proboscidea* infests only the surface of the shells, it will not directly affect the biological performance of cultured shellfish, its mere presence however may have negative impacts on the half-shell oyster industry, reducing the presentation/desirability of oysters and their...
commercial value (Royer et al., 2006). If, on the other hand, the species acts as a secondary borer or assumes self-excavating boring behaviour, potential impacts on shellfish aquaculture can be much more severe (see Qu. 5.10 above), but there is high uncertainty associated with such an eventuality.

Potential impacts may extend to wild abalone and mussel seed populations harvested for commercial purposes, as well as oyster spat collectors in the form of dead oyster shell, which constitute settlement habitat for B. proboscidea larvae.

Finally, under foreseeable climate change conditions, increased frequency and intensity of storms associated with increased coastal erosion and terrigenous inputs, has the potential to create conditions suitable for spionid outbreaks both on cultured and wild populations of bivalves, i.e. high siltation rates and organic matter inputs that can reduce the fitness of the bivalves and promote both infestations and tube-building and smothering by the worms (Ogburn et al., 2007; Clements et al., 2017 and references therein; Jaubet et al., 2018).

**Qu. 5.12. How great are the economic costs / losses associated with managing this organism currently in the risk assessment area (include any past costs in your response)?**

- In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer “No information has been found on the issue”. This is necessary to avoid confusion between “no information found” and “no impact found”.

| RESPONSE   | minimal   | CONFIDENCE | medium |

Comments: No specific management plans are in place for this particular organism in Europe. For marine invasive species introduced by ballast water/hull fouling and aquaculture, there are considerable management measures at various stages of implementation (see also Management Annex). These costs are not specific for B. proboscidea and therefore not included in the score.

**Qu. 5.13. How great are the economic costs / losses associated with managing this organism likely to be in the future in the risk assessment area?**

- See guidance to Qu. 5.12.

| RESPONSE   | moderate  | CONFIDENCE | medium |

Comments: Considerable costs may be expected if the shellfish aquaculture sector is heavily impacted. A ban of imports or restrictions in the movement of shellfish seed/stock could have potentially significant economic implications for shellfish producers (but the alternative of allowing the risk of introduction may
be even more harmful). Taking into consideration that infestations of bivalve stock may occur due to other means, such as settlement by naturally dispersing larvae or larvae transported by ballast water to nearby locations, decisions on potential restrictions of shellfish translocations need also be risk-based with respect to larval dispersal simulations, estimating possible arrival times from known invaded areas, as well as possible introduction hotspots. Nevertheless, due to the high densities *B. proboscidea* can attain on/within bivalve populations, infestations caused by infected stock have the potential to be acute and highly impactful. Thus, where deemed appropriate, translocation restrictions would still be a desirable and effective measure.

Mitigation measures to reduce infestation risk and rates, including manipulating planting shore height (e.g. Handley & Bergquist, 1997) and regular cleaning (Nell, 2007; Haupt et al., 2012; Morse et al., 2015) may alter production costs and profits. See also Management Annex. Using hatchery-produced seed may circumvent infestations on seed collectors and reduce the risk of spread of *B. proboscidea* with stock transfers, but comes at a much higher cost (Kamermans, 2008).

General costs related to the prevention of introduction and spread of all marine NIS are not included in the estimation.

**Social and human health impacts**

<table>
<thead>
<tr>
<th><strong>Qu. 5.14. How important is social, human health or other impact (not directly included in any earlier categories) caused by the organism for the risk assessment area and for third countries, if relevant (e.g. with similar eco-climatic conditions).</strong></th>
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<tbody>
<tr>
<td>The description of the known impact and the assessment of potential future impact on human health, safety and the economy, shall, if relevant, include information on</td>
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<tr>
<td>• illnesses, allergies or other affections to humans that may derive directly or indirectly from a species;</td>
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<tr>
<td>• damages provoked directly or indirectly by a species with consequences for the safety of people, property or infrastructure;</td>
</tr>
<tr>
<td>• direct or indirect disruption of, or other consequences for, an economic or social activity due to the presence of a species.</td>
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</table>

Social and human health impacts can be a direct or indirect consequence of the earlier-noted impacts on ecosystem services. In such case, please provide an indication of the interlinkage.

| **RESPONSE** | minor | **CONFIDENCE** | medium |

Comments: Despite the documented impacts of *B. proboscidea* on cultured abalone in South Africa, the abalone aquaculture industry is still thriving (see Qu. 5.9) and no information on consequent social impacts were found. Moreover, abalone infestations by the organism in recent years seem to be under control by the farmers (Carol Simon, personal communication, June 2019), thus any disruption to socio-economic activities is assumed to have been minor at worst. In the RA area, no information on possible social and
health impacts was found but no substantial impacts are anticipated to have occurred at the present time due to the low densities of *B. proboscidea* (see Qu. 5.2, 5.10).

**Qu. 5.15. How important is social, human health or other impact (not directly included in any earlier categories) caused by the organism in the future for the risk assessment area.**

- In absence of specific studies or other direct evidences this should be clearly stated by using the standard answer “No information has been found on the issue”. This is necessary to avoid confusion between “no information found” and “no impact found”.

| RESPONSE | minor | CONFIDENCE | low |

Comments: If any social impacts occur in the future in the RA area, these are expected to be associated with the disruption of aquaculture activities and, to a lesser extent, the harvesting of wild mollusks. The information currently at hand indicates that any such impacts are not likely to be stronger than minor (i.e. “Mild short-term reversible effects to identifiable groups, localized”).

**Other impacts**

**Qu. 5.16. How important is the impact of the organism as food, a host, a symbiont or a vector for other damaging organisms (e.g. diseases)?**

| RESPONSE | minimal | CONFIDENCE | medium |

Comments: No such impact information has been found in the literature.

**Qu. 5.17. How important might other impacts not already covered by previous questions be resulting from introduction of the organism?**

| RESPONSE | minimal | CONFIDENCE | medium |

Comments: No additional impact information has been found in the literature.
Question 5.18. How important are the expected impacts of the organism despite any natural control by other organisms, such as predators, parasites or pathogens that may already be present in the risk assessment area?

**Response**  moderate  **Confidence**  low

Comments: Information on selective predation, parasitism or pathogens of *B. proboscidea* in the RA area could not be found (but see Qu. 3.5), based however on its invasion history in the RA area and worldwide, the impacts of the species as described in previous sections are not expected to be significantly modified through natural control by other organisms. Besides, its boring behaviour is likely to help the species evade predation.

Question 5.19. Estimate the overall impact in the risk assessment area under current climate conditions. In addition, details of overall impact in relevant biogeographical regions should be provided.

Thorough assessment of the overall impact on biodiversity and ecosystem services, with impacts on economy as well as social and human health as aggravating factors, in current conditions.

**Response**  major  **Confidence**  Low to medium

Comments: At the current reported densities, it is unlikely that the organism will have caused any significant impacts on economic activities (i.e. shellfish culture) in the RA area, although the potential for misidentifications lowers the confidence of this assessment.

Currently, the strongest ecological impacts are reported from Helgoland, Germany, where there are signs of possible displacement of the native polychaete *P. ciliata* by high densities of *B. proboscidea*, as well as concerns about coastal erosion of abrasion platforms by the boring activity of the invader, which has a larger size compared with the native (up to 4.5cm for *B. proboscidea*, up to 3cm for *P. ciliata*).

At organically enriched locations, *B. proboscidea* at moderate densities (e.g. San Sebastian, Spain) may be in competition for space with native mytilids, oysters and barnacles and possibly structuring algae. However, as the species continues spreading in European Seas, particularly the North East Atlantic, the likelihood of population explosions occurring (under current climate conditions) is bound to increase.

Taking into consideration the uncertainties related to predicting population increases of *B. proboscidea*, the species has the potential to cause moderate impacts on biodiversity and ecosystem functioning, particularly in organically enriched areas that favour its proliferation. It can compete for space with native polychaetes, mytilids, oysters and barnacles and possibly structuring algae, and, in a worst-case scenario can smother and displace native species and severely alter native communities. Its boring activity in intertidal firm and hard substrata may have implications for coastal erosion processes, especially in chalk reef habitats, while
its tube-building activities can modify soft-sediment habitats. As a pest on wild and cultivated mollusk populations (mussels, oysters and abalone) and depending on the densities achieved, it can affect food provisioning services and cause moderate losses to the aquaculture industry by reducing the desirability and commercial value of oysters (half-shell market), causing serious infestations on native abalone (which however sustains small scale harvesting and culture operations) and possibly interfering with the development of mussel seed beds and seed collectors of mussels and oysters. As an interstitial species on mussel and oyster beds/reefs it has the potential to disrupt the ecological role of these important habitats.

Due to high summer temperatures, strong localized populations sustained by directly developing (adelphophagic) larvae and commonly associated with bivalve transfers, are more likely to develop in the Mediterranean Sea, while ecosystem functioning and structural impacts on a wider scale may be anticipated in the colder, temperate waters of Atlantic Europe, where the species is already established and natural dispersal of planktotrophic larvae by currents will be stronger.

**Qu. 5.20. Estimate the overall impact in the risk assessment area in foreseeable climate change conditions. In addition, details of overall impact in relevant biogeographical regions should be provided.**

Thorough assessment of the overall impact on biodiversity and ecosystem services, with impacts on economy as well as social and human health as aggravating factors, under future conditions.

| RESPONSE | major | CONFIDENCE | Low to medium |

Comments: Under foreseeable climate change conditions, increased frequency and intensity of storms associated with increased coastal erosion and terrigenous inputs, has the potential to create conditions suitable for spionid outbreaks both on cultured and wild populations of bivalves, i.e. high siltation rates and organic matter inputs that can reduce the fitness of the bivalves and promote both infestations and tube-building and smothering by the worms, thus exacerbating the likelihood of evidencing more serious environmental and socio-economic impacts, than currently demonstrated.

Additionally, a predicted increase in seawater temperatures under foreseeable climate change conditions is anticipated to lead to a northward expansion of the species, reducing the extent of the areas at risk from localized strong populations and associated impacts in the Mediterranean and the Black Sea and increasing the respective risks in Atlantic Europe.
### RISK SUMMARIES

<table>
<thead>
<tr>
<th>Summarise Introduction*</th>
<th>RESPONSE</th>
<th>CONFIDENCE</th>
<th>COMMENT</th>
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<tbody>
<tr>
<td></td>
<td>likely</td>
<td>high</td>
<td>Occurrence of <em>B. proboscidea</em> at locations in the vicinity of ports implies that vessels transfer (either in ballasts or as fouling) is the most plausible pathway of its introduction. Management measures implemented so far (i.e. BWE) have not proven adequate to prevent its introduction in EU marine waters and this will partly continue until the BWMC is fully implemented. On the other hand aquaculture (contaminant on shellfish imported from outside the RA area) is a very likely mode of its introduction but existing management measures scale down this probability. Conclusively vessels are a likely pathway of <em>B. proboscidea</em> introduction, mostly in the North East Atlantic.</td>
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<th>Summarise Entry*</th>
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<th>medium</th>
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| Summarise Establishment*| Very likely | high      | *Boccardia proboscidea* is already established in the Celtic Seas, the Greater North Sea, the Bay of Biscay and the Iberian Coast and further establishment in these regions is considered very likely. In the Baltic Sea the species will be constrained by low salinities and low winter temperatures, while in the Mediterranean Sea high summer temperatures are |
likely to favour more localized populations, sustained by directly developing larvae. In the Black Sea, establishment is considered unlikely due to a combination of high temperatures and low salinities. Future climate conditions are anticipated to lead to a slight northward expansion of the species, very much limiting the areas suitable for establishment in the Mediterranean and the Black Sea.

<table>
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<tr>
<th>Summarise Spread*</th>
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<th>high</th>
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</thead>
</table>
| Unaided dispersal (dispersal of larvae with oceanic currents or rafting on natural debris) and multiple pathways of human-aided spread (by vessels, or as pests on shellfish transports) create a considerable potential for rapid spread, in the order of 103 km within 5 years. Planktonic larvae can be transported via ballast waters of commercial vessels and ferryboats but also through bilge waters of leisure and other small craft, while sessile stages (adults brooding eggs and developing larvae) can be widely transferred within fouling communities of ship hulls as well as with bivalve consignments. Natural dispersal of planktotrophic larvae is more pronounced in Atlantic Europe, where further northward spread is expected under future climate conditions; in the Mediterranean Sea bivalve transfers are likely to be the dominant means of spread, both now and in the future.

<table>
<thead>
<tr>
<th>Summarise Impact*</th>
<th>major</th>
<th>medium</th>
</tr>
</thead>
</table>
| B. proboscidea has the potential to cause major impacts on biodiversity and ecosystem functioning, particularly in organically enriched areas that favour its proliferation. It can compete for space with native mytilids, oysters and barnacles and possibly structuring algae, and, in a worst-case scenario can smother and displace native
species and alternative communities, as evidenced in other parts of the invaded range. Early reports of species displacement and structural impacts on invaded habitats are currently available from Germany and the United Kingdom and potential impacts can be even more serious and irreversible, especially on intertidal soft rock habitats that support unique faunal communities. As a pest on wild and cultivated mollusc populations (mussels, oysters and abalone) it can affect food provisioning services and cause moderate losses to the aquaculture industry.

<table>
<thead>
<tr>
<th>Conclusion of the risk assessment (overall risk)</th>
<th>High</th>
<th>medium</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Boccardia proboscidea</em> is already established in the Celtic Seas, the Greater North Sea, the Bay of Biscay and the Iberian Coast and further establishment in these regions is considered very likely. Apart from natural dispersal, vessel related vectors (ballast &amp; bilge waters, hull fouling) have and will continue to aid spread, primarily in Atlantic Europe, while in the Mediterranean Sea bivalve transfers pose the strongest risk for spread. Being a well-known shellfish pest, it may endanger wild and cultivated mollusc populations, particularly oysters, mussels and abalone. In the wild, impactful densities are more likely to develop in organically enriched locations, with implications for native polychaete, mytilid and algal species and associated communities and the structural integrity of the invaded habitats. Such impacts are already manifested in Germany but will most likely have a localised character. Soft rock habitats (e.g. abrasion platforms, chalk cliffs) that harbor unique biological communities are at particular risk of irreversible damage by the boring activity of <em>B. proboscidea</em>, which may also have</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
implications for coastal erosion processes.

*in current climate conditions and in foreseeable future climate conditions
REFERENCES


Fletcher, S., Saunders, J., Herbert, R., Roberts, C. & Dawson, K. (2012). Description of the ecosystem services provided by broad-scale habitats and features of conservation importance that are likely to be protected by Marine Protected Areas in the Marine Conservation Zone Project area. Natural England Commissioned Reports, Number 088.


OSPAR, 2008. Case Reports for the OSPAR List of Threatened and/or Declining Species and Habitats. OSPAR Commission, London.


Distribution Summary

Please answer as follows:
Yes if recorded, established or invasive
– if not recorded, established or invasive
? Unknown; data deficient

The columns refer to the answers to Questions A5 to A12 under Section A.
For data on marine species at the Member State level, delete Member States that have no marine borders.
In all other cases, provide answers for all columns.

EU Member States and the United Kingdom

<table>
<thead>
<tr>
<th></th>
<th>Recorded</th>
<th>Established (currently)</th>
<th>Possible establishment (under current climate)</th>
<th>Possible establishment (under foreseeable climate)</th>
<th>Invasive (currently)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>-</td>
<td>-</td>
<td>?</td>
<td>?</td>
<td>-</td>
</tr>
<tr>
<td>Croatia</td>
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<td>-</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
</tr>
<tr>
<td>Cyprus</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Denmark</td>
<td>-</td>
<td>-</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
</tr>
<tr>
<td>Estonia</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Finland</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>France</td>
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<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
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<tr>
<td>Germany</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
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<tr>
<td>Greece</td>
<td>-</td>
<td>-</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
</tr>
<tr>
<td>Ireland</td>
<td>YES</td>
<td>-</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
</tr>
<tr>
<td>Italy</td>
<td>-</td>
<td>-</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
</tr>
<tr>
<td>Latvia</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<tr>
<td>Lithuania</td>
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<td>-</td>
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</tr>
<tr>
<td>Malta</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Netherlands</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
</tr>
<tr>
<td>Poland</td>
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<tr>
<td>Portugal</td>
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<td>YES</td>
<td>-</td>
</tr>
<tr>
<td>Romania</td>
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<td>?</td>
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<td>Slovenia</td>
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<td>Spain</td>
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<td>YES</td>
<td>YES</td>
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<tr>
<td>Sweden</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>YES (Skagerrak)</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
</tr>
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</table>
### Marine regions and subregions of the risk assessment area

<table>
<thead>
<tr>
<th>Region</th>
<th>Recorded</th>
<th>Established (currently)</th>
<th>Possible establishment (under current climate)</th>
<th>Possible establishment (under foreseeable climate)</th>
<th>Invasive (currently)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baltic Sea</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Black Sea</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>North-east Atlantic Ocean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bay of Biscay and the Iberian Coast</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>-</td>
</tr>
<tr>
<td>Celtic Sea</td>
<td>YES</td>
<td></td>
<td>YES</td>
<td>YES</td>
<td>-</td>
</tr>
<tr>
<td>Greater North Sea</td>
<td>YES</td>
<td>YES</td>
<td>YES (not in the Kattegat)</td>
<td>YES (not in the Kattegat)</td>
<td>YES</td>
</tr>
<tr>
<td>Adriatic Sea</td>
<td></td>
<td></td>
<td>YES</td>
<td>YES (limited)</td>
<td>-</td>
</tr>
<tr>
<td>Aegean-Levantine Sea</td>
<td></td>
<td></td>
<td>YES</td>
<td>YES (limited)</td>
<td>-</td>
</tr>
<tr>
<td>Ionian Sea and the Central Mediterranean Sea</td>
<td></td>
<td></td>
<td>YES (limited)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Western Mediterranean Sea</td>
<td>?</td>
<td></td>
<td>YES</td>
<td>YES (limited)</td>
<td>-</td>
</tr>
</tbody>
</table>
ANNEX I Scoring of Likelihoods of Events

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very unlikely</td>
<td>This sort of event is theoretically possible, but is never known to have occurred and is not expected to occur</td>
<td>1 in 10,000 years</td>
</tr>
<tr>
<td>Unlikely</td>
<td>This sort of event has not occurred anywhere in living memory</td>
<td>1 in 1,000 years</td>
</tr>
<tr>
<td>Possible</td>
<td>This sort of event has occurred somewhere at least once in recent years, but not locally</td>
<td>1 in 100 years</td>
</tr>
<tr>
<td>Likely</td>
<td>This sort of event has happened on several occasions elsewhere, or on at least one occasion locally in recent years</td>
<td>1 in 10 years</td>
</tr>
<tr>
<td>Very likely</td>
<td>This sort of event happens continually and would be expected to occur</td>
<td>Once a year</td>
</tr>
</tbody>
</table>
## ANNEX II Scoring of Magnitude of Impacts


<table>
<thead>
<tr>
<th>Score</th>
<th>Biodiversity and ecosystem impact</th>
<th>Ecosystem Services impact</th>
<th>Economic impact (Monetary loss and response costs per year)</th>
<th>Social and human health impact, and other impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal</td>
<td>Local, short-term population loss, no significant ecosystem effect</td>
<td>No services affected(^7)</td>
<td>Up to 10,000 Euro</td>
<td>No social disruption. Local, mild, short-term reversible effects to individuals.</td>
</tr>
<tr>
<td>Minor</td>
<td>Some ecosystem impact, reversible changes, localised</td>
<td>Local and temporary, reversible effects to one or few services</td>
<td>10,000-100,000 Euro</td>
<td>Significant concern expressed at local level. Mild short-term reversible effects to identifiable groups, localised.</td>
</tr>
<tr>
<td>Moderate</td>
<td>Measureable long-term damage to populations and ecosystem, but reversible; little spread, no extinction</td>
<td>Measureable, temporary, local and reversible effects on one or several services</td>
<td>100,000-1,000,000 Euro</td>
<td>Temporary changes to normal activities at local level. Minor irreversible effects and/or larger numbers covered by reversible effects, localised.</td>
</tr>
<tr>
<td>Major</td>
<td>Long-term irreversible ecosystem change, spreading beyond local area</td>
<td>Local and irreversible or widespread and reversible effects on one / several services</td>
<td>1,000,000-10,000,000 Euro</td>
<td>Some permanent change of activity locally, concern expressed over wider area. Significant irreversible effects locally or reversible effects over large area.</td>
</tr>
<tr>
<td>Massive</td>
<td>Widespread, long-term population loss or extinction, affecting several species with serious ecosystem effects</td>
<td>Widespread and irreversible effects on one / several services</td>
<td>Above 10,000,000 Euro</td>
<td>Long-term social change, significant loss of employment, migration from affected area. Widespread, severe, long-term, irreversible health effects.</td>
</tr>
</tbody>
</table>

\(^7\) Not to be confused with “no impact”.

---

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ANNEX III Scoring of Confidence Levels
(modified from Bacher et al. 2017)

Each answer provided in the risk assessment must include an assessment of the level of confidence attached to that answer, reflecting the possibility that information needed for the answer is not available or is insufficient or available but conflicting.

The responses in the risk assessment should clearly support the choice of the confidence level.

<table>
<thead>
<tr>
<th>Confidence level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>There is no direct observational evidence to support the assessment, e.g. only inferred data have been used as supporting evidence and/or Impacts are recorded at a spatial scale which is unlikely to be relevant to the assessment area and/or Evidence is poor and difficult to interpret, e.g. because it is strongly ambiguous and/or The information sources are considered to be of low quality or contain information that is unreliable.</td>
</tr>
<tr>
<td>Medium</td>
<td>There is some direct observational evidence to support the assessment, but some information is inferred and/or Impacts are recorded at a small spatial scale, but rescaling of the data to relevant scales of the assessment area is considered reliable, or to embrace little uncertainty and/or The interpretation of the data is to some extent ambiguous or contradictory.</td>
</tr>
<tr>
<td>High</td>
<td>There is direct relevant observational evidence to support the assessment (including causality) and Impacts are recorded at a comparable scale and/or There are reliable/good quality data sources on impacts of the taxa and The interpretation of data/information is straightforward and/or Data/information are not controversial or contradictory.</td>
</tr>
</tbody>
</table>
# ANNEX IV Ecosystem services classification (CICES V5.1, simplified) and examples

For the purposes of this risk assessment, please feel free to use what seems as the most appropriate category / level / combination of impact (Section – Division – Group), reflecting information available.

<table>
<thead>
<tr>
<th>Section</th>
<th>Division</th>
<th>Group</th>
<th>Examples (i.e. relevant CICES “classes”)</th>
</tr>
</thead>
</table>
| Provisioning     | Biomass       | Cultivated terrestrial plants | Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes; Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials); Cultivated plants (including fungi, algae) grown as a source of energy.  
Example: negative impacts of non-native organisms to crops, orchards, timber etc. |
|                  |               | Cultivated aquatic plants     | Plants cultivated by in-situ aquaculture grown for nutritional purposes; Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials); Plants cultivated by in-situ aquaculture grown as an energy source.  
Example: negative impacts of non-native organisms to aquatic plants cultivated for nutrition, gardening etc. purposes. |
|                  |               | Reared animals                | Animals reared for nutritional purposes; Fibres and other materials from reared animals for direct use or processing (excluding genetic materials); Animals reared to provide energy (including mechanical).  
Example: negative impacts of non-native organisms to livestock |
|                  |               | Reared aquatic animals        | Animals reared by in-situ aquaculture for nutritional purposes; Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials); Animals reared by in-situ aquaculture as an energy source  
Example: negative impacts of non-native organisms to fish farming |
|                  |               | Wild plants (terrestrial and aquatic) | Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition; Fibres and other materials from wild plants for direct use or processing (excluding genetic materials); Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy  
Example: reduction in the availability of wild plants (e.g. wild berries, ornamentals) due to non-native organisms (competition, spread of disease etc.). |
|                  |               | Wild animals (terrestrial and aquatic) | Wild animals (terrestrial and aquatic) used for nutritional purposes; Fibres and other materials from wild animals for direct use or processing (excluding genetic materials); Wild animals (terrestrial and aquatic) used as a source of energy.  
Example: reduction in the availability of wild animals (e.g. fish stocks, game) due to non-native organisms (competition, predations, spread of disease etc.). |
<table>
<thead>
<tr>
<th>Genetic material from all biota</th>
<th>Genetic material from plants, algae or fungi</th>
<th>Seeds, spores and other plant materials collected for maintaining or establishing a population; Higher and lower plants (whole organisms) used to breed new strains or varieties; Individual genes extracted from higher and lower plants for the design and construction of new biological entities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genetic material from animals</td>
<td>Animal material collected for the purposes of maintaining or establishing a population; Wild animals (whole organisms) used to breed new strains or varieties; Individual genes extracted from organisms for the design and construction of new biological entities</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Surface water used for nutrition, materials or energy</td>
<td>Surface water for drinking; Surface water used as a material (non-drinking purposes); Freshwater surface water, coastal and marine water used as an energy source</td>
</tr>
<tr>
<td>Ground water used for nutrition, materials or energy</td>
<td>Ground (and subsurface) water for drinking; Ground water (and subsurface) used as a material (non-drinking purposes); Ground water (and subsurface) used as an energy source</td>
<td></td>
</tr>
<tr>
<td>Regulation of physical, chemical, biological conditions</td>
<td>Baseline flows and extreme event regulation</td>
<td>Control of erosion rates; Buffering and attenuation of mass movement; Hydrological cycle and water flow regulation (Including flood control, and coastal protection); Wind protection; Fire protection</td>
</tr>
<tr>
<td>Lifecycle maintenance, habitat</td>
<td>Pollination (or 'gamete' dispersal in a marine context); Seed dispersal;</td>
<td></td>
</tr>
</tbody>
</table>

---

Note: in the CICES classification provisioning of water is considered as an abiotic service whereas the rest of ecosystem services listed here are considered biotic.
and gene pool protection
Maintaining nursery populations and habitats (Including gene pool protection)

Example: changes caused by non-native organisms to the abundance and/or distribution of wild pollinators; changes to the availability / quality of nursery habitats for fisheries

Pest and disease control
Pest control; Disease control

Example: changes caused by non-native organisms to the abundance and/or distribution of pests

Soil quality regulation
Weathering processes and their effect on soil quality; Decomposition and fixing processes and their effect on soil quality

Example: changes caused by non-native organisms to vegetation structure and/or soil fauna leading to reduced soil quality

Water conditions
Regulation of the chemical condition of freshwaters by living processes; Regulation of the chemical condition of salt waters by living processes

Example: changes caused by non-native organisms to buffer strips along water courses that remove nutrients in runoff and/or fish communities that regulate the resilience and resistance of water bodies to eutrophication

Atmospheric composition and conditions
Regulation of chemical composition of atmosphere and oceans; Regulation of temperature and humidity, including ventilation and transpiration

Example: changes caused by non-native organisms to ecosystems’ ability to sequester carbon and/or evaporative cooling (e.g. by urban trees)

Cultural
Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting
Physical and experiential interactions with natural environment

Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions; Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions

Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that make it attractive for recreation, wild life watching etc.

Intellectual and representative interactions with natural environment
Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge; Characteristics of living systems that enable education and training; Characteristics of living systems that are resonant in terms of culture or heritage; Characteristics of living systems that enable aesthetic experiences

Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that have cultural importance

Indirect, remote, often indoor interactions with living systems that do not require Spiritual, symbolic and other interactions with natural environment
Elements of living systems that have symbolic meaning; Elements of living systems that have sacred or religious meaning; Elements of living systems used for entertainment or representation
<table>
<thead>
<tr>
<th>presence in the environmental setting</th>
<th>Example: changes caused by non-native organisms to the qualities of ecosystems (structure, species composition etc.) that have sacred or religious meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other biotic characteristics that have a non-use value</td>
<td>Characteristics or features of living systems that have an existence value; Characteristics or features of living systems that have an option or bequest value</td>
</tr>
<tr>
<td></td>
<td>Example: changes caused by non-native organisms to ecosystems designated as wilderness areas, habitats of endangered species etc.</td>
</tr>
</tbody>
</table>
ANNEX V EU Biogeographic Regions and MSFD Subregions

ANNEX VI Delegated Regulation (EU) 2018/968 of 30 April 2018

Salinity
With respect to salinity, in Australia, the species is established in conditions that range from brackish to fully marine (21 to 34.8 psu) (Coleman & Sinclair, 1996) but in laboratory experiments it has been shown to thrive at high salinities of up to 39-40 psu (Hillyard, 1979). Additionally, peak densities in Argentina were observed at salinities between 15-20 psu (Garaffo et al., 2016), associated with increased organic matter conditions at untreated sewage outflows with high freshwater input. Thus, salinity is not expected to pose limitations to survival and establishment at the range of values encountered in the Black Sea (SSS = Sea Surface Salinity of 14-18 psu) but is very likely to become a prohibitive factor in most of the Baltic with the exception of the westernmost parts of the Western Baltic. A salinity threshold of 15 psu was established for mapping and predictive purposes.

Note: All maps in Annex VII were specifically developed for the purposes of this study.

Figure 1. Yearly average sea surface salinity (SSS) above (blue) and below (red) the salinity threshold (=15 psu) for establishment of *Boccardia proboscidea*. Yellow dots are *B. proboscidea* occurrence records.
**Temperature**

*Boccardia proboscidea* has been recorded from locations with **minimum yearly temperatures** as low as 1.15 °C in northern China (Radashevsky *et al.*, in press) and 2.6 °C in Japan (Imajima & Hartmann, 1956), it is more regularly encountered however at minimum temperatures between 5-7 °C (Argentina, Canada) and in European waters between 3.7-6 °C. Low winter temperatures in the Baltic (besides the salinity limitations) will hamper establishment in the region.

![Figure 2. Minimum yearly sea surface temperature (SST Min) under present conditions above (blue) and below (red) the threshold (=1°C) for establishment of *Boccardia proboscidea*.](image)

With regards to high temperature thresholds, the species can be found in Japan, at locations where average temperature of the warmest month reaches ≈26.5 °C (species records from Abe *et al.*, 2019a; 2019b – all temperature values according to BIO-ORACLE data layers, Assis *et al.*, 2018, URL: [http://www.bio-oracle.org/downloads-to-email.php](http://www.bio-oracle.org/downloads-to-email.php). Present conditions represent the period 2000-2014). Additionally, water temperatures of 24 °C and 28 °C severely reduce the survivorship of planktotrophic and adelphophagic larvae respectively (David and Simon, 2014 - see also Qu 3.9), while at 30 °C embryos do not develop at all (Oyarzun, 2010). The two types of larvae achieve survival optima at different temperatures. At relatively low temperatures (12-17 °C), females release larvae at an earlier stage of development, favouring the survivorship of planktotrophic larvae which manage to escape predation by their adelphophagous siblings (David and Simon, 2014). At higher temperatures, increased developmental rates result in shorter brooding times, increased adelphophagia and higher survivorship of directly developing larvae, potentially leading to strong local populations. For mapping purposes temperature thresholds were determined as follows:
Average temperature of the warmest month

12 °C – the minimum for establishment
12-17 °C – temperatures that favour planktotrophic larvae but do not preclude adelphophages
17-24 °C – temperatures that favour the establishment of both types of larvae
24-26.5 °C – temperatures that favour the establishment of adelphophagic larvae only
> 26.5 °C – prohibitively high for establishment

Accordingly, high summer temperatures in the Levantine and large parts of the Ionian and the Central Mediterranean are expected to limit the species distribution in the Mediterranean Sea to the relatively cooler regions. The Mediterranean Sea in general is more susceptible to invasion by adelphophagic larvae.

It should be noted that the reproductive period for the species lasts around 6 months, between March and September in the northern hemisphere (Oyarzun, 2011; Gibson, 1997), thus temperature thresholds based on maximum yearly temperatures may push the predicted distribution slightly northwards and correspond to shorter reproductive periods.

Future climate conditions are approximated as a rough estimate based on a maximum increase in seawater temperatures of 0.8 °C by 2065, according to the medium timeframe RCP 4.5 scenario (Figure 4). It is evident that warming seas will restrict even more the suitable areas for establishment in the Mediterranean Sea and will cause a northward shift in the potential distribution of the species in Atlantic Europe, accompanied by a wider area that will offer favourable conditions for both types of larvae (green areas).
Figure 4. Same as figure 3 but for temperatures under foreseeable climate conditions (rough estimate based on a maximum increase in seawater temperatures of 0.8 °C by 2065, according to the medium timeframe RCP 4.5 scenario).

**Note for the Black Sea:** the species distribution model (SDM), presented in Annex VIII, predicts a rather low likelihood of occurrence in the Black Sea, limited primarily by low salinities in the region (see map of limiting factors in Annex VIII). It is believed however that the model has a low sensitivity for salinity as a predictive layer due to the resolution of the underlying data layer, which would not pick up local salinity differences (this is the case for example for Argentina, where peak densities were observed at salinities between 15-20 psu (Garaffo *et al*., 2016), associated with increased organic matter conditions at untreated sewage outflows with high freshwater input. The global salinity layer however indicates salinities in the range of 32psu at the same locations.) Maximum summer temperatures in the western Black Sea are very close to the absolute limit we set for establishment and salinities are within the acceptable range for *B. proboscidea* (assumed here as >15psu) in most of the Black Sea and especially the western part (salinity range 14-19psu). In any case, the species will most likely find itself at the edge of its physiological tolerance both in terms of temperature and salinity simultaneously, facing challenging conditions.
As an alternative to using min and max yearly temperatures to estimate the potential distribution of the species, maps are also presented with average yearly temperature (SST Mean) as a “predictor” (Figure 6). Thresholds correspond to the minimum (9 °C) and maximum (22 °C) mean yearly SST values encountered by *B. proboscidea*, based on global occurrence records and BIO-ORACLE2 data layers as above. Green areas represent climatic conditions suitable for establishment.

Figure 5. Top: Same as figure 1 but at the global scale. Bottom: Same as figure 3 but at the global scale.
Figure 6. Top: Average yearly sea surface temperature (SST Mean) above (>22°C in red), below (<9°C in blue) and within (9-22°C in green) the temperatures encountered by *B. proboscidea* in the native and invaded range, according to occurrence records and current climatic conditions, retrieved from BIO-ORACLE for the period 2000-2014. Bottom: Same as the top but for foreseeable climatic conditions, defined as an increase in seawater temperatures of 0.8 °C by 2065, according to the medium timeframe RCP 4.5 scenario.

All the produced maps are only indicative of potential distributions and were used to inform and supplement a Species Distribution Model, presented in Annex VIII.
ANNEX VIII: Projection of climatic suitability for \textit{Boccardia proboscidea} establishment

Björn Beckmann, Marika Galanidi, Argyro Zenetos, Vasily Radashevsky, Beth Purse and Dan Chapman
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\textbf{Aim}

To project the suitability for potential establishment of \textit{Boccardia proboscidea} in Europe, under current and predicted future climatic conditions. The model and all its outputs (Tables and Figures of Annex VIII) were specifically developed during the framework of this study.

\textbf{Data for modelling}

Species occurrence data were provided by the risk assessment team. The records were gridded at a 0.25 x 0.25 degree resolution for modelling, yielding 104 grid cells with occurrences (Figure 1a). As a proxy for recording effort, the density of Polychaeta records held by GBIF was also compiled on the same grid (Figure 1b).

Predictors describing the marine environment were selected from the ‘Bio-ORACLE’ set of GIS rasters providing geophysical, biotic and environmental data for surface and benthic marine realms (Tyberghein et al., 2012, Assis et al. 2017), originally at 5 arcminute resolution (0.083 x 0.083 degrees of longitude/latitude) and aggregated to a 0.25 x 0.25 degree grid for use in the model.

Based on the biology of \textit{Boccardia proboscidea}, the following climate variables were used in the modelling, with all except diffuse attenuation measured at the sea surface:

- Maximum long-term temperature (templtmax\_ss)
- Mean salinity (salinitymean\_ss)
- Mean current velocity (curvelmean\_ss)
- Maximum primary production (ppmax\_ss)
- Mean diffuse attenuation (damean)

To estimate the effect of climate change on the potential distribution of \textit{Boccardia proboscidea}, equivalent modelled future conditions for the 2070s under the Representative Concentration Pathways (RCP) 2.6 and 4.5 were also obtained. These represent low and medium emissions scenarios, respectively. Projections for the 2070s were calculated as averages of projections for the 2040s and 2090s (which are the time periods available on Bio-ORACLE). Future projections are not available for dissolved oxygen concentration, primary production and diffuse attenuation - for these, current values were used.
Species distribution model

A presence-background (presence-only) ensemble modelling strategy was employed using the BIOMOD2 R package v3.3-7.1 (Thuiller et al., 2019, Thuiller et al., 2009). These models contrast the environment at the species’ occurrence locations against a random sample of the global background environmental conditions (often termed ‘pseudo-absences’) in order to characterise and project suitability for occurrence. This approach has been developed for distributions that are in equilibrium with the environment. Because invasive species’ distributions are not at equilibrium and subject to dispersal constraints at a global scale, we took care to minimise the inclusion of locations suitable for the species but where it has not been able to disperse to (Chapman et al. 2019). Therefore, the background sampling region included:
The area accessible by native *Boccardia proboscidea* populations, in which the species is likely to have had sufficient time to disperse to all locations. Based on presumed maximum dispersal distances, the accessible region was defined as a 300km buffer around the native range occurrences; AND

- A 100km buffer around the non-native occurrences, encompassing regions likely to have had high propagule pressure for introduction by humans and/or dispersal of the species; AND

- Regions where we have an *a priori* expectation of high unsuitability for the species so that absence is assumed irrespective of dispersal constraints (see Figure 2). The following rules were applied to define a region expected to be highly unsuitable for *Boccardia proboscidea* at the spatial scale of the model:
  - Minimum long-term temperature (templtmin_ss) < 1.5
  - Maximum long-term temperature (templtmax_ss) > 27.5
  - Mean salinity (salinitymean_ss) < 15

Altogether, 0% of occurrence grid cells were located in the unsuitable background region.

Within the background region, 10 samples of 1000 randomly sampled grid cells were obtained, weighting the sampling by recording effort (Figure 2).

**Figure 2.** The background from which pseudo-absence samples were taken in the modelling of *Boccardia proboscidea*. Samples were taken from a 300km buffer around the native range and a 100km buffer around non-native occurrences (together forming the accessible background), and from areas expected to be highly unsuitable for the species (the unsuitable background region). Samples were weighted by a proxy for recording effort (Figure 1(b)).

Each dataset (i.e. combination of the presences and the individual background samples) was randomly split into 80% for model training and 20% for model evaluation. With each training dataset, seven statistical
algorithms were fitted with the default BIOMOD2 settings and rescaled using logistic regression, except where specified below:

- Generalised linear model (GLM)
- Generalised boosting model (GBM)
- Generalised additive model (GAM) with a maximum of four degrees of freedom per smoothing spline
- Artificial neural network (ANN)
- Multivariate adaptive regression splines (MARS)
- Random forest (RF)
- Maxent

Since the background sample was much larger than the number of occurrences, prevalence fitting weights were applied to give equal overall importance to the occurrences and the background. Normalised variable importance was assessed and variable response functions were produced using BIOMOD2’s default procedure.

Model predictive performance was assessed by the following three measures:

- AUC, the area under the receiver operating characteristic curve (Fielding & Bell 1997). Predictions of presence-absence models can be compared with a subset of records set aside for model evaluation (here 20%) by constructing a confusion matrix with the number of true positive, false positive, false negative and true negative cases. For models generating non-dichotomous scores (as here) a threshold can be applied to transform the scores into a dichotomous set of presence-absence predictions. Two measures that can be derived from the confusion matrix are sensitivity (the proportion of observed presences that are predicted as such, quantifying omission errors), and specificity (the proportion of observed absences that are predicted as such, quantifying commission errors). A receiver operating characteristic (ROC) curve can be constructed by using all possible thresholds to classify the scores into confusion matrices, obtaining sensitivity and specificity for each matrix, and plotting sensitivity against the corresponding proportion of false positives (equal to 1 - specificity). The use of all possible thresholds avoids the need for a selection of a single threshold, which is often arbitrary, and allows appreciation of the trade-off between sensitivity and specificity. The area under the ROC curve (AUC) is often used as a single threshold-independent measure for model performance (Manel, Williams & Ormerod 2001). AUC is the probability that a randomly selected presence has a higher model-predicted suitability than a randomly selected absence (Allouche et al. 2006).

- Cohen’s Kappa (Cohen 1960). This measure corrects the overall accuracy of model predictions (ratio of the sum of true presences plus true absences to the total number of records) by the accuracy expected to occur by chance. The kappa statistic ranges from -1 to +1, where +1 indicates perfect agreement and values of zero or less indicate a performance no better than random. Advantages of kappa are its simplicity, the fact that both commission and omission errors are accounted for in one parameter, and its relative tolerance to zero values in the confusion matrix (Manel, Williams & Ormerod 2001). However, Kappa has been criticised for being sensitive to prevalence (the proportion of sites in which the species was recorded as present) and may therefore be inappropriate.
for comparisons of model accuracy between species or regions (McPherson, Jetz & Rogers 2004, Allouche et al. 2006).

- TSS, the true skill statistic (Allouche et al. 2006). TSS is defined as sensitivity + specificity - 1, and corrects for Kappa’s dependency on prevalence. TSS compares the number of correct forecasts, minus those attributable to random guessing, to that of a hypothetical set of perfect forecasts. Like kappa, TSS takes into account both omission and commission errors, and success as a result of random guessing, and ranges from -1 to +1, where +1 indicates perfect agreement and values of zero or less indicate a performance no better than random (Allouche et al. 2006).

An ensemble model was created by first rejecting poorly performing algorithms with relatively extreme low AUC values and then averaging the predictions of the remaining algorithms, weighted by their AUC. To identify poorly performing algorithms, AUC values were converted into modified z-scores based on their difference to the median and the median absolute deviation across all algorithms (Iglewicz & Hoaglin, 1993). Algorithms with z < -2 were rejected. In this way, ensemble projections were made for each dataset and then averaged to give an overall suitability, as well as its standard deviation. The projections were then classified into suitable and unsuitable regions using the ‘minROCdist’ method, which minimizes the distance between the ROC plot and the upper left corner of the plot (point (0,1)).

We also produced limiting factor maps for Europe following Elith et al. (2010). For this, projections were made separately with each individual variable fixed at a near-optimal value. These were chosen as the median values at the occurrence grid cells. Then, the most strongly limiting factors were identified as the one resulting in the highest increase in suitability in each grid cell.

Results

The ensemble model suggested that suitability for *Boccardia proboscidea* was most strongly determined by Maximum long-term temperature (tempmax_ss), accounting for 72.9% of variation explained, followed by Mean salinity (salinitymean_ss) (14.2%), Mean current velocity (curvelmean_ss) (5.6%), Maximum primary production (ppmax_ss) (5.6%) and Mean diffuse attenuation (damean) (1.7%) (Table 1, Figure 3).
Table 1. Summary of the cross-validation predictive performance (ROC, Kappa, TSS) and variable importance of the fitted model algorithms and the ensemble (AUC-weighted average of the best performing algorithms). Results are the average from models fitted to 10 different background samples of the data.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>AUC</th>
<th>Kappa</th>
<th>TSS</th>
<th>Used in the ensemble</th>
<th>Maximum long-term temperature (templtmax_ss)</th>
<th>Mean salinity (salinitymean_ss)</th>
<th>Mean current velocity (curvelmean_ss)</th>
<th>Maximum primary production (ppmax_ss)</th>
<th>Mean diffuse attenuation (damean)</th>
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<tbody>
<tr>
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<td>0.615</td>
<td>0.844</td>
<td>yes</td>
<td>86.0</td>
<td>4.2</td>
<td>6.9</td>
<td>2.0</td>
<td>1.0</td>
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<tr>
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<td>0.638</td>
<td>0.852</td>
<td>no</td>
<td>76.9</td>
<td>8.2</td>
<td>7.3</td>
<td>6.4</td>
<td>1.2</td>
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<tr>
<td>ANN</td>
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<td>0.655</td>
<td>0.867</td>
<td>yes</td>
<td>72.0</td>
<td>15.7</td>
<td>5.8</td>
<td>4.5</td>
<td>2.1</td>
</tr>
<tr>
<td>GBM</td>
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<td>0.678</td>
<td>0.854</td>
<td>yes</td>
<td>76.3</td>
<td>12.4</td>
<td>6.5</td>
<td>3.6</td>
<td>1.1</td>
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<tr>
<td>MARS</td>
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<td>16.5</td>
<td>5.3</td>
<td>5.0</td>
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<td>12.6</td>
<td>7.8</td>
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<tr>
<td>Ensemble</td>
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<td>0.693</td>
<td>0.869</td>
<td>72.9</td>
<td>14.2</td>
<td>5.6</td>
<td>5.6</td>
<td>1.7</td>
<td></td>
</tr>
</tbody>
</table>
Figure 3. Partial response plots from the fitted models. Thin coloured lines show responses from the algorithms in the ensemble, while the thick black line is their ensemble. In each plot, other model variables are held at their median value in the training data. Some of the divergence among algorithms is because of their different treatment of interactions among variables.
Figure 4. For visualisation, the projection has been aggregated to a 0.5 x 0.5 degree resolution, by taking the maximum suitability of constituent higher resolution grid cells. Values > 0.55 may be suitable for the species. Grey areas have climatic conditions outside the range of the training data and were excluded from the projection. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.
Figure 5. (a) Projected current suitability for *Boccardia proboscidea* establishment in Europe and the Mediterranean region. Grey areas have climatic conditions outside the range of the training data and were excluded from the projection. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.
Figure 6. The most strongly limiting factors for *Boccardia proboscidea* establishment estimated by the model in Europe and the Mediterranean region in current climatic conditions.
Figure 7. (a) Projected suitability for *Boccardia proboscidea* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP2.6, equivalent to Figure 5. Grey areas have climatic conditions outside the range of the training data and were excluded from the projection. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.
Figure 8. (a) Projected suitability for *Boccardia proboscidea* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP4.5, equivalent to Figure 5. Grey areas have climatic conditions outside the range of the training data and were excluded from the projection. (b) Uncertainty in the ensemble projections, expressed as the among-algorithm standard deviation in predicted suitability, averaged across the 10 datasets.
Figure 9. Variation in projected suitability for *Boccardia proboscidea* establishment among marine subregions of Europe (https://www.eea.europa.eu/data-and-maps/data/msfd-regions-and-subregions-1/technical-document/pdf/at_download/file). The bar plots show the proportion of grid cells in each region classified as suitable in the current climate and projected climate for the 2070s under two RCP emissions scenarios. The location of each region is also shown.
Figure 10. Variation in projected suitability for *Boccardia proboscidea* establishment among the 12-nautical-mile national waters of European Union countries. The bar plots show the proportion of grid cells in each country’s waters classified as suitable in the current climate and projected climates for the 2070s under two RCP emissions scenarios.

The predictions from the SDM are in very good agreement with the conclusions drawn from the limiting factor maps of Annex VII. In brief, the model indicates high suitability for establishment of *B. proboscidea* throughout most of Atlantic Europe and in the cooler, northern basins of the Mediterranean Sea under current climate conditions (Figure 5). Limiting factors for establishment are primarily the average temperature of the warmest month (i.e. SST max of Annex VII), especially in the south and east Mediterranean, and salinity in the Black Sea and the Baltic (Figure 6), following our assumptions. Under foreseeable climate conditions (RCP2.6, RCP4.5 for the 2070’s), areas suitable for establishment in the Mediterranean are very much restricted to the eastern Aegean, north-western Adriatic, the Gulf of Lyon and the Alboran Sea (Figures 7 & 8), while a northward shift is evident for the North-East Atlantic.

**Caveats to the modelling**

To remove spatial recording biases, the selection of the background sample was weighted by the density of Polychaeta records on the Global Biodiversity Information Facility (GBIF). While this is preferable to not accounting for recording bias at all, it may not provide the perfect measure of recording bias.

There was substantial variation among modelling algorithms in the partial response plots (Figure 3). In part this will reflect their different treatment of interactions among variables. Since partial plots are made with other variables held at their median, there may be values of a particular variable at which this does not provide a realistic combination of variables to predict from.
Other variables potentially affecting the distribution of the species, such as sea depth were not included in the model.

References