Initial risk assessment under Regulation A-4 of the Ballast Water Management Convention for Belgium using the joint HELCOM/OSPAR Harmonised Procedure

Flanders Marine Institute VLIZ

Beleidsinformerende Nota

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CONTENT OF THE REPORT

Concerns: Database-based risk analyses on the granting of exemptions under Regulation A-4 of the Ballast Water Management Convention, focusing on specific shipping routes (with a Belgian port) based on the expression of interest of particular shipping companies.

Date: 2015

ISSN number: 2295-7464

ISBN number: 978-94-920432-0-7

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Citation:
VLIZ (2015). Beleidsinformerende Nota: Initial risk assessment under Regulation A-4 of the Ballast Water Management Convention for Belgium using the joint HELCOM/OSPAR Harmonised Procedure. *VLIZ Beleidsinformerende nota's BIN 2015_002*. Oostende. 88 pp.

Cover picture: www.green4sea.com

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1. Question

As the conditions required for the entry into force of the *International Convention for the Control and Management of Ships' Ballast Water and Sediments* (2004) (Ballast Water Management Convention; BWMC) are almost fulfilled, there is quite an urgency to move forward with the Belgian exemption procedure (cf. BWMC Regulation A-4). In this framework, the Federal Public Service (FPS) Mobility and Transport asked Flanders Marine Institute (VLIZ) to make a first database-based analyses of species distributions in the ports of interest in order to make an initial risk assessment under Regulation A-4 of the BMWC based on the joint HELCOM/OSPAR binary risk assessment algorithm (cf. HELCOM/OSPAR, 2015). This report discusses all the shipping routes for which the shipping companies expressed their interest for inclusion into the exemption procedure.

2. Ballast Water Management Convention framework

2.1 The BWMC and related regulations

The *International Convention for the Control and Management of Ships' Ballast Water and Sediments* (BWMC) was adopted by the International Maritime Organization (IMO) in 2004 (see also Verleye *et al.,* 2015). The convention aims to prevent the spread of invasive aquatic organisms from one region to another by establishing standards and procedures for the management and control of ships' ballast water and sediments. Invasive (aquatic) species pose different threats to biodiversity and related ecosystem services (alteration of habitats, predation, competition, diseases, etc.), but can also have a significant adverse impact on the economy and human health. Within this respect, the European Union published the *Regulation (EU) No 1143/2014 on the Prevention and Management of the Introduction and Spread of Invasive Alien Species*, also mentioning the importance of the measures formulated by the BWMC. The introduction of non-indigenous species has also been considered as a biological disturbance in the Marine Strategy Framework Directive (2008/56/EC) and introduced as a descriptor for a good environmental status (GES) (e.g. Neyts *et al.,* 2015).

Shipping has been identified as a major pathway for introducing alien species into new environments. Taking into account the increasing volumes of seaborne trade (90% of the international trade of developing countries occurs by sea (UNCTAD 2015)), action is needed. Therefore, BWMC requires all ships in international traffic to manage their ballast water and sediments to a certain standard, according to a ship-specific ballast water and sediments management plan. All ships will also have to carry a ballast water record book and an international ballast water management certificate.

BWMC Regulation A-4 provides the scope to issue exemptions from Regulation B-3 (Ballast Water Management for Ships) and Regulation C-1 (Additional Measures). Regulation A-4 states the following:

1. A Party or Parties, in waters under their jurisdiction, may grant exemptions to any requirements to apply regulations B-3 or C-1, in addition to those exemptions contained elsewhere in this Convention, but only when they are:
    a. granted to a ship or ships on a voyage or voyages between specified ports or locations; or to a ship which operates exclusively between specified ports or locations;
    b. effective for a period of no more than five years subject to intermediate review;
    c. granted to ships that do not mix ballast water or sediments other than between the ports or locations specified in paragraph 1.a;
    d. granted based on the Guidelines on risk assessment developed by the Organization.
2. Exemptions granted pursuant to paragraph 1 shall not be effective until after communication to the Organization and circulation of relevant information to the Parties;
3. Any exemptions granted under this regulation shall not impair or damage the environment, human health, property or resources of adjacent or other States. Any State that the Party determines may be adversely affected shall be consulted, with a view to resolving any identified concerns;
4. Any exemptions granted under this regulation shall be recorded in the Ballast Water record book.

2.2 OSPAR/HELCOM Harmonised Procedure

In accordance with article 13(3) of the convention, which states that Parties shall seek to cooperate with the Parties to regional agreements to develop harmonised procedures, the HELCOM/OSPAR Harmonised Procedure on the granting of exemptions (Regulation A-4) was developed. The Harmonised Procedure can be divided in several sections:

- Port survey protocol (in case no data for a risk assessment is available from official or other sources);
- Target species identification (dynamic list);
- Data storage;
- Risk assessment;
- Decision support tool;
- Administrative procedures.

Both the OSPAR and HELCOM target species lists are included in the annex of the HELCOM/OSPAR Harmonised Procedure. The lists will be updated on a yearly basis to take into account new scientific knowledge and information on the introduction, impact and spread of non-indigenous species. Such lists are one of the key requirements for the risk assessment procedure. The HELCOM/OSPAR risk assessment procedure applies the 'species-specific risk assessment' (see also IMO Guidelines G7) supported with information on environmental conditions and shipping activities. The key risk criteria to distinguish between unacceptable (high) risk and acceptable (low) risk are:

- Presence and abundance of target species in either port/location being visited by the vessel;
- Difference in water salinity between ports/locations being visited;
- Salinity tolerance of target species present.

The risk assessment procedure includes a set of binary questions (yes/no) based on a number of key criteria as mentioned above. The HELCOM/OSPAR risk assessment algorithm includes 3 possible assessments: low risk, medium risk and high risk (figure 1).

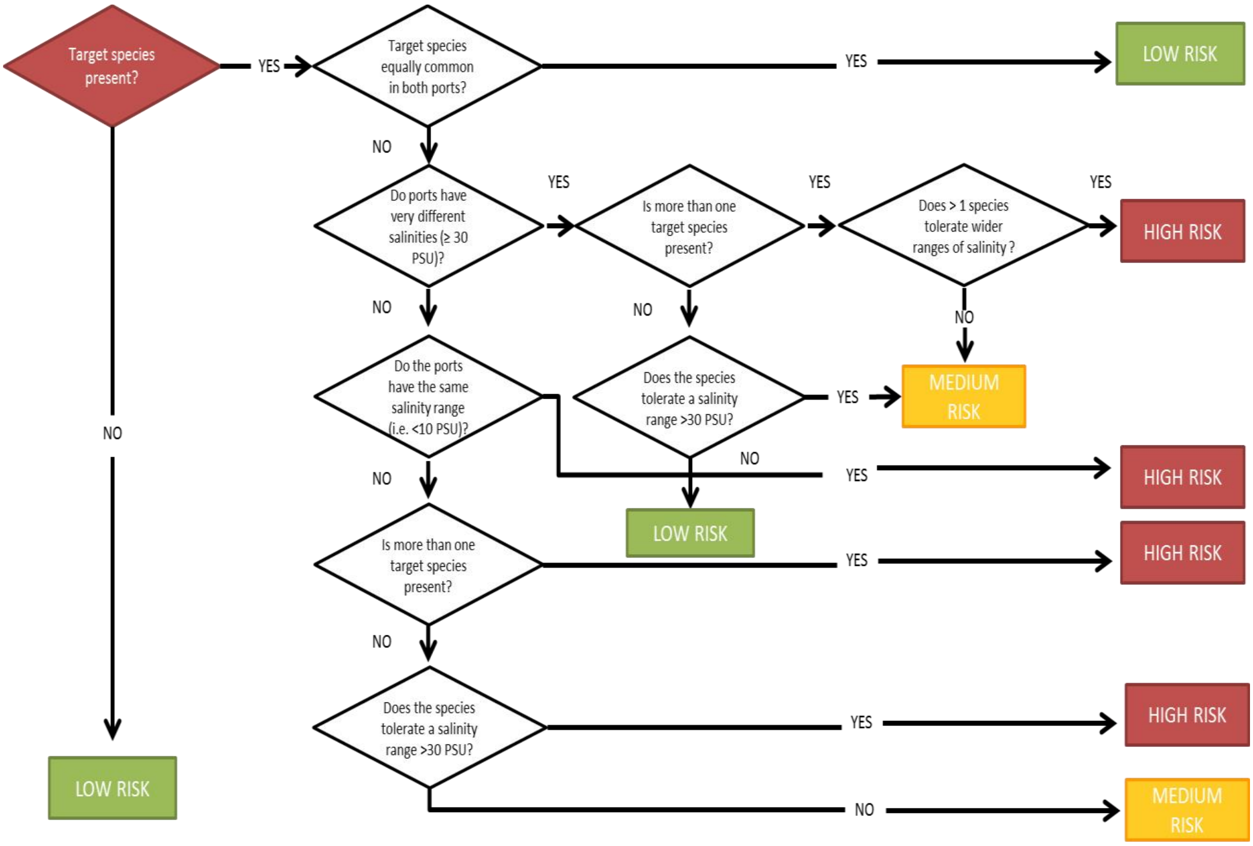

Figure 1. The HELCOM/OSPAR risk assessment algorithm.

The different risk levels are defined as follows (HELCOM/OSPAR 2015):

- **Low risk**
  It is not very likely that target species are distributed with ballast water and occupy a new habitat. The risk is acceptable. **An exemption can be granted**.
- **Medium risk**
  Target species could be distributed with ballast water and might occupy a new habitat. Further review is necessary to evaluate risk. This includes e.g., local conditions in the ports and salinity tolerance, temperature, behaviour as well as dispersal ability/mobility of the species. Negative impacts of related species in other ecosystems are also relevant for this review. **Based on the additional information, a decision must be reached as to whether to grant an exception permit**. Individual mitigation measures other than those defined under the BWMC may be required.
- **High risk**
  It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. **An exemption cannot be granted**.

3. Methodology

3.1 Identification of international shipping routes

Based on the discussions between ship owners and FPS Mobility and Transport, the regular shipping lines for which ship owners would like to apply for an exemption were identified. Those shipping routes are analysed in this report and listed in table 1.

Table 1. Overview of the shipping lines for which ship owners would like to apply for an exemption under Regulation A-4 of the BWMC.

Shipping companies	Belgian port	Foreign port(s)
DFDS	Ghent	Göteborg (Sweden); Brevik (Norway)
DFDS	Zeebrugge	Rosyth (UK)
P&O	Zeebrugge	Hull (UK); Tilbury (UK); Teesport (UK)
CLdN	Zeebrugge	Purfleet (UK); Killingholme (UK); Dublin (Ireland); Göteborg (Sweden); Esbjerg (Denmark); Leixoes (Portugal)
TOYOFUJI	Zeebrugge	Sheerness (UK); Grimsby (UK)

3.2 Target species

The target species considered in this report are those listed in both the OSPAR and HELCOM Target Species Lists. Those include the following species (species in red are not observed in any port of interest):

Acartia tonsa
Alexandrium acatenella
Alexandrium monilatum
Alexandrium ostenfeldii
Amphibalanus eburneus, ex. *Balanus eburnus*
Anadara transversa
Arcuatula senhousia
Asterias amurensis
Austrominus modestus (Elminius modestus)
Brachidontes pharaonis
Callinectes sapidus
Caprella mutica
Caulerpa cylindracea
Caulerpa taxifolia
Cercopagis pengoi
Chama pacifica
Chionoecetes opilio
Corbicula fluminea
Coscinodiscus wailesii
Crassostrea gigas
Crepidula fornicata
Didemnum vexilum
Dikerogammarus villosus
Dinophysis sacculus
Dreissena bugensis
Dreissena polymorpha
Ensis americanus (syn. *E. directus)*
Eriocheir sinensis
Fibrocapsa japonica
Ficopomatus enigmaticus
Gammarus tigrinus
Gracilaria vermiculophylla
Grateloupia doryphora
Grateloupia turuturu
Halophila stipulacea
Hemigrapsus sanguineus
Hemigrapsus takanoi
Hemimysis anomala
Hydroides dianthus
Hydroides elegans
Karenia (syn. *Gymnodinium) mikimotoi*
Lophocladia lallemandii
Marenzelleria neglecta
Marenzelleria viridis
Microcosmus squamiger
Mnemiopsis leidyi
Mytilopsis (syn. *Congeria) leucophaeata*
Mytilus galloprovincialis
Neogobius (syn. *Apollonia) melanostomus*
Palaemon elegans
Palaemon macrodactylus
Paralithodes camtschatica
Pfiesteria piscicida
Phaeocystis pouchetii
Potamocorbula amurensis
Pseudochattonella verruculosa
Rangia cuneata
Rapana venosa
Rhithropanopeus harrisii
Styela clava
Stypopodium schimperi
Undaria pinnatifida

3.3 Target species distribution

The geographical distribution of each target species was analysed using several databases and other information sources (i.e. scientific publications) in order to (1) minimise the occurrence-bias related to the non-randomised distribution of sampling locations within a single database/publication and to (2) take into account the differences in geographical resolution of species distributions in the databases. Due to the latter, species observed in coastal waters near a 'river (estuary) – sea' interface were considered as present in the estuary (and the ports of the estuary) as long as the observed salinity levels fall within the salinity tolerance range of the species, except when scientific publications prove the opposite.

The following databases were consulted:

- LifeWatch (www.lifewatch.be)
- European Marine Data and Information network (EMODnet; www.emodnet-biology.eu)
- European Ocean Biogeographic Information System (EurOBIS; www.eurobis.org)
- World Register for Introduced Marine Species (WRIMS; www.marinespecies.org/introduced)
- Delivering Alien Invasive Species Inventories for Europe (DAISIE; www.europe-aliens.org)
- UK National Biodiversity Network's Gateway (NBN; https://data.nbn.org.uk)

Other information sources include:

- Centre for Agriculture and Biosciences International (CABI) - Invasive Species Compendium (www.cabi.org/isc)
- VLIZ Information sheets on alien species in the Belgian part of the North Sea and adjacent estuaries (www.vliz.be/wiki; Vandepitte *et al.* 2012)
- Scientific publications (table 2)

Table 2. Overview of the scientific publications used to improve the insights on species compositions in the ports, complementing database analyses.

Port	Additional data sources on species occurrences
BEL – Ghent	Boets *et al.* (2011a); Bosveld & Kroes (2011); Vandepitte *et al.* (2012)
BEL – Zeebrugge	Den Hartog (1953); Rullier (1966); Rappé (1989); Leliaert *et al.* (2000); Wouters (2002); d'Udekem d'Acoz *et al.* (2005); De Blauwe (2006); Cook *et al.* (2007); De Blauwe & Dumoulin (2009); Boets (2013)
DEN – Esbjerg	Cook *et al.* (2007); Tendal *et al.* (2008)
IRE – Dublin	Allen *et al.* (2006); Minchin & Holmes (2006); Minchin (2007)
NOR – Brevik	Wrange *et al.* (2009)
POR – Leixoes	Bárbara & Cremades (2004); Davis & Davis (2005) ; Araújo *et al.* (2009)
SWE – Göteborg	Jansson (1994); Jaspers *et al.* (2011); data available in the Risk Assessment Tool HELCOM/OSPAR (Accessed on 4/12/2015)
UK – Rosyth	Meadows (1969)

Based on the available species-specific biogeographical information, the following codes were used to indicated the presence/absence of a particular species in a specific area:

- 1 The species is **present** in the area
- 0 The species is **absent** in the area
- 0/1 **Not clear** whether a species occurs in the area
- 0/1(1) **Highly probable** that the species is **present** in the area
- 0/1(0) **Highly probable** that the species is **absent** in the area

3.4 Target species ecology and effects

Species-specific ecological characteristics, including salinity and temperature tolerances, were analysed based on scientific literature, the CABI Invasive Species Compendium and the VLIZ Information sheets on alien species in the Belgian part of the North Sea and adjacent estuaries. The same sources were used to collect information on the ecological, economic and heath-related impact of the harmful aquatic species. The combination of these data and the data on physical characteristics of the water in the ports (see 3.5) allows a first estimate of the risk for further spread (and the potential impact) of each single species from one port to another. More information regarding the species ecology and species-related impact can be found in '4. Risk assessments for individual shipping routes' and '6. Annex – Target species of interest'.

3.5 Physical characteristics of the water in the ports

For each port, the physical characteristics of the (surface) water were determined based on the available literature. The salinity ranges of the ports are highly important in order to estimate the invasion potential of a single species, based on the species-specific salinity tolerances cf. HELCOM/OSPAR (2015). An overview of the data sources is given in table 3.

Table 3. Overview of the data sources on the salinity ranges of the water in the ports.

Port	Data sources on salinity
BEL – Ghent	Gollasch & Leppäkoski (2007); Boets et al. (2011a); Rijkswaterstaat (Accessed on 26/11/15)
BEL – Zeebrugge	Gollasch & Leppäkoski (2007); BMM (Accessed on 26/11/15)
DEN – Esbjerg	Gollasch & Leppäkoski (2007); BMM (Accessed on 26/11/15)
IRE – Dublin	Dublin waste to energy project (2006); Gollasch & Leppäkoski (2007); Briciu-Burghina & Regan (2012)
NOR – Brevik	Maar et al. (2011); LifeWatch.be data portal (Accessed on 13/11/15)
POR – Leixoes	Gollasch & Leppäkoski (2007); Gollasch (2010)
SWE – Göteborg	Gollasch & Leppäkoski (2007); Maar et al. (2011)
UK – Grimsby	Mallowney (1982); Gollasch & Leppäkoski (2007) ['port-sea' distance calculations based on Google Earth]
UK – Hull	Mallowney (1982); Gollasch & Leppäkoski (2007) ['port-sea' distance calculations based on Google Earth]
UK – Killingholme	Mallowney (1982) ['port-sea' distance calculations based on Google Earth]
UK – Purfleet	Attrill (1998) ['port-sea' distance calculations based on Google Earth]
UK – Rosyth	Forth Replacement Crossing (2009)
UK – Sheerness	Attrill (1998); BMM (Accessed on 26/11/15) ['port-sea' distance calculations based on Google Earth]
UK – Teesport	Gollasch & Leppäkoski (2007)
UK – Tilbury	Attrill (1998); Gollasch & Leppäkoski (2007) ['port-sea' distance calculations based on Google Earth]

4. Risk assessments for individual shipping routes

This chapter discusses the invasion potential of individual species for those shipping routes for which ship owners would like to apply for an exemption under Regulation A-4 of the BWMC (see 3.1). For each trajectory, the target species of interest are identified. The possible ecological, economic and social impacts related to a new introduction are mentioned in short. For a more extended overview of the species characteristics and their potential impacts, see '6. Annex – Targes species of interest'. Furthermore, the HELCOM/OSPAR risk assessment algorithm was applied on the individual trajectories resulting in a specific risk level.

4.1 Ghent (BEL) – Brevik (NOR)

Table 4. Target species present in the port of Ghent and/or Brevik and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Ghent	Brevik	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	0/1 (1)	0	risk	Ghent	0-52	Brevik	25-35	risk
2	*Alexandrium ostenfeldii*	0/1	1	unclear					
3	*Austrominus modestus (Elminius modestus)*	0/1(0)	0/1	unclear					
4	*Callinectes sapidus*	0/1	0	unclear					
5	*Chionoecetes opilio*	0	0/1	unclear					
6	*Corbicula fluminea*	1	0	risk	Ghent	0.16-24	Brevik	25-35	no risk
7	*Coscinodiscus wailesii*	0/1(0)	1	risk	Brevik	25-35	Ghent	1-7	no risk
8	*Crassostrea gigas*	0/1	1	unclear					
9	*Crepidula fornicata*	1	1	no risk					
10	*Dikerogammarus villosus*	1	0	risk	Ghent	0-24	Brevik	25-35	no risk
11	*Dreissena polymorpha*	1	1	no risk					
12	*Ensis americanus (syn. E. directus)*	0/1	1	unclear					
13	*Eriocheir sinensis*	1	1	no risk					
14	*Fibrocapsa japonica*	0/1	0	unclear					
15	*Ficopomatus enigmaticus*	0/1	0/1	unclear					
16	*Gammarus tigrinus*	1	0	risk	Ghent	0.3-29.5	Brevik	25-35	risk
17	*Gracilaria vermiculophylla*	1	0	risk	Ghent	5-60	Brevik	25-35	risk
18	*Grateloupia doryphore*	0/1	0	unclear					
19	*Grateloupia turuturu*	0/1	0	unclear					
20	*Hemigrapsus takanoi*	0/1	1	unclear					
21	*Hemimysis anomala*	0/1	1	unclear					
22	*Hydroides dianthus*	0/1	0	unclear					
23	*Hydroides elegans*	0/1	0	unclear					
24	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1	unclear					
25	*Marenzelleria neglecta*	0/1	1	unclear					
26	*Marenzelleria viridis*	0/1	0	unclear					
27	*Mnemiopsis leidyi*	0/1(0)	0/1	unclear					
28	*Mytilopsis (syn. Congeria) leucophaeata*	1	0	risk	Ghent	0-25	Brevik	25-35	risk
29	*Mytilus galloprovincialis*	0/1	0	unclear					
30	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
31	*Palaemon elegans*	1	1	no risk					
32	*Palaemon macrodactylus*	1	0	risk	Ghent	0.6-48	Brevik	25-35	risk
33	*Pfiesteria piscicida*	0	1	risk	Brevik	2-35	Ghent	1-7	risk
34	*Rangia cuneata*	1	0	risk	Ghent	0-33	Brevik	25-35	risk
35	*Rhithropanopeus harrisii*	1	0	risk	Ghent	0.2-40	Brevik	25-35	risk

General

Based on the species distribution analysis for the trajectory 'Gent – Brevik', 35 target species (15 of which are questionable[1]) are likely present in, or in the immediate vicinity of, one or both ports (table 4). However, more research and/or monitoring is necessary to unravel the questionable occurrences. 4 target species do not pose a threat cf. the HELCOM/OSPAR procedure as they occur in both ports: *Crepidula fornicata, Dreissena polymorpha, Eriocheir sinensis* and *Palaemon elegans*. 11 target species are considered present in only one port and therefore pose an initial threat to the other port. Additionally, the presence/absence of another 21 target species in the ports is unclear. Therefore, some of these 21 target species may pose a secondary risk.

Brevik – Gent

In the port of Brevik, 2 target species may pose an initial threat for invasion to Ghent: *Coscinodiscus wailesii* and *Pfiesteria piscicida*. However, when taking into account the ecological characteristics of *Coscinodiscus wailesii*, it is most unlikely that the species would survive in the port of Ghent due to unsuitable salinity levels. In contrary, *Pfiesteria piscicida* can be considered as a potential invader based on its tolerance ranges for salinity and temperature. The species has been responsible for a number of major fish and shellfish kills, and may therefore impact ecosystem functioning.

Gent – Brevik

In the port of Ghent, 9 target species can be considered as a potential threat for invasion in Brevik; *Acartia tonsa, Corbicula fluminea, Dikerogammarus villosus, Gammarus tigrinus, Gracilaria vermiculophylla, Mytilopsis* (syn. *Congeria*) *leucophaeata, Palaemon macrodactylus, Rangia cuneata* and *Rhithropanopeus harrisii*. As the salinity tolerances of *Corbicula fluminea* and *Dikerogammarus villosus* do not correspond with the physical characteristics of the water in the port of Brevik, it is unlikely that the species would survive.

When considering the salinity tolerances, 7 target species could pose a threat for Brevik. *Gammarus tigrinus*, *Palaemon macrodactylus* and *Acartia tonsa* can outcompete native species (gammarids, copepods and native *Crangon* species, respectively). *Mytilopsis* (syn. *Congeria*) *leucophaeata* and *Rangia cuneata* are biofouling species and may cause problems in intake pipes used in the power and water industries. *Gracilaria vermiculophylla* inhibits the growth and survival of native algae through competition. The latter species is reported to be a problem in fishing industries through fouling of nets. *Rhithropanopeus harrisii* may alter species interactions and cause some economic damage, notably through competition with native species, alteration of food webs and the fouling of water intake pipes.

Risk assessment

Taking into account the physical characteristics of the water in the ports and the salinity tolerances of the species, 9 species can be considered as a potential threat to one of the ports. Therefore, the risk assessment algorithm (figure 2) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Ghent: 1-7 psu)
		(Brevik: 25-35 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	NO	(18 psu)
Is more than one target species present?	YES	(≥20)

[1] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 4. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

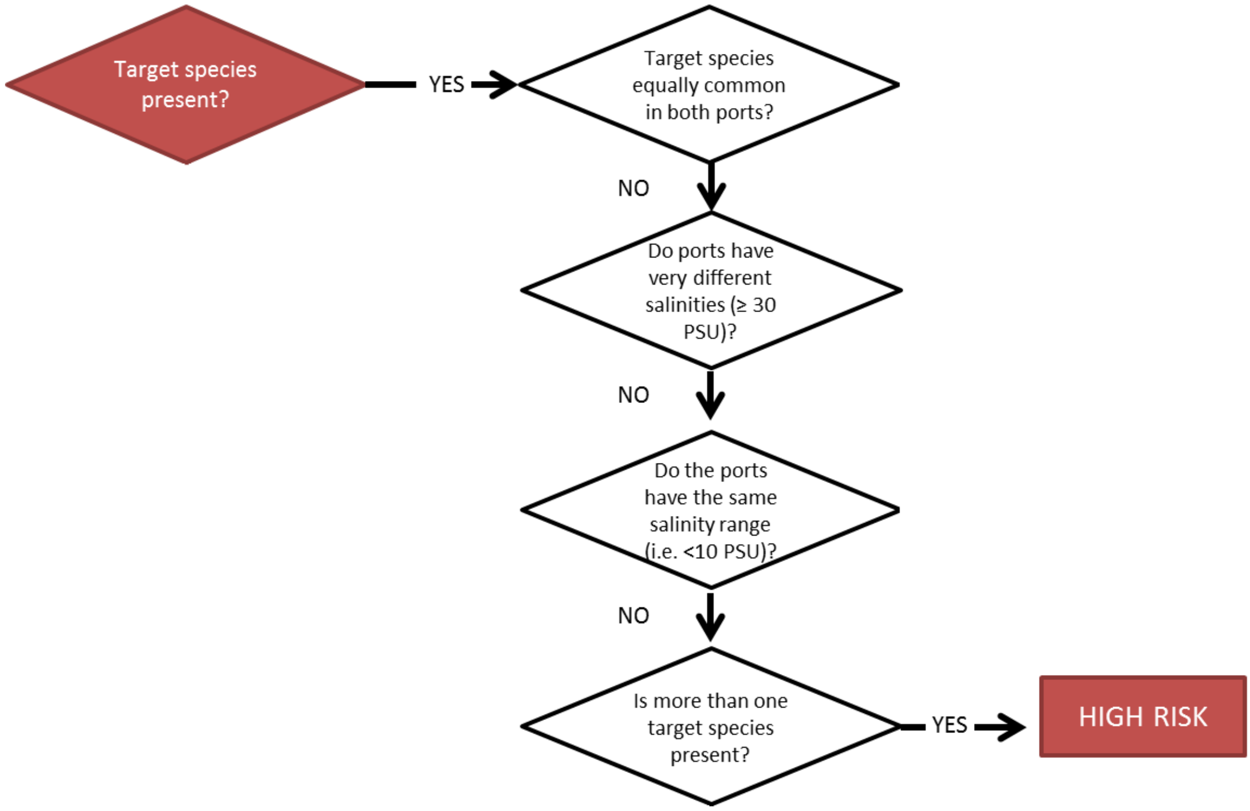

Figure 2. Risk assessment algorithm for the ports of Ghent and Brevik.

4.2 Ghent (BEL) – Göteborg (SWE)

Table 5. Target species present in the port of Ghent and/or Göteborg and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Ghent	Göteborg	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	0/1 (1)	0/1 (1)	no risk					
2	*Alexandrium ostenfeldii*	0/1	0/1 (1)	unclear					
3	*Callinectes sapidus*	0/1	0	unclear					
4	*Corbicula fluminea*	1	0	risk	Ghent	0.16-24	Göteborg	13-25	risk
5	*Coscinodiscus wailesii*	0/1(0)	1	risk	Göteborg	25-35	Ghent	1-7	no risk
6	*Crassostrea gigas*	0/1	1	unclear					
7	*Crepidula fornicata*	1	1	no risk					
8	*Dikerogammarus villosus*	1	0	risk	Ghent	0-24	Göteborg	13-25	risk
9	*Dreissena polymorpha*	1	1	no risk					
10	*Ensis americanus (syn. E. directus)*	0/1	1	unclear					
11	*Eriocheir sinensis*	1	1	no risk					
12	*Fibrocapsa japonica*	0/1	1	unclear					
13	*Ficopomatus enigmaticus*	0/1	0	unclear					
14	*Gammarus tigrinus*	1	0	risk	Ghent	0.3-29.5	Göteborg	13-25	risk
15	*Gracilaria vermiculophylla*	1	1	no risk					
16	*Grateloupia doryphore*	0/1	0	unclear					
17	*Grateloupia turuturu*	0/1	0	unclear					
18	*Hemigrapsus takanoi*	0/1	0/1	unclear					
19	*Hemimysis anomala*	0/1	1	unclear					
20	*Hydroides dianthus*	0/1	0	unclear					
21	*Hydroides elegans*	0/1	0	unclear					
22	*Karenia (syn. Gymnodinium) mikimotoi*	0	1	risk	Göteborg	5-35	Ghent	1-7	risk
23	*Marenzelleria neglecta*	0/1	0/1	unclear					
24	*Marenzelleria viridis*	0/1	1	unclear					
25	*Mnemiopsis leidyi*	0/1(0)	1	risk	Göteborg	4-39	Ghent	1-7	risk
26	*Mytilopsis (syn. Congeria) leucophaeata*	1	0	risk	Ghent	0-25	Göteborg	13-25	risk
27	*Mytilus galloprovincialis*	0/1	0	unclear					
28	*Neogobius (syn. Apollonia) melanostomus*	0/1	1	unclear					
29	*Palaemon elegans*	1	1	no risk					
30	*Palaemon macrodactylus*	1	0	risk	Ghent	0.6-48	Göteborg	13-25	risk
31	*Phaeocystis pouchetii*	0	1	risk	Göteborg	10-40	Ghent	1-7	no risk
32	*Pseudochattonella verruculosa*	0	1	risk	Göteborg	10-35	Ghent	1-7	no risk
33	*Rangia cuneata*	1	0	risk	Ghent	0-33	Göteborg	13-25	risk
34	*Rapana venosa*	0/1	0	unclear					
35	*Rhithropanopeus harrisii*	1	1	no risk					

General

The species distribution analysis for ‘Gent – Göteborg’ points out that 35 target species (12 of which are questionable[2]) are likely present in, or in the immediate vicinity of, one or both ports (table 5). However, further monitoring is necessary to provide more clarity regarding the questionable occurrences. 7 target species seem to occur in both ports and do therefore not pose any threat cf. the HELCOM/OSPAR protocol. Those species are the following: *Acartia tonsa, Crepidula fornicata, Dreissena polymorpha, Eriocheir sinensis, Rhithropanopeus harrisii, Palaemon elegans and Gracilaria vermiculophylla*. On the other hand, 11 target species are considered present in only one port and therefore pose an initial threat for further spread. Additionally, the presence/absence of another 17 target species in the ports cannot be defined with certainty. Some of these 17 target species may pose a secondary risk.

Göteborg – Ghent

In the port of Göteborg, 5 target species can be considered as a potential initial threat to Ghent: *Coscinodiscus wailesii, Karenia (*syn*. Gymnodinium) mikimotoi, Mnemiopsis leidyi, Phaeocystis pouchetii* and *Pseudochattonella verruculosa.* However, literature points out that only *Karenia (*syn*. Gymnodinium) mikimotoi* and *Mnemiopsis leidyi* are able to cope with the salinity levels in the port of Ghent. *Karenia (*syn*. Gymnodinium) mikimotoi* is associated with the production of toxins, hereby they can cause harmfull algal blooms which can result in massive fish mortalities. High abundances of *Mnemiopsis leidyi* can in turn lead to cascading effects at both higher and lower trophic levels.

Ghent – Göteborg

6 target species occurring in the port of Ghent have invasion potential in Göteborg: *Corbicula fluminea, Dikerogammarus villosus, Gammarus tigrinus, Mytilopsis (*syn*. Congeria) leucophaeata, Palaemon macrodactylus* and *Rangia cuneata.* All these 6 species tolerate wide ranges of salinity and can survive in the port of Göteborg on the basis of salinity ranges. *Corbicula fluminea, Mytilopsis (*syn*. Congeria) leucophaeata* and *Rangia cuneata* are biofouling organisms, causing problems in intake pipes used in the power and water industries. Another major concern, in terms of social impact, is *Corbicula fluminea* as a possible vector of diseases. *Dikerogammarus villosus* has largely outcompeted both indigenous and exotic amphipod species in all the European aquatic systems where it has become established. In addition, it readily consumes fish eggs and even attacks fish larvae. Due to its predatory activities, *D. villosus* significantly changes natural food webs of invaded ecosystems and occupies high trophic levels comparable to fish. *Gammarus tigrinus* is able to outcompete many native gammarids and *Palaemon macrodactylus* is thought to be outcompeting native *Crangon* species.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 8 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 3) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Ghent: 1-7 psu)
		(Göteborg: 13-25 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(6 psu)

[2] ‘Questionable occurrences’ are not necessarily the same as ‘Initial risk = unclear’ cf. table 5. If a species is present in one port but its occurrence is doubtful in the other port, the species’ occurrence is not considered questionable as its presence is demonstrated in at least one port.

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

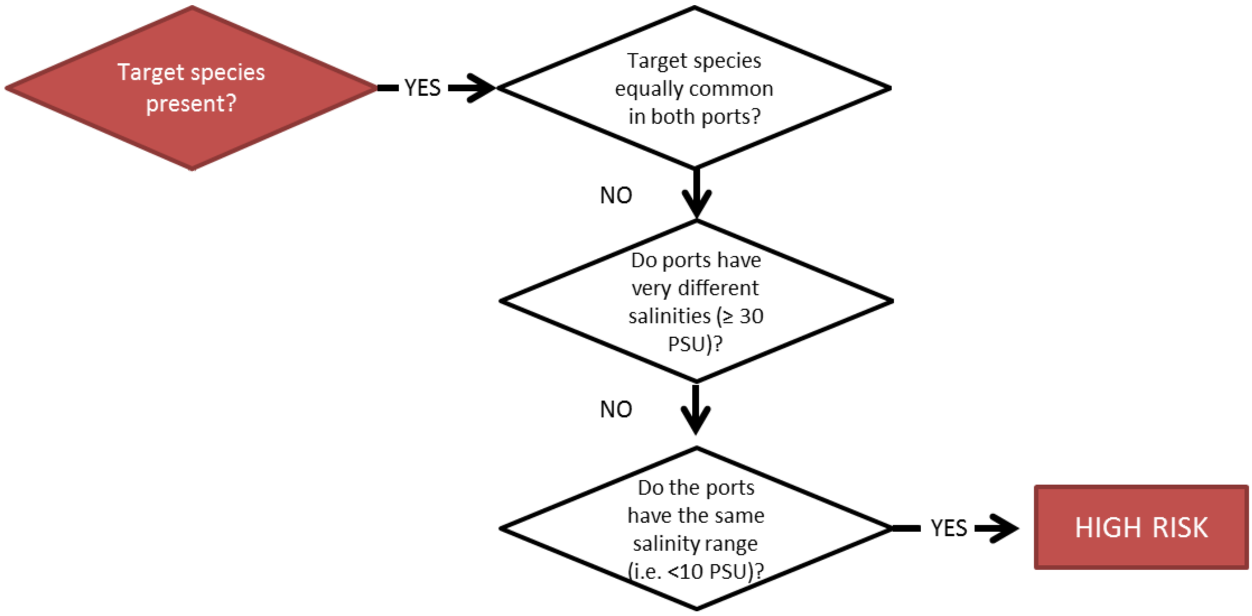

Figure 3. Risk assessment algorithm for the ports of Ghent and Göteborg.

4.3 Zeebrugge (BEL) – Dublin (IRE)

Table 6. Target species present in the port of Zeebrugge and/or Dublin and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Dublin	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0	risk	Zeebrugge	0-52	Dublin	31	risk
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1	unclear					
3	*Austrominus modestus (Elminius modestus)*	1	1	no risk					
4	*Callinectes sapidus*	1	0	risk	Zeebrugge	5-48	Dublin	31	risk
5	*Caprella mutica*	1	1	no risk					
6	*Corbicula fluminea*	0	0/1	unclear					
7	*Coscinodiscus wailesii*	1	1	no risk					
8	*Crassostrea gigas*	1	1	no risk					
9	*Crepidula fornicata*	1	0/1(1)	no risk					
10	*Didemnum vexillum*	0	1	risk	Dublin	20-45	Zeebrugge	30.9-33	risk
11	*Dreissena polymorpha*	1	0/1(1)	no risk					
12	*Ensis americanus (syn. E. directus)*	1	0/1(1)	no risk					
13	*Eriocheir sinensis*	1	0/1	unclear					
14	*Ficopomatus enigmaticus*	1	0/1(1)	no risk					
15	*Gammarus tigrinus*	1	0/1	unclear					
16	*Gracilaria vermiculophylla*	1	0	risk	Zeebrugge	5-60	Dublin	31	risk
17	*Grateloupia doryphore*	0/1	0/1	unclear					
18	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	10-34	Dublin	31	risk
19	*Hemigrapsus takanoi*	1	0	risk	Zeebrugge	7-35	Dublin	31	risk
20	*Hemimysis anomala*	0/1	0/1(1)	unclear					
21	*Hydroides dianthus*	0/1 (1)	0	risk	Zeebrugge	28-50	Dublin	31	risk
22	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1	unclear					
23	*Marenzelleria neglecta*	0/1	0	unclear					
24	*Marenzelleria viridis*	0/1	0	unclear					
25	*Mnemiopsis leidyi*	1	0	risk	Zeebrugge	4-39	Dublin	31	risk
26	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0	unclear					
27	*Mytilus galloprovincialis*	0/1(1)	0	risk	Zeebrugge	9-38	Dublin	31	risk
28	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
29	*Palaemon elegans*	1	1	no risk					
30	*Palaemon macrodactylus*	1	0	risk	Zeebrugge	0.6-48	Dublin	31	risk
31	*Phaeocystis pouchetii*	1	0/1	unclear					
32	*Rangia cuneata*	1	0	risk	Zeebrugge	0-33	Dublin	31	risk
33	*Rapana venosa*	0/1	0	unclear					
34	*Rhithropanopeus harrisii*	1	0	risk	Zeebrugge	0.2-40	Dublin	31	risk
35	*Styela clava*	1	1	no risk					
36	*Undaria pinnatifida*	1	0	risk	Zeebrugge	11-'≥34(?)'	Dublin	31	risk

General

The species distribution analysis for 'Zeebrugge – Dublin' points out that 36 target species (12 of which are questionable[3]) are likely present in, or in the immediate vicinity of, one or both ports (table 6). Further monitoring may provide more clarity regarding the questionable occurrences. 10 species are present in both ports and therefore are excluded from the risk assessment cf. the HELCOM/OSPAR: *Austrominus modestus (Elminius modestus), Caprella mutica, Coscinodiscus wailesii, Crassostrea gigas, Crepidula fornicata, Dreissena polymorpha, Ensis americanus (*syn. *E. directus), Ficopomatus enigmaticus, Palaemon elegans* and *Styela clava.* However, 13 target species are considered present in only one port and therefore pose an initial threat for the other port. Additionally, the presence/absence of another 13 target species in the ports of interest is unclear. Therefore, some of these 13 target species may pose a secondary risk.

Dublin – Zeebrugge

In the port of Dublin, 1 target species can be considered as a potential threat to Zeebrugge: *Didemnum vexillum.* This species is a dominant spatial competitor and can therefore negatively impact the ecosystem.

Zeebrugge – Dublin

In the port of Zeebrugge, 12 target species may pose a threat for invasion in Dublin: *Acartia tonsa, Callinectes sapidus, Gracilaria vermiculophylla, Hemigrapsus sanguineus, Hemigrapsus takanoi, Hydroides dianthus, Mnemiopsis leidyi, Mytilus galloprovincialis, Palaemon macrodactylus, Rangia cuneata, Rhithropanopeus harrisii* and *Undaria pinnatifida.* The salinity ranges in the port of Dublin are suitable for all of these species and therefore they can exert a negative impact. *Acartia tonsa* can outcompete other copepods. *Callinectes sapidus* may mutilate fish caught in traps and trammel nets. As the species prefers to prey on clams, mussels and oysters, it impacts commercial fisheries and aquaculture. *Gracilaria vermiculophylla* inhibits the growth and survival of native algae through competition. Furthermore, this species has been reported to cause problems for the fishing industry through fouling of nets. *Hemigrapsus sanguineus* can exert negative impacts on small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves). The apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* for instance has both ecological and economic implications. *Hemigrapsus takanoi* can outcompete the native European green crab *Carcinus maenas* in Europe. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation. *Hydroides dianthus* and *Rangia cuneata* are biofouling species and cause problems in intake pipes used in the power and water industries. High abundances of *Mnemiopsis leidyi* can cause cascading effects both at higher and lower trophic levels. *Mytilus galloprovincialis* can outcompete and displace native mussels and become the dominant mussel species in certain localities. *Palaemon macrodactylus* is thought to be outcompeting native *Crangon* species but evidence for its impact on native species in other regions is lacking. *Rhithropanopeus harrisii* may alter species interactions and cause some economic damage, notably through competition with native species, alteration of food webs and fouling of water intake pipes. The ecological impact of invasive *Undaria pinnatifida* is spatially variable, in some locations the introduction of the species decreases native species diversity through competition, in other cases *U. pinnatifida* has no impact (likely due to high native diversity), and in a few cases *U. pinnatifida* facilitates native species.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 14 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 4) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

[3] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 6. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Dublin: 31 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(0 psu)

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

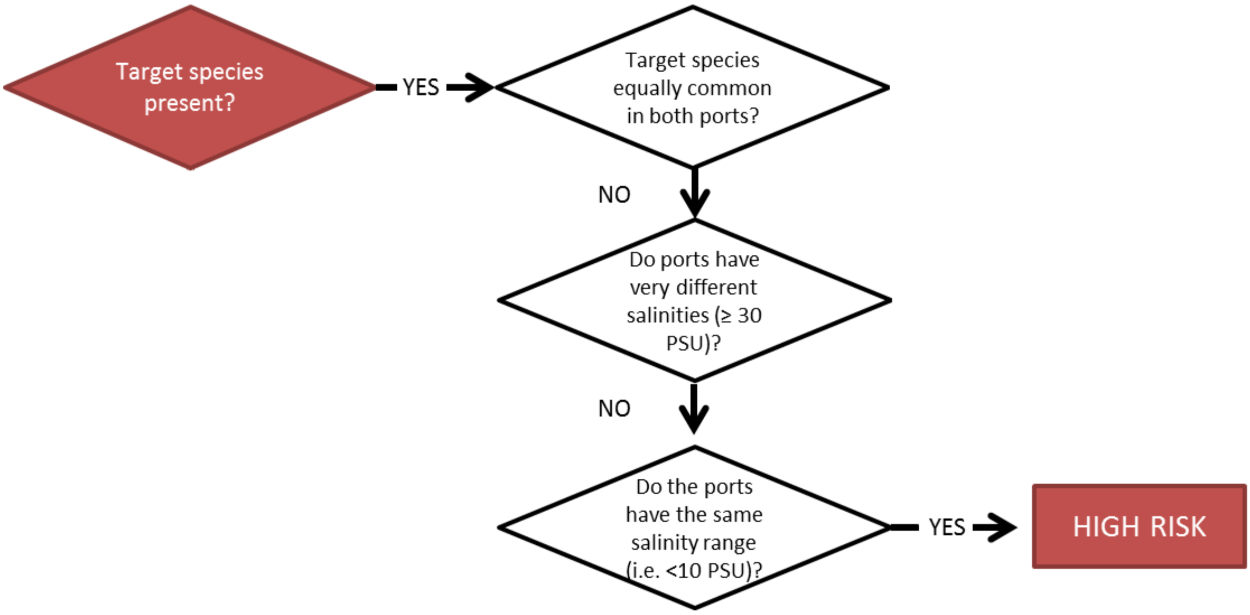

Figure 4. Risk assessment algorithm for the ports of Zeebrugge and Dublin.

4.4 Zeebrugge (BEL) – Esbjerg (DEN)

Table 7. Target species present in the port of Zeebrugge and/or Esbjerg and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Esbjerg	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0/1	unclear					
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1	unclear					
3	*Austrominus modestus (Elminius modestus)*	1	1	no risk					
4	*Callinectes sapidus*	1	1	no risk					
5	*Caprella mutica*	1	0/1	unclear					
6	*Corbicula fluminea*	0	0/1	unclear					
7	*Coscinodiscus wailesii*	1	1	no risk					
8	*Crassostrea gigas*	1	1	no risk					
9	*Crepidula fornicata*	1	1	no risk					
11	*Dinophysis sacculus*	0	0/1	unclear					
12	*Dreissena polymorpha*	1	1	no risk					
13	*Ensis americanus (syn. E. directus)*	1	1	no risk					
14	*Eriocheir sinensis*	1	1	no risk					
15	*Fibrocapsa japonica*	0	1	risk	Esbjerg	11-35	Zeebrugge	30.9-33	risk
16	*Ficopomatus enigmaticus*	1	0/1	unclear					
17	*Gammarus tigrinus*	1	0/1	unclear					
18	*Gracilaria vermiculophylla*	1	1	no risk					
19	*Grateloupia doryphore*	0/1	0/1	unclear					
20	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	10-34	Esbjerg	28	risk
21	*Hemigrapsus takanoi*	1	0	risk	Zeebrugge	7-35	Esbjerg	28	risk
22	*Hemimysis anomala*	0/1	0	unclear					
23	*Hydroides dianthus*	0/1 (1)	0	risk	Zeebrugge	28-50	Esbjerg	28	risk
24	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1(1)	risk	Esbjerg	5-35	Zeebrugge	30.9-33	risk
25	*Marenzelleria neglecta*	0/1	1	unclear					
26	*Marenzelleria viridis*	0/1	1	unclear					
27	*Mnemiopsis leidyi*	1	0/1(1)	no risk					
28	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0/1	unclear					
29	*Mytilus galloprovincialis*	0/1(1)	0	risk	Zeebrugge	9-38	Esbjerg	28	risk
30	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
31	*Palaemon elegans*	1	1	no risk					
32	*Palaemon macrodactylus*	1	0	risk	Zeebrugge	0.6-48	Esbjerg	28	risk
33	*Phaeocystis pouchetii*	1	0/1	unclear					
34	*Pseudochattonella verruculosa*	0	1	risk	Esbjerg	10-35	Zeebrugge	30.9-33	risk
35	*Rangia cuneata*	1	0	risk	Zeebrugge	0-33	Esbjerg	28	risk
36	*Rapana venosa*	0/1	0	unclear					
37	*Rhithropanopeus harrisii*	1	1	no risk					
38	*Styela clava*	1	1	no risk					
39	*Undaria pinnatifida*	1	0/1	unclear					

General

The species distribution analysis for the shipping route 'Zeebrugge – Esbjerg' points out that 39 target species (11 of which are questionable[4]) are likely present in, or in the immediate vicinity of, one or both ports (table 7). Further monitoring is recommended to collect more information on the species-specific distributions. 13 species occur in both ports and are therefore excluded from the risk assessment procedure cf. the HELCOM/OSPAR: *Austrominus modestus (Elminius modestus)*, *Callinectes sapidus*, *Coscinodiscus wailesii*, *Crassostrea gigas*, *Crepidula fornicata*, *Dreissena polymorpha*, *Ensis americanus (*syn. *E. directus)*, *Eriocheir sinensis*, *Gracilaria vermiculophylla*, *Mnemiopsis leidyi*, *Palaemon elegans*, *Rhithropanopeus harrisii* and *Styela clava.* On the other hand, 9 target species seem to be present in only one port. Therefore, the invasion potential of those species is taken into account for the risk assessment procedure. In addition, the presence/absence of another 16 target species in the ports is unclear. Some of these 16 target species may pose a secondary risk.

Esbjerg – Zeebrugge

In the port of Esbjerg, 3 target species can be considered as a potential threat to Zeebrugge: *Fibrocapsa japonica*, *Karenia (*syn. *Gymnodinium) mikimotoi* and *Pseudochattonella verruculosa.* These algae are associated with the production of toxins and are thought to have caused massive fish mortality events.

Zeebrugge – Esbjerg

In the port of Zeebrugge, 6 target species may pose a threat for invasion in Esbjerg: *Hemigrapsus sanguineus, Hemigrapsus takanoi, Hydroides dianthus, Mytilus galloprovincialis, Palaemon macrodactylus* and *Rangia cuneata*. As the salinity tolerances of all of these species do correspond with the salinity range of the water in the port of Esbjerg, it is likely that the species would survive. These 6 target species can have the following negative impact on the ecosystems' ecology, economics and human health: *Hemigrapsus sanguineus* can have negative impacts on small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves). The apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* appeared to have both ecological and economic implications. *Hemigrapsus takanoi* can outcompete the native European green crab *Carcinus maenas* in Europe. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation. *Mytilus galloprovincialis* can outcompete and displace native mussels and become the dominant mussel species in certain localities. *Palaemon macrodactylus* is thought to be outcompeting native *Crangon* species but evidence for its impact on native species in other regions is lacking. *Hydroides dianthus* and *Rangia cuneata* are biofouling species and cause problems in intake pipes used in the power and water industries.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 9 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 5) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Esbjerg: 28 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(2.9 psu)

[4] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 7. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

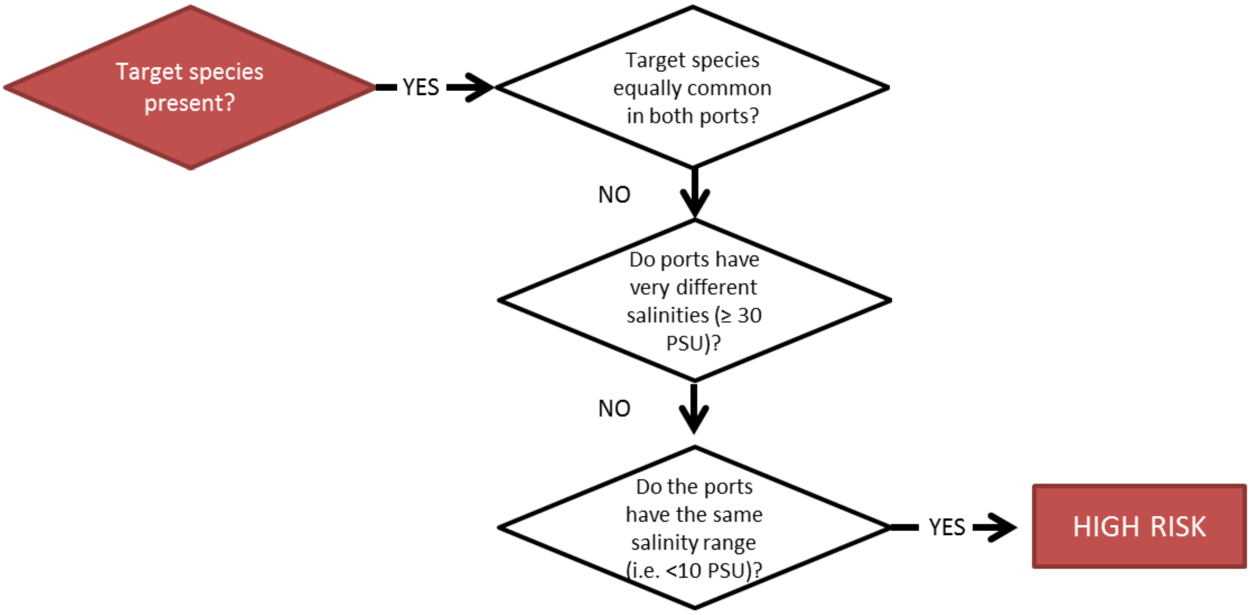

Figure 5. Risk assessment algorithm for the ports of Zeebrugge and Esbjerg.

4.5 Zeebrugge (BEL) – Göteborg (SWE)

Table 8. Target species present in the port of Zeebrugge and/or Göteborg and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Göteborg	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0/1 (1)	no risk					
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1 (1)	no risk					
3	*Austrominus modestus (Elminius modestus)*	1	0	risk	Zeebrugge	19-40	Göteborg	13.1-25	risk
4	*Callinectes sapidus*	1	0	risk	Zeebrugge	5-48	Göteborg	13.1-25	risk
5	*Caprella mutica*	1	0	risk	Zeebrugge	11-40	Göteborg	13.1-25	risk
6	*Coscinodiscus wailesii*	1	1	no risk					
7	*Crassostrea gigas*	1	1	no risk					
8	*Crepidula fornicata*	1	1	no risk					
9	*Dreissena polymorpha*	1	1	no risk					
10	*Ensis americanus (syn. E. directus)*	1	1	no risk					
11	*Eriocheir sinensis*	1	1	no risk					
12	*Fibrocapsa japonica*	0	1	risk	Göteborg	11-35	Zeebrugge	30.9-33	risk
13	*Ficopomatus enigmaticus*	1	0	risk	Zeebrugge	0.2-45	Göteborg	13.1-25	risk
14	*Gammarus tigrinus*	1	0	risk	Zeebrugge	0.3-29.5	Göteborg	13.1-25	risk
15	*Gracilaria vermiculophylla*	1	1	no risk					
16	*Grateloupia doryphora*	0/1	0	unclear					
17	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	25-35	Göteborg	13.1-25	risk
18	*Hemigrapsus takanoi*	1	0/1	unclear					
19	*Hemimysis anomala*	0/1	1	unclear					
20	*Hydroides dianthus*	0/1 (1)	0	risk	Zeebrugge	28-50	Göteborg	13.1-25	no risk
21	*Karenia (syn. Gymnodinium) mikimotoi*	0	1	risk	Göteborg	5-35	Zeebrugge	30.9-33	risk
22	*Marenzelleria neglecta*	0/1	0/1	unclear					
23	*Marenzelleria viridis*	0/1	1	unclear					
24	*Mnemiopsis leidyi*	1	1	no risk					
25	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0	unclear					
26	*Mytilus galloprovincialis*	0/1(1)	0	risk	Zeebrugge	9-38	Göteborg	13.1-25	risk
27	*Neogobius (syn. Apollonia) melanostomus*	0/1	1	unclear					
28	*Palaemon elegans*	1	1	no risk					
29	*Palaemon macrodactylus*	1	0	risk	Zeebrugge	0.6-48	Göteborg	13.1-25	risk
30	*Phaeocystis pouchetii*	1	1	no risk					
31	*Pseudochattonella verruculosa*	0	1	risk	Göteborg	10-35	Zeebrugge	30.9-33	risk
32	*Rangia cuneata*	1	0	risk	Zeebrugge	0-33	Göteborg	13.1-25	risk
33	*Rapana venosa*	0/1	0	unclear					
34	*Rhithropanopeus harrisii*	1	1	no risk					
35	*Styela clava*	1	0	risk	Zeebrugge	22-35	Göteborg	13.1-25	risk
36	*Undaria pinnatifida*	1	0	risk	Zeebrugge	11-'≥34(?)'	Göteborg	13.1-25	risk

General

The species distribution analysis for the shipping route 'Zeebrugge – Göteborg' points out that 36 target species (7 of which are questionable[5]) are likely present in, or in the immediate vicinity of, one or both ports (table 7). Future monitoring activities in the ports can provide more information on the species-specific distributions within each port. 13 species are present in both ports and do therefore not pose a threat cf. the HELCOM/OSPAR risk assessment protocol: *Acartia tonsa, Alexandrium ostenfeldii, Rhithropanopeus harrisii, Gracilaria vermiculophylla, Mnemiopsis leidyi, Palaemon elegans, Phaeocystis pouchetii, Coscinodiscus wailesii, Crassostrea gigas, Crepidula fornicata, Dreissena polymorpha, Ensis americanus (*syn. *E. directus)* and *Eriocheir sinensis.* However, 15 target species are considered present in only one port and should therefore be included into the risk assessment procedure. Additionally, the presence/absence of another 8 target species in the ports is unclear. Some of the latter target species may pose a secondary risk.

Göteborg – Zeebrugge

In the port of Göteborg, 3 target species can be considered as a potential threat to Zeebrugge; *Fibrocapsa japonica*, *Karenia (*syn. *Gymnodinium) mikimotoi* and *Pseudochattonella verruculosa.* These algae are associated with the production of toxins and are thought to have caused massive fish mortality events.

Zeebrugge – Göteborg

In the port of Zeebrugge, 12 target species are present that pose an initial risk for further spread towards Göteborg; *Austrominus modestus (Elminius modestus), Callinectes sapidus, Caprella mutica, Ficopomatus enigmaticus, Gammarus tigrinus, Hemigrapsus sanguineus, Hydroides dianthus, Mytilus galloprovincialis, Palaemon macrodactylus, Rangia cuneata, Styela clava* and *Undaria pinnatifida.* However, the salinity range in the port of Göteborg is too low for *Hydroides dianthus* to survive. The other species (11) are able to survive in Göteborg, based on the salinity range. *Austrominus modestus (Elminius modestus)* competes with a.o. native barnacles, oysters and mussels for food and space, allowing the species to pose a threat to the local native fauna. This species can also cause additional economic problems by fouling on ships (i.e. increasing fuel and maintenance costs). *Callinectes sapidus* mutilate fish caught in traps and trammel nets. As its preferred prey is clams, mussels and oysters, it has an impact on the commercial fisheries and aquaculture industry. Detailed knowledge on community or ecosystem level impacts of *Caprella mutica* is still lacking. *Ficopomatus enigmaticus* is causing important ecological impacts in several regions by modifying the ecosystems' ecological and physical processes. At some locations, an economic impact has been observed due to the prolific growth that can cause blocking of thermal effluents and fouling of aquaculture ponds and leisure crafts. *Gammarus tigrinus* is able to outcompete many native gammarids. *Hemigrapsus sanguineus* is able to achieve extremely high densities. It also occupies habitats very similar to our native mud crabs, overwhelming and dominating their habitat. Therefore, it has the potential to affect populations of native species such as crabs, fish and shellfish by disrupting the food web. For example, the apparent replacement of *Carcinus maenas* by *Hemigrapsus sanguineus* has ecological and economic implications. *Rangia cuneata* is a fouling organism that may kill young oysters by overgrowing them. *Mytilus galloprovincialis* is able to outcompete and displace native mussels and become the dominant mussel species in certain localities. *Palaemon macrodactylus* is thought to be outcompeting native *Crangon* species, but evidence for its impact on native species in other regions is lacking. *Styela clava* can outcompete native organisms for food in the water column. *S. clava* also predates on the larvae of native species causing population declines. It fouls aquaculture, fishing equipment and ship hulls and is difficult to remove. High abundances of *S. clava* may outcompete native species for food. The ecological impact of *Undaria pinnatifida* is spatially variable. In some locations, the introduction of *U. pinnatifica* decreases native species diversity through competition.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 14 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 6) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

[5] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 8. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Göteborg: 13.1-25 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(5.9 psu)

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

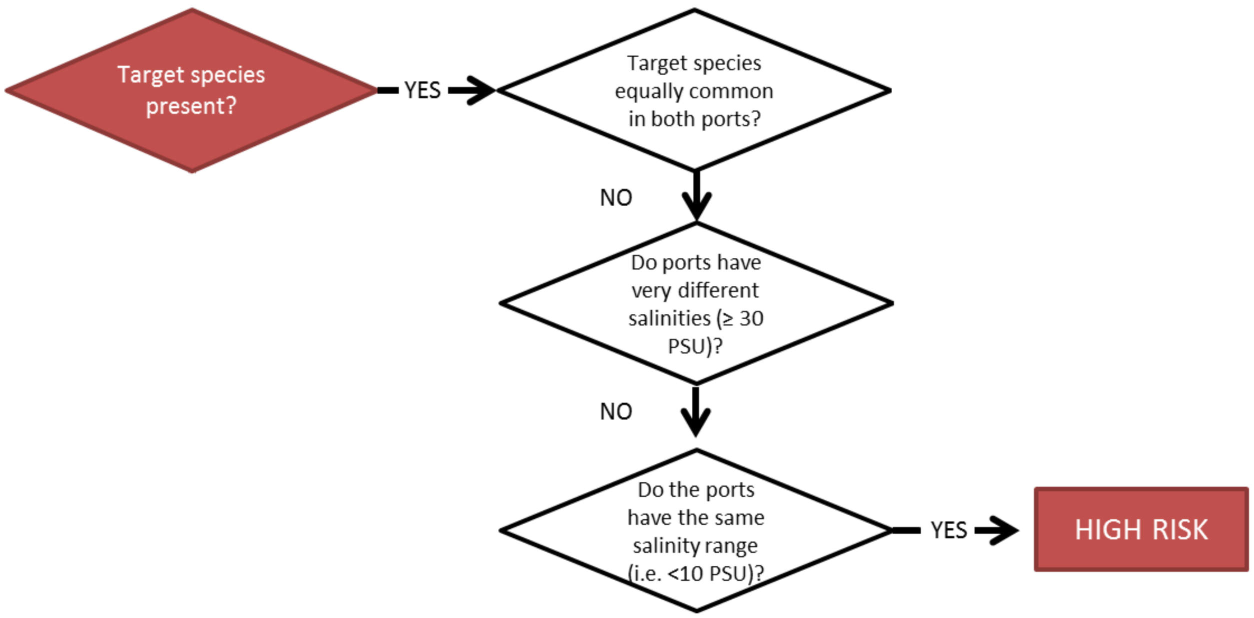

Figure 6. Risk assessment algorithm for the ports of Zeebrugge and Göteborg.

4.6 Zeebrugge (BEL) – Grimsby (UK)

Table 9. Target species present in the port of Zeebrugge and/or Grimsby and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Grimsby	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0/1 (0)	risk	Zeebrugge	0-52	Grimsby	21-30	risk
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1	unclear					
3	*Austrominus modestus (Elminius modestus)*	1	1	no risk					
4	*Callinectes sapidus*	1	1	no risk					
5	*Caprella mutica*	1	1	no risk					
6	*Corbicula fluminea*	0	0/1	unclear					
7	*Coscinodiscus wailesii*	1	1	no risk					
8	*Crassostrea gigas*	1	1	no risk					
9	*Crepidula fornicata*	1	0/1	unclear					
10	*Didemnum vexillum*	0	0/1	unclear					
11	*Dreissena polymorpha*	1	1	no risk					
12	*Ensis americanus (syn. E. directus)*	1	1	no risk					
13	*Eriocheir sinensis*	1	1	no risk					
14	*Ficopomatus enigmaticus*	1	0/1	unclear					
15	*Gammarus tigrinus*	1	1	no risk					
16	*Gracilaria vermiculophylla*	1	0	risk	Zeebrugge	5-60	Grimsby	21-30	risk
17	*Grateloupia doryphore*	0/1	0/1	unclear					
18	*Grateloupia turuturu*	0	0/1	unclear					
19	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	10-34	Grimsby	21-30	risk
20	*Hemigrapsus takanoi*	1	0	risk	Zeebrugge	7-35	Grimsby	21-30	risk
21	*Hemimysis anomala*	0/1	0/1	unclear					
22	*Hydroides dianthus*	0/1 (1)	0/1	unclear					
23	*Hydroides elegans*	0/1 (0)	0/1	unclear					
24	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1	unclear					
25	*Marenzelleria neglecta*	0/1	0/1	unclear					
26	*Marenzelleria viridis*	0/1	0/1	unclear					
27	*Mnemiopsis leidyi*	1	0	risk	Zeebrugge	4-39	Grimsby	21-30	risk
28	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0/1	unclear					
29	*Mytilus galloprovincialis*	0/1(1)	0	risk	Zeebrugge	9-'≥38(?)'	Grimsby	21-30	risk
30	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
31	*Palaemon elegans*	1	0/1	unclear					
32	*Palaemon macrodactylus*	1	0/1	unclear					
33	*Phaeocystis pouchetii*	1	0/1	unclear					
34	*Rangia cuneata*	0/1	0	unclear					
35	*Rapana venosa*	0/1	0	unclear					
36	*Rhithropanopeus harrisii*	1	0/1	unclear					
37	*Styela clava*	1	1	no risk					
38	*Undaria pinnatifida*	1	1	no risk					

General

The species distribution analysis for the shipping route 'Zeebrugge – Grimsby' points out that 38 target species (16 of which are questionable[6]) are likely present in, or in the immediate vicinity of, one or both ports (table 9). Future monitoring activities in the ports can provide more information on the species-specific distributions within each port. 11 target species do not pose a threat cf. the HELCOM/OSPAR procedure as they are present in both ports: *Austrominus modestus (Elminius modestus), Callinectes sapidus, Caprella mutica, Coscinodiscus wailesii, Crassostrea gigas, Dreissena polymorpha, Ensis americanus (*syn*. E. directus), Eriocheir sinensis, Gammarus tigrinus, Styela clava* and *Undaria pinnatifida*. 6 target species are considered present in only one port and therefore pose an initial threat for the other port. Furthermore, the presence/absence of another 21 target species in the ports is unclear. Some of these 21 target species may pose an additional risk.

Grimsby – Zeebrugge

In the port of Grimsby, no target species are considered as a potential threat to Zeebrugge.

Zeebrugge – Grimsby

In the port of Zeebrugge, 6 target species may pose a threat for invasion in Grimsby, all having a wide salinity tolerance range: *Acartia tonsa, Gracilaria vermiculophylla, Hemigrapsus sanguineus, Hemigrapsus takanoi, Mnemiopsis leidyi* and *Mytilus galloprovincialis. Acartia tonsa* can outcompete other copepods. *Gracilaria vermiculophylla* inhibits the growth and survival of native algae through competition. Furthermore, this species impacts the fishing industry through the fouling of nets. *Hemigrapsus sanguineus* can exert a negative impact on small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves). The apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* has both ecological and economic implications. *Hemigrapsus takanoi* can outcompete the native European green crab *Carcinus maenas* in Europe. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation. Very high abundances of *Mnemiopsis leidyi* may induce cascading effects at both higher and lower trophic levels. *Mytilus galloprovincialis* can outcompete and displace native mussels and become the dominant mussel species in certain localities. *Palaemon macrodactylus* is thought to be out-competing native *Crangon* species but evidence for its impact on native species in other regions is lacking.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 6 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 7) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Grimsby: 21-30 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(0.9 psu)

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

[6] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 9. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

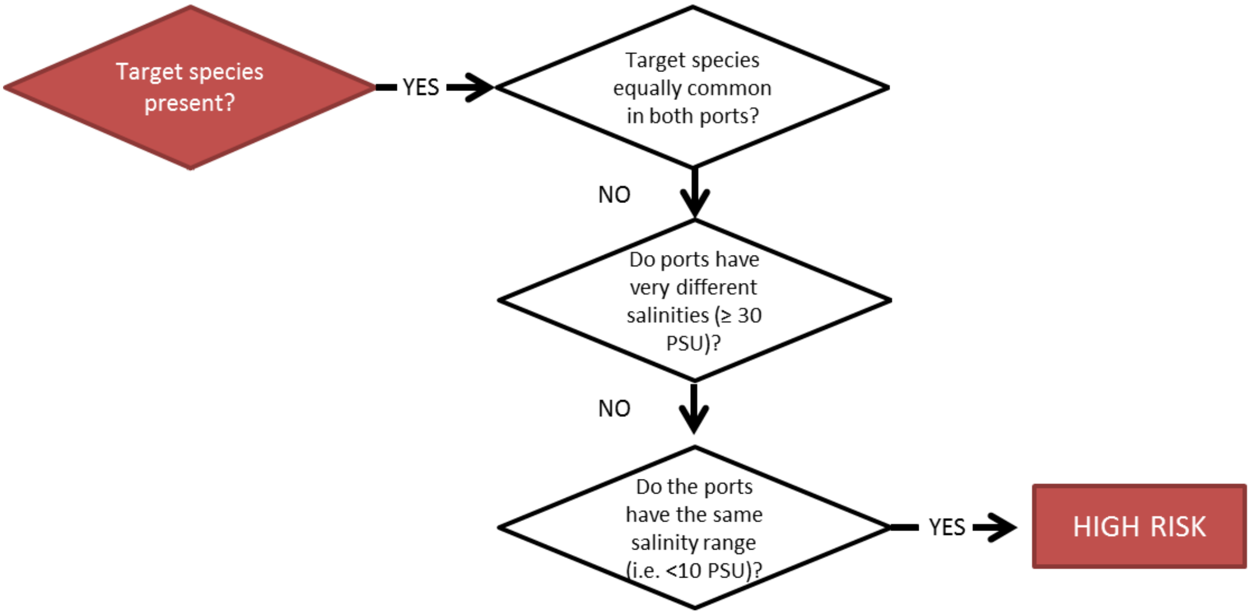

Figure 7. Risk assessment algorithm for the ports of Zeebrugge and Grimsby.

4.7 Zeebrugge (BEL) – Hull (UK)

Table 10. Target species present in the port of Zeebrugge and/or Hull and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Hull	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0/1 (0)	risk	Zeebrugge	0-52	Hull	15-22	risk
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1	unclear					
3	*Austrominus modestus (Elminius modestus)*	1	1	no risk					
4	*Callinectes sapidus*	1	1	no risk					
5	*Caprella mutica*	1	1	no risk					
6	*Corbicula fluminea*	0	0/1	unclear					
7	*Coscinodiscus wailesii*	1	1	no risk					
8	*Crassostrea gigas*	1	0/1	unclear					
9	*Crepidula fornicata*	1	0/1	unclear					
10	*Didemnum vexillum*	0	0/1	unclear					
11	*Dreissena polymorpha*	1	1	no risk					
12	*Ensis americanus (syn. E. directus)*	1	0/1	unclear					
13	*Eriocheir sinensis*	1	1	no risk					
14	*Ficopomatus enigmaticus*	1	1	no risk					
15	*Gammarus tigrinus*	1	0/1	unclear					
16	*Gracilaria vermiculophylla*	1	0	risk	Zeebrugge	5-60	Hull	15-22	risk
17	*Grateloupia doryphore*	0/1	0/1	unclear					
18	*Grateloupia turuturu*	0	0/1	unclear					
19	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	10-34	Hull	15-22	risk
20	*Hemigrapsus takanoi*	1	0	risk	Zeebrugge	7-35	Hull	15-22	risk
21	*Hemimysis anomala*	0/1	0/1	unclear					
22	*Hydroides dianthus*	0/1 (1)	0/1	unclear					
23	*Hydroides elegans*	0/1 (0)	0/1	unclear					
24	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1	unclear					
25	*Marenzelleria neglecta*	0/1	0/1	unclear					
26	*Marenzelleria viridis*	0/1	0/1	unclear					
27	*Mnemiopsis leidyi*	1	0	risk	Zeebrugge	4-39	Hull	15-22	risk
28	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0/1	unclear					
29	*Mytilus galloprovincialis*	0/1(1)	0	risk	Zeebrugge	9-'≥38(?)'	Hull	15-22	risk
30	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
31	*Palaemon elegans*	1	0/1	unclear					
32	*Palaemon macrodactylus*	1	0/1	unclear					
33	*Phaeocystis pouchetii*	1	0	risk	Zeebrugge	10-40	Hull	15-22	risk
34	*Rangia cuneata*	1	0	risk	Zeebrugge	0-33	Hull	15-22	risk
35	*Rapana venosa*	0/1	0	unclear					
36	*Rhithropanopeus harrisii*	1	0/1	unclear					
37	*Styela clava*	1	0/1(1)	no risk					
38	*Undaria pinnatifida*	1	0/1	unclear					

General

Based on the species distribution analysis for the trajectory 'Zeebrugge – Hull', 38 target species (15 of which are questionable[7]) are likely present in, or in the immediate vicinity of, one or both ports (table 10). However, more research and/or monitoring is necessary to unravel the questionable occurrences. 8 target species do not pose a threat cf. the HELCOM/OSPAR procedure as they occur in both ports: *Austrominus modestus (Elminius modestus), Callinectes sapidus, Caprella mutica, Coscinodiscus wailesii, Dreissena polymorpha, Eriocheir sinensis, Ficopomatus enigmaticus* and *Styela clava.* However, 8 target species are considered present in only one port and therefore pose an initial threat for the other port. Additionally, the presence/absence of another 22 target species in the ports is questionable. Some of these 22 target species may therefore pose a secondary risk.

Hull – Zeebrugge

No target species are present in the port of Hull which may be introduced to Zeebrugge.

Zeebrugge – Hull

In the port of Zeebrugge, 8 target species can be considered as a potential threat for invasion in Hull: *Acartia tonsa, Gracilaria vermiculophylla, Hemigrapsus sanguineus, Hemigrapsus takanoi, Mnemiopsis leidyi, Mytilus galloprovincialis, Phaeocystis pouchetii* and *Rangia cuneata.* All of these species can cope with the salinity range within the port of Hull. *Acartia tonsa* can outcompete other copepods. *Gracilaria vermiculophylla* inhibits the growth and survival of native algae through competition. This species also causes problems for the fishing industry through the fouling of fishing nets. *Hemigrapsus sanguineus* can have negative impacts on small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves). The apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* has ecological and economic implications. *Hemigrapsus takanoi* can outcompete the native European green crab *Carcinus maenas* in Europe. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation. *Mnemiopsis leidyi* may impact both higher and lower trophic levels (cascading effects) if present in high abundances. *Mytilus galloprovincialis* can outcompete and displace native mussels and become the dominant mussel species in certain localities. *Phaeocystis pouchetii* has been found to be toxic to cod larvae in Norway. *Rangia cuneata* is a biofouling species and can cause problems in intake pipes used in the power and water industries.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 8 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 8) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Hull: 15-22 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(8.9 psu)

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

[7] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 10. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

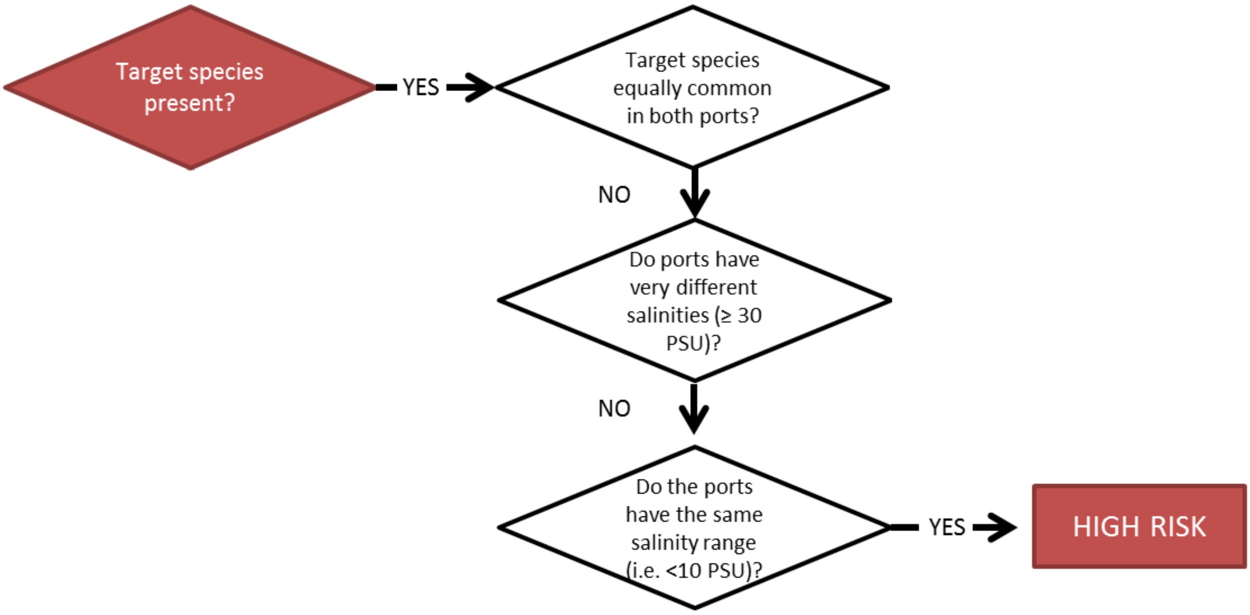

Figure 8. Risk assessment algorithm for the ports of Zeebrugge and Hull.

4.8 Zeebrugge (BEL) – Killingholme (UK)

Table 11. Target species present in the port of Zeebrugge and/or Killingholme and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Killingholme	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0/1 (0)	risk	Zeebrugge	0-52	Killingholme	27	risk
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1	unclear					
3	*Austrominus modestus (Elminius modestus)*	1	1	no risk					
4	*Callinectes sapidus*	1	1	no risk					
5	*Caprella mutica*	1	1	no risk					
6	*Corbicula fluminea*	0	0/1	unclear					
7	*Coscinodiscus wailesii*	1	1	no risk					
8	*Crassostrea gigas*	1	0/1	unclear					
9	*Crepidula fornicata*	1	0/1	unclear					
10	*Didemnum vexillum*	0	0/1	unclear					
11	*Dreissena polymorpha*	1	1	no risk					
12	*Ensis americanus (syn. E. directus)*	1	0/1	unclear					
13	*Eriocheir sinensis*	1	1	no risk					
14	*Ficopomatus enigmaticus*	1	0/1	unclear					
15	*Gammarus tigrinus*	1	0/1	unclear					
16	*Gracilaria vermiculophylla*	1	0	risk	Zeebrugge	5-60	Killingholme	27	risk
17	*Grateloupia doryphore*	0/1	0/1	unclear					
18	*Grateloupia turuturu*	0	0/1	unclear					
19	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	10-34	Killingholme	27	risk
20	*Hemigrapsus takanoi*	1	0	risk	Zeebrugge	7-35	Killingholme	27	risk
21	*Hemimysis anomala*	0/1	0/1	unclear					
22	*Hydroides dianthus*	0/1 (1)	0/1	unclear					
23	*Hydroides elegans*	0/1 (0)	0/1	unclear					
24	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1	unclear					
25	*Marenzelleria neglecta*	0/1	0/1	unclear					
26	*Marenzelleria viridis*	0/1	0/1	unclear					
27	*Mnemiopsis leidyi*	1	0	risk	Zeebrugge	4-39	Killingholme	27	risk
28	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0/1	unclear					
29	*Mytilus galloprovincialis*	0/1(1)	0	risk	Zeebrugge	9-'≥38(?)'	Killingholme	27	risk
30	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
31	*Palaemon elegans*	1	0/1	unclear					
32	*Palaemon macrodactylus*	1	0/1	unclear					
33	*Phaeocystis pouchetii*	1	0	risk	Zeebrugge	10-40	Killingholme	27	risk
34	*Rangia cuneata*	1	0	risk	Zeebrugge	0-33	Killingholme	27	risk
35	*Rapana venosa*	0/1	0	unclear					
36	*Rhithropanopeus harrisii*	1	0/1	unclear					
37	*Styela clava*	1	0/1(1)	no risk					
38	*Undaria pinnatifida*	1	0/1	unclear					

General

The species distribution analysis for 'Zeebrugge – Killingholme' points out that 38 target species (15 of which are questionable[8]) are likely present in, or in the immediate vicinity of, one or both ports (table 11). Future monitoring activities in the ports can provide more information on the species-specific distributions within each port. 7 target species do not pose a threat cf. the HELCOM/OSPAR procedure as they occur in both ports: *Austrominus modestus (Elminius modestus), Callinectes sapidus, Caprella mutica, Coscinodiscus wailesii, Dreissena polymorpha, Eriocheir sinensis* and *Styela clava*. However, 8 target species are considered present in only one port and therefore pose an initial threat for the other port. Additionally, the presence/absence of another 23 target species in the ports is unclear. Some of these 23 target species may pose a secondary risk.

Killingholme – Zeebrugge

In the port of Killingholme, no target species are considered as a potential threat to Zeebrugge.

Zeebrugge – Killingholme

8 target species of Zeebrugge have invasion potential in the port of Killingholme based on their salinity tolerance ranges: *Acartia tonsa, Gracilaria vermiculophylla, Hemigrapsus sanguineus, Hemigrapsus takanoi, Mnemiopsis leidyi, Mytilus galloprovincialis, Phaeocystis pouchetii* and *Rangia cuneata. Acartia tonsa* can outcompete other copepods. *Gracilaria vermiculophylla* inhibits the growth and survival of native algae through competition. This species also impacts fisheries through the fouling of nets. *Hemigrapsus sanguineus* can have negative impacts on small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves). The apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* has ecological and economic implications. *Hemigrapsus takanoi* can outcompete the native European green crab *Carcinus maenas* in Europe. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation. High abundances of *Mnemiopsis leidyi* may cause cascading effects at higher and lower trophic levels. *Mytilus galloprovincialis* can outcompete and displace native mussels and become the dominant mussel species in certain localities. *Phaeocystis pouchetii* has been found to be toxic to cod larvae in Norway. *Rangia cuneata* is a biofouling species and can cause problems in intake pipes used in the power and water industries.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 8 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 9) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Killingholme: 27 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(3.9 psu)

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

[8] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 11. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

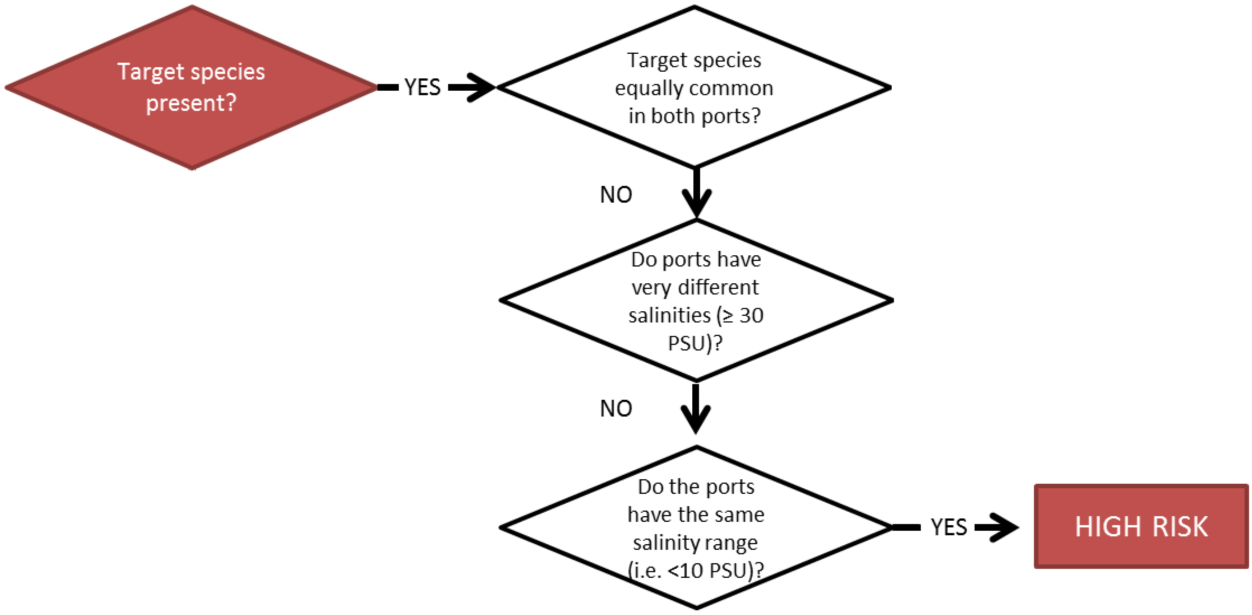

Figure 9. Risk assessment algorithm for the ports of Zeebrugge and Killingholme.

4.9 Zeebrugge (BEL) – Leixous (POR)

Table 12. Target species present in the port of Zeebrugge and/or Leixous and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Leixous	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0/1 (1)	no risk					
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1	unclear					
3	*Amphibalanus eburneus, ex. Balanus eburnus*	0	0/1 (1)	risk	Leixous	6-40	Zeebrugge	30.9-33	risk
4	*Austrominus modestus (Elminius modestus)*	1	0/1(1)	no risk					
5	*Callinectes sapidus*	1	0	risk	Zeebrugge	5-48	Leixous	32-35	risk
6	*Caprella mutica*	1	0	risk	Zeebrugge	11-40	Leixous	32-35	risk
7	*Caulerpa cylindracea*	0	1	risk	Leixous	10-40	Zeebrugge	30.9-33	risk
8	*Corbicula fluminea*	0	0/1	unclear					
9	*Coscinodiscus wailesii*	1	0/1 (0)	risk	Zeebrugge	25-35	Leixous	32-35	risk
10	*Crassostrea gigas*	1	0	risk	Zeebrugge	5-45	Leixous	32-35	risk
11	*Crepidula fornicata*	1	0	risk	Zeebrugge	20-40	Leixous	32-35	risk
12	*Dinophysis sacculus*	0	1	risk	Leixous	? (present between 27-34)	Zeebrugge	30.9-33	risk
13	*Dreissena polymorpha*	1	0/1(1)	no risk					
14	*Ensis americanus (syn. E. directus)*	1	0	risk	Zeebrugge	7-32	Leixous	32-35	risk
15	*Eriocheir sinensis*	1	0/1	unclear					
16	*Ficopomatus enigmaticus*	1	0/1(1)	no risk					
17	*Gammarus tigrinus*	1	0	risk	Zeebrugge	0.3-29.5	Leixous	32-35	no risk
18	*Gracilaria vermiculophylla*	1	1	no risk					
19	*Grateloupia doryphore*	0/1	1	unclear					
20	*Grateloupia turuturu*	0	1	risk	Leixous	12-52	Zeebrugge	30.9-33	risk
21	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	10-34	Leixous	32-35	risk
22	*Hemigrapsus takanoi*	1	0	risk	Zeebrugge	7-35	Leixous	32-35	risk
23	*Hemimysis anomala*	0/1	0	unclear					
24	*Hydroides dianthus*	0/1 (1)	0	risk	Zeebrugge	28-50	Leixous	32-35	risk
25	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1	unclear					
26	*Marenzelleria neglecta*	0/1	0	unclear					
27	*Marenzelleria viridis*	0/1	0	unclear					
28	*Microcosmus squamiger*	0	0/1(1)	risk	Leixous	15-36	Zeebrugge	30.9-33	risk
29	*Mnemiopsis leidyi*	1	0	risk	Zeebrugge	4-39	Leixous	32-35	risk
30	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0	unclear					
31	*Mytilus galloprovincialis*	0/1(1)	1	no risk					
32	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
33	*Palaemon elegans*	1	0/1(1)	no risk					
34	*Palaemon macrodactylus*	1	0/1(1)	no risk					
35	*Phaeocystis pouchetii*	1	0/1	unclear					
36	*Rangia cuneata*	1	0	risk	Zeebrugge	0-33	Leixous	32-35	risk
37	*Rapana venosa*	0/1	0	unclear					
38	*Rhithropanopeus harrisii*	1	0/1(1)	no risk					
39	*Styela clava*	1	0/1(1)	no risk					
40	*Stypopodium schimperi*	0	0/1	unclear					
41	*Undaria pinnatifida*	1	0/1(1)	no risk					

General

The species distribution analysis for the shipping route 'Zeebrugge – Leixous' points out that 41 target species (13 of which are questionable[9]) are likely present in, or in the immediate vicinity of, one or both ports (table 12). Future monitoring activities in the ports can provide more information on the species-specific distributions within each port. 11 species occur in both ports and do therefore not pose any threat cf. the HELCOM/OSPAR: *Acartia tonsa*, *Austrominus modestus (Elminius modestus)*, *Dreissena polymorpha*, *Ficopomatus enigmaticus*, *Gracilaria vermiculophylla*, *Mytilus galloprovincialis*, *Palaemon elegans*, *Palaemon macrodactylus*, *Rhithropanopeus harrisii*, *Styela clava* and *Undaria pinnatifida.* On the other hand, 17 target species are considered present in only one port and therefore pose an initial threat for the other port. In addition, the presence/absence of another 13 target species in the ports is unclear. Some of these 13 target species may pose a secondary risk.

Leixoes – Zeebrugge

In the port of Leixoes, 5 target species can be considered as a potential threat to Zeebrugge: *Amphibalanus eburneus (Balanus eburnus)*, *Caulerpa cylindracea*, *Dinophysis sacculus*, *Grateloupia turuturu* and *Microcosmus squamiger.* The salinity levels of the port of Zeebrugge do fall within the tolerable range of these species. *Amphibalanus eburneus* poses an economic threat to several marine-associated industries. Adults and juveniles can attach to ship hulls, creating drag and increasing fuel costs. In addition, intakes of marine-cooled nuclear power plants can become fouled, requiring costly removal. Furthermore, it can alter food webs in regions where it is invasive. The spread of *Caulerpa cylindracea* induces a homogenisation of habitats at different levels, and a decrease in diversity and in abundance of invertebrates. This species produces some metabolites showing phytotoxic effects, and research suggests a possible allelopathic activity of caulerpenyne, which may play a role in the successful competition of the invasive *C. cylindracea* with native macrophytes. *Dinophysis sacculus* is a toxic species associated with diarrhetic shellfish poisoning (DSP) outbreaks in Europe. *Grateloupia turuturu* is a nuisance organism that can outcompete many native seaweeds within the low intertidal and shallow subtidal zones. It can alter typical trophic patterns and cause habitat loss. *Microcosmus squamiger* can colonise adjacent natural communities, forming dense crusts that can outcompete native species. The economic impact of *M. squamiger* is mainly related to its interference with oyster cultures, where it competes for food and space.

Zeebrugge – Leixoes

In the port of Zeebrugge, 12 target species may pose a threat for invasion in Leixoes: *Callinectes sapidus, Caprella mutica, Coscinodiscus wailesii, Crassostrea gigas, Crepidula fornicata, Ensis americanus (*syn*. E. directus), Gammarus tigrinus, Hemigrapsus sanguineus, Hemigrapsus takanoi, Hydroides dianthus, Mnemiopsis leidyi* and *Rangia cuneata.* However, when taking into account the tolerable salinity range of *Gammarus tigrinus,* it is most unlikely that the species would survive in the port of Leixoes. As the salinity tolerances of the other 11 species correspond with the physical characteristics of the water in the port of Leixoes, it is likely that the species would survive. *Callinectes sapidus* mutilate fish caught in traps and trammel nets. As the species prefers to prey on clams, mussels and oysters, it impacts commercial fisheries and aquaculture. For *Caprella mutica*, detailed knowledge on community or ecosystem level impacts of the species is still lacking. *Coscinodiscus wailesii* can produce enormous amounts of slime, which cloggs trawls and may hamper fishing due to accumulating clay particles. The huge slime production, especially when mixed with clay and dead organisms, may also have a negative effect on recreation. Substantial damage is caused if the copious mucilage sinks and covers the seabed, likely causing anoxic conditions. *Crassostrea gigas* has been demonstrated invasive in several countries and it is therefore considered as a pest or a noxious species in such areas. The introduction of *C. gigas* has had economic side effects in several countries such as Australia, where the native Sydney rock oyster was partly outcompeted by *C. gigas*, leading to the collapse of several businesses. The indirect economic impact includes the increasing coastal management costs to limit *C. gigas* reef expansion and eradication costs. In other regions, the species appears to be of economic interest. Dense populations of *Crepidula fornicata* have a significant impact on fisheries or oyster farming activities. Even if the original ground is a nursery for commercial fishes, the complete occupation of the area may result in the disappearance of the fish which has economic consequences. *Ensis americanus (*syn*. E. directus)* may colonise new areas very rapidly and can dominate in abundance over all other shellfish species, causing competition for food and space. The presence of dead shells from *Ensis americanus (*syn*. E. directus)* on beaches is a nuisance for bare-footed beach walkers. *Gammarus tigrinus* is

[9] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 12. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

able to outcompete many native gammarids. *Hemigrapsus sanguineus* can have negative impacts on small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves). Futhermore, the apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* has ecological and economic implications. *Hemigrapsus takanoi* can outcompete the native European green crab *Carcinus maenas* in Europe. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation. High abundances of *Mnemiopsis leidyi* may cause cascading effects at both higher and lower trophic levels. *Hydroides dianthus* and *Rangia cuneata* are biofouling species and cause problems in intake pipes used in the power and water industries.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 17 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 10) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Leixous: 32-35 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(0 psu)

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

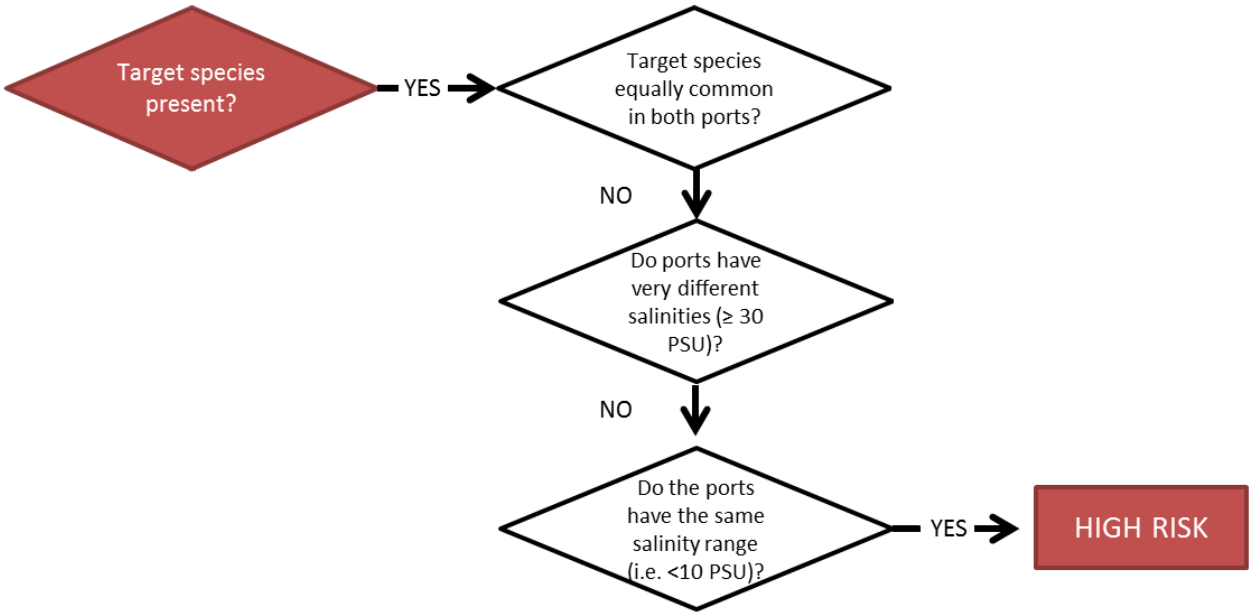

Figure 10. Risk assessment algorithm for the ports of Zeebrugge and Leixous.

4.10 Zeebrugge (BEL) – Purfleet (UK)

Table 13. Target species present in the port of Zeebrugge and/or Purfleet and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Purfleet	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0/1 (0)	risk	Zeebrugge	0-52	Purfleet	13-22	risk
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1	unclear					
3	*Austrominus modestus (Elminius modestus)*	1	1	no risk					
4	*Callinectes sapidus*	1	1	no risk					
5	*Caprella mutica*	1	1	no risk					
6	*Corbicula fluminea*	0	1	risk	Purfleet	0.16-24	Zeebrugge	30.9-33	no risk
7	*Coscinodiscus wailesii*	1	1	no risk					
8	*Crassostrea gigas*	1	1	no risk					
9	*Crepidula fornicata*	1	1	no risk					
10	*Didemnum vexillum*	0	0/1	unclear					
11	*Dreissena polymorpha*	1	1	no risk					
12	*Ensis americanus (syn. E. directus)*	1	1	no risk					
13	*Eriocheir sinensis*	1	1	no risk					
14	*Ficopomatus enigmaticus*	1	0/1	unclear					
15	*Gammarus tigrinus*	1	0/1	unclear					
16	*Gracilaria vermiculophylla*	1	0	risk	Zeebrugge	5-60	Purfleet	13-22	risk
17	*Grateloupia doryphore*	0/1	0/1	unclear					
18	*Grateloupia turuturu*	0	0/1	unclear					
19	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	10-34	Purfleet	13-22	risk
20	*Hemigrapsus takanoi*	1	0	risk	Zeebrugge	7-35	Purfleet	13-22	risk
21	*Hemimysis anomala*	0/1	0/1	unclear					
22	*Hydroides dianthus*	0/1 (1)	0/1	unclear					
23	*Hydroides elegans*	0/1 (0)	0/1	unclear					
24	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1	unclear					
25	*Marenzelleria neglecta*	0/1	0/1	unclear					
26	*Marenzelleria viridis*	0/1	0/1	unclear					
27	*Mnemiopsis leidyi*	1	0	risk	Zeebrugge	4-39	Purfleet	13-22	risk
28	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0/1	unclear					
29	*Mytilus galloprovincialis*	0/1(1)	0	risk	Zeebrugge	9-'≥38(?)'	Purfleet	13-22	risk
30	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
31	*Palaemon elegans*	1	0/1	unclear					
32	*Palaemon macrodactylus*	1	1	no risk					
33	*Phaeocystis pouchetii*	1	0	risk	Zeebrugge	10-40	Purfleet	13-22	risk
34	*Rangia cuneata*	1	0	risk	Zeebrugge	0-33	Purfleet	13-22	risk
35	*Rapana venosa*	0/1	0	unclear					
36	*Rhithropanopeus harrisii*	1	0/1	unclear					
37	*Styela clava*	1	1	no risk					
38	*Undaria pinnatifida*	1	0/1	unclear					

General

The species distribution analysis for the shipping route 'Zeebrugge – Purfleet' points out that 38 target species (14 of which are questionable[10]) are likely present in, or in the immediate vicinity of, one or both ports (table 13). Further monitoring is recommended to collect more information on the species-specific distributions. 11 target species occur in both ports and do therefore not pose an initial threat cf. the HELCOM/OSPAR procedure: *Austrominus modestus (Elminius modestus), Callinectes sapidus, Caprella mutica, Coscinodiscus wailesii, Crassostrea gigas, Crepidula fornicata, Dreissena polymorpha, Ensis americanus (*syn. *E. directus), Eriocheir sinensis, Palaemon macrodactylus* and *Styela clava*. However, 9 target species are considered present in only one port and therefore pose an initial threat to the other port. Additionally, the presence/absence of another 18 target species in the ports is unclear. Some of these 18 target species may pose a secondary risk.

Purfleet – Zeebrugge

In the port of Purfleet, 1 target species may pose a threat for invasion to Zeebrugge: *Corbicula fluminea.* However, *Corbicula fluminea* cannot cope with the salinity levels in the port of Zeebrugge, it is therefore unlikely that the species would survive after the initial introduction.

Zeebrugge – Purfleet

In the port of Zeebrugge, 8 target species can be considered as a potential threat for invasion in Purfleet: *Acartia tonsa, Gracilaria vermiculophylla, Hemigrapsus sanguineus, Hemigrapsus takanoi, Mnemiopsis leidyi, Mytilus galloprovincialis, Phaeocystis pouchetii* and *Rangia cuneata.* The wide ranges in salinity tolerances of those species make that they are able to survive in the less saline waters of Purfleet. *Gracilaria vermiculophylla* inhibits the growth and survival of native algae through competition. This species also causes problems in the fishing industries through the fouling of nets. *Acartia tonsa* can outcompete other copepods. *Hemigrapsus sanguineus* may negatively impact small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves). The apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* has ecological and economic implications. *Hemigrapsus takanoi* can outcompete the native European green crab *Carcinus maenas* in Europe. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation. When present in high abundances, *Mnemiopsis leidyi* may impact both higher and lower trophic levels through cascading effects. *Mytilus galloprovincialis* can outcompete and displace native mussels and become the dominant mussel species in certain localities. *Phaeocystis pouchetii* has been found to be toxic to cod larvae in Norway. *Rangia cuneata* is a biofouling species and can cause problems in intake pipes used in the power and water industries.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 8 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 11) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Purfleet: 13-22 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(8.9 psu)

[10] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 13. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

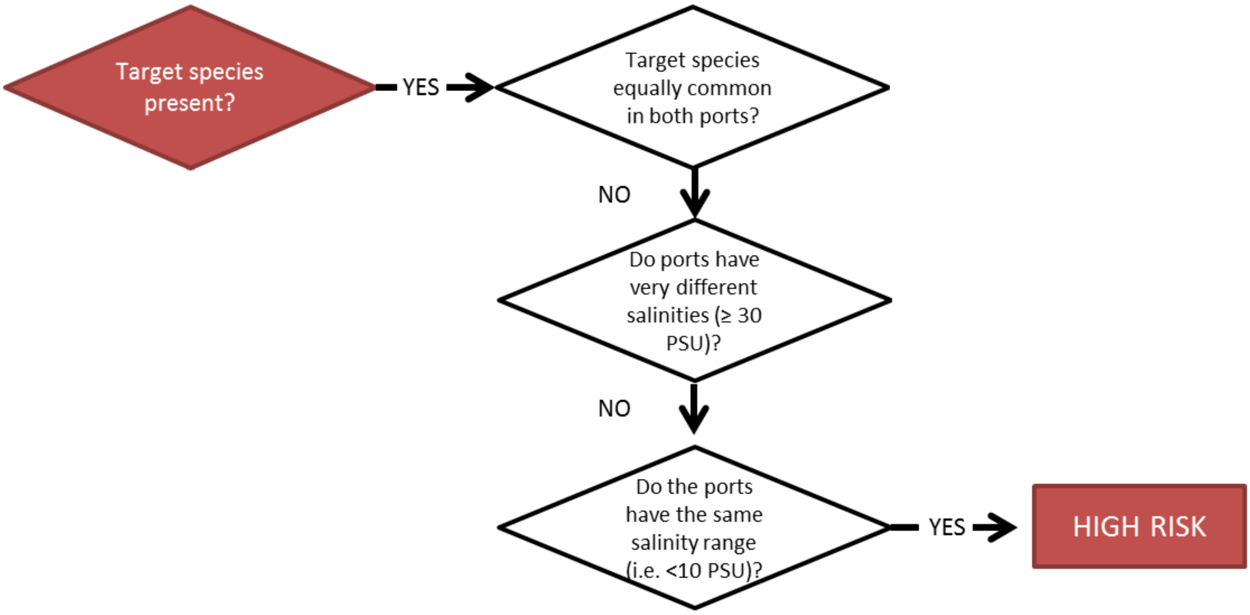

Figure 11. Risk assessment algorithm for the ports of Zeebrugge and Purfleet.

4.11 Zeebrugge (BEL) – Rosyth (UK)

Table 14. Target species present in the port of Zeebrugge and/or Rosyth and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Rosyth	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0/1 (0)	risk	Zeebrugge	0-52	Rosyth	28.5-30	risk
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1	unclear					
3	*Austrominus modestus (Elminius modestus)*	1	1	no risk					
4	*Callinectes sapidus*	1	0/1	unclear					
5	*Caprella mutica*	1	1	no risk					
6	*Corbicula fluminea*	0	0/1	unclear					
7	*Coscinodiscus wailesii*	1	1	no risk					
8	*Crassostrea gigas*	1	1	no risk					
9	*Crepidula fornicata*	1	1	no risk					
10	*Didemnum vexillum*	0	0/1	unclear					
11	*Dreissena polymorpha*	1	1	no risk					
12	*Ensis americanus (syn. E. directus)*	1	1	no risk					
13	*Eriocheir sinensis*	1	0/1	unclear					
14	*Ficopomatus enigmaticus*	1	0/1	unclear					
15	*Gammarus tigrinus*	1	0/1	unclear					
16	*Gracilaria vermiculophylla*	1	0	risk	Zeebrugge	5-60	Rosyth	28.5-30	risk
17	*Grateloupia doryphore*	0/1	0/1	unclear					
18	*Grateloupia turuturu*	0	0/1	unclear					
19	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	10-34	Rosyth	28.5-30	risk
20	*Hemigrapsus takanoi*	1	0	risk	Zeebrugge	7-35	Rosyth	28.5-30	risk
21	*Hemimysis anomala*	0/1	0/1	unclear					
22	*Hydroides dianthus*	0/1 (1)	0/1	unclear					
23	*Hydroides elegans*	0/1 (0)	0/1	unclear					
24	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1	unclear					
25	*Marenzelleria neglecta*	0/1	0/1	unclear					
26	*Marenzelleria viridis*	0/1	0/1	unclear					
27	*Mnemiopsis leidyi*	1	0	risk	Zeebrugge	4-39	Rosyth	28.5-30	risk
28	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0/1	unclear					
29	*Mytilus galloprovincialis*	0/1(1)	0	unclear					
30	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
31	*Palaemon elegans*	1	1	no risk					
32	*Palaemon macrodactylus*	1	0/1	unclear					
33	*Phaeocystis pouchetii*	1	0/1	unclear					
34	*Rangia cuneata*	1	0	risk	Zeebrugge	0-33	Rosyth	28.5-30	risk
35	*Rapana venosa*	0/1	0	unclear					
36	*Rhithropanopeus harrisii*	1	0/1	unclear					
37	*Styela clava*	1	0/1	unclear					
38	*Undaria pinnatifida*	1	0	risk	Zeebrugge	11-'≥34(?)'	Rosyth	28.5-30	risk

General

The species distribution analysis for 'Zeebrugge-Rosyth' points out that 38 target species (15 of which are questionable[11]) are likely present in, or in the immediate vicinity of, one or both ports (table 14). However, further monitoring is necessary to provide more clarity regarding the questionable occurrences. 8 target species do not pose a threat cf. the HELCOM/OSPAR procedure as they occur in both ports: *Austrominus modestus (Elminius modestus), Caprella mutica, Coscinodiscus wailesii, Crassostrea gigas, Crepidula fornicata, Dreissena polymorpha, Ensis americanus (*syn*. E. directus)* and *Palaemon elegans*. However, 7 target species are considered present in only one port and thus pose an initial threat to the other port. Furthermore, the presence/absence of another 21 target species in the ports is unclear. Some of the latter species may pose an additional risk.

Rosyth – Zeebrugge

No target species are present in the port of Rosyth which may be introduced to Zeebrugge.

Zeebrugge – Rosyth

Taking into account the salinity tolerances of the organisms, 7 target species of Zeebrugge could pose a threat for invasion in Rosyth: *Acartia tonsa, Gracilaria vermiculophylla, Hemigrapsus sanguineus, Hemigrapsus takanoi, Mnemiopsis leidyi, Rangia cuneata* and *Undaria pinnatifida. Acartia tonsa* can outcompete other copepods. *Gracilaria vermiculophylla* inhibits the growth and survival of native algae through competition. Furthermore, it has been reported that this species impacts the fishing industry through the fouling of nets. *Hemigrapsus sanguineus* can have negative impacts on small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves). Moreover, the apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* has both ecological and economic implications. *Hemigrapsus takanoi* can outcompete the native European green crab *Carcinus maenas* in Europe. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation. High abundances of *Mnemiopsis leidyi* may lead to cascading effects at both higher and lower trophic levels. *Rangia cuneata* is a biofouling species and can cause problems in intake pipes used in the power and water industries. The ecological impact of *Undaria pinnatifida* is spatially variable, in some locations the introduction of the species decreases native species diversity through competition, while at other location, no specific impact has been observed.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 7 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 12) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Rosyth: 28.5-30 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(0.9 psu)

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

[11] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 14. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

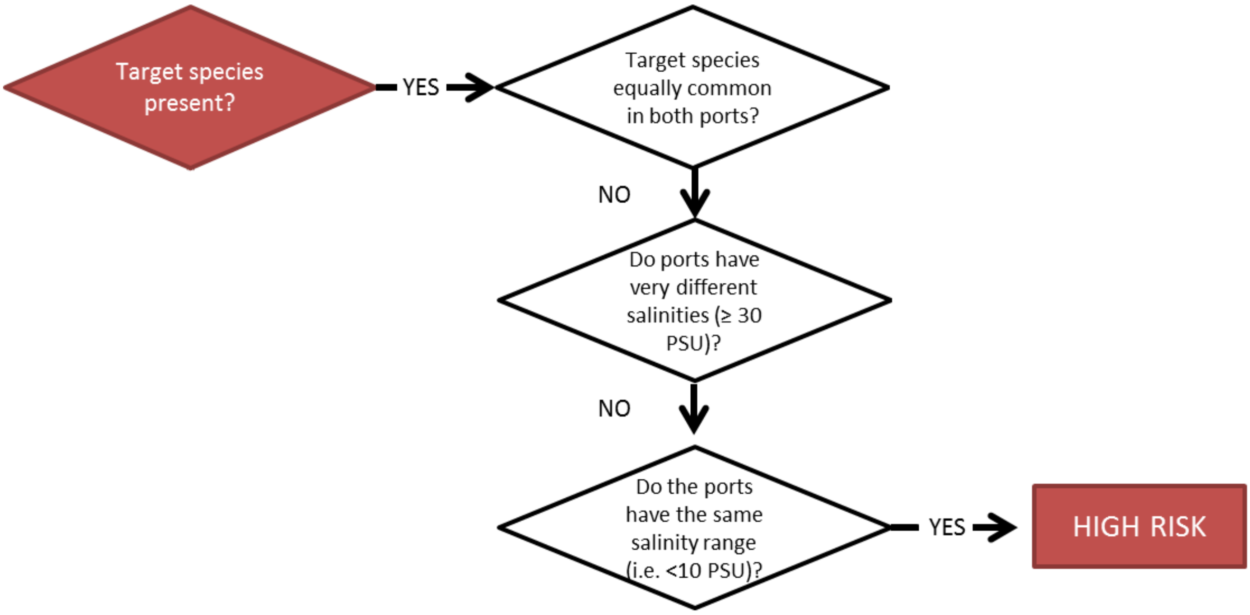

Figure 12. Risk assessment algorithm for the ports of Zeebrugge and Rosyth.

4.12 Zeebrugge (BEL) – Sheerness (UK)

Table 15. Target species present in the port of Zeebrugge and/or Sheerness and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Sheerness	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0/1 (0)	risk	Zeebrugge	0-52	Sheerness	28-35	risk
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1	unclear					
3	*Austrominus modestus (Elminius modestus)*	1	1	no risk					
4	*Callinectes sapidus*	1	1	no risk					
5	*Caprella mutica*	1	1	no risk					
6	*Corbicula fluminea*	0	0/1	unclear					
7	*Coscinodiscus wailesii*	1	1	no risk					
8	*Crassostrea gigas*	1	1	no risk					
9	*Crepidula fornicata*	1	1	no risk					
10	*Didemnum vexillum*	0	0/1	unclear					
11	*Dreissena polymorpha*	1	1	no risk					
12	*Ensis americanus (syn. E. directus)*	1	1	no risk					
13	*Eriocheir sinensis*	1	1	no risk					
14	*Ficopomatus enigmaticus*	1	0/1	unclear					
15	*Gammarus tigrinus*	1	0/1	unclear					
16	*Gracilaria vermiculophylla*	1	0	risk	Zeebrugge	5-60	Sheerness	28-35	risk
17	*Grateloupia doryphore*	0/1	0/1	unclear					
18	*Grateloupia turuturu*	0	0/1	unclear					
19	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	10-34	Sheerness	28-35	risk
20	*Hemigrapsus takanoi*	1	0	risk	Zeebrugge	7-35	Sheerness	28-35	risk
21	*Hemimysis anomala*	0/1	0/1	unclear					
22	*Hydroides dianthus*	0/1 (1)	0/1	unclear					
23	*Hydroides elegans*	0/1 (0)	0/1	unclear					
24	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1	unclear					
25	*Marenzelleria neglecta*	0/1	0/1	unclear					
26	*Marenzelleria viridis*	0/1	0/1	unclear					
27	*Mnemiopsis leidyi*	1	0	risk	Zeebrugge	4-39	Sheerness	28-35	risk
28	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0/1	unclear					
29	*Mytilus galloprovincialis*	0/1(1)	0	risk	Zeebrugge	9-'≥38(?)'	Sheerness	28-35	risk
30	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
31	*Palaemon elegans*	1	0/1	unclear					
32	*Palaemon macrodactylus*	1	1	no risk					
33	*Phaeocystis pouchetii*	1	0	risk	Zeebrugge	10-40	Sheerness	28-35	risk
34	*Rangia cuneata*	1	0	risk	Zeebrugge	0-33	Sheerness	28-35	risk
35	*Rapana venosa*	0/1	0	unclear					
36	*Rhithropanopeus harrisii*	1	0/1	unclear					
37	*Styela clava*	1	1	no risk					
38	*Undaria pinnatifida*	1	0/1 (1)	no risk					

General

The species distribution analysis for 'Zeebrugge – Sheerness' points out that 38 target species (15 of which are questionable[12]) are likely present in, or in the immediate vicinity of, one or both ports (table 15). Future monitoring activities in the ports can provide more information on the species-specific distributions within each port. 12 target species do not pose a threat cf. the HELCOM/OSPAR procedure as they occur in both ports: *Austrominus modestus (Elminius modestus), Callinectes sapidus, Caprella mutica, Coscinodiscus wailesii, Crassostrea gigas, Crepidula fornicata, Dreissena polymorpha, Ensis americanus (*syn*. E. directus), Eriocheir sinensis, Palaemon macrodactylus, Styela clava* and *Undaria pinnatifida*. 8 target species are considered present in only one port and therefore pose an initial threat for the other port. Furthermore, the presence/absence of another 18 target species in the ports is unclear. Some of the latter species may pose an additional risk.

Sheerness – Zeebrugge

In the port of Sheerness, no target species are considered as a potential threat to Zeebrugge.

Zeebrugge – Sheerness

In the port of Zeebrugge, 8 target species may pose a threat for further spread towards Sheerness: *Acartia tonsa, Gracilaria vermiculophylla, Hemigrapsus sanguineus, Hemigrapsus takanoi, Mnemiopsis leidyi, Mytilus galloprovincialis, Phaeocystis pouchetii* and *Rangia cuneata.* Since both ports have a similar salinity range, all of these species are supposed to be able to survive in Sheerness based on the HELCOM/OSPAR key criteria. *Acartia tonsa* can outcompete other copepods. *Gracilaria vermiculophylla* inhibits the growth and survival of native algae through competition. This species also impacts the fishing industry through the fouling of nets. *Hemigrapsus sanguineus* can have a negative impact on small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves). The apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* has both ecological and economic implications. *Hemigrapsus takanoi* can outcompete the native European green crab *Carcinus maenas* in Europe. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation. High abundances of *Mnemiopsis leidyi* may negatively impact both higher and lower trophic levels through cascading effects. *Mytilus galloprovincialis* can outcompete and displace native mussels and become the dominant mussel species in certain localities. *Phaeocystis pouchetii* has been found to be toxic to cod larvae in Norway. *Rangia cuneata* is a biofouling species and can cause problems in intake pipes used in the power and water industries.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 8 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 13) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Sheerness: 28-35 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(0 psu)

[12] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 15. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

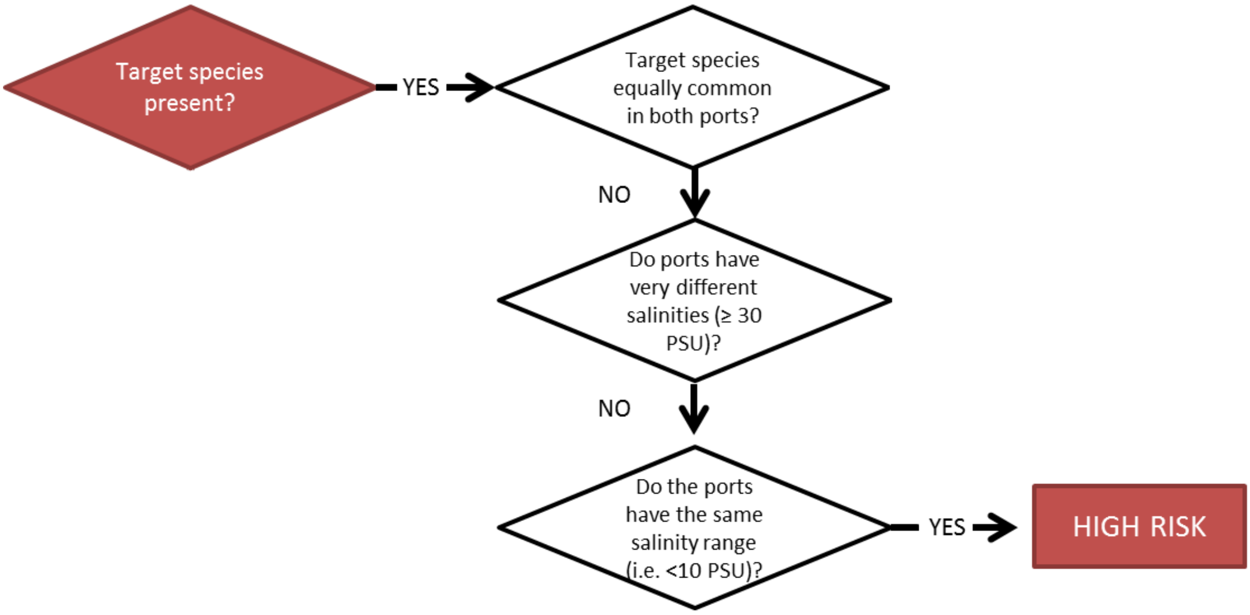

Figure 13. Risk assessment algorithm for the ports of Zeebrugge and Sheerness.

4.13 Zeebrugge (BEL) – Teesport (UK)

Table 16. Target species present in the port of Zeebrugge and/or Teesport and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Teesport	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0/1 (0)	risk	Zeebrugge	0-52	Teesport	30.9	risk
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1	unclear					
3	*Austrominus modestus (Elminius modestus)*	1	1	no risk					
4	*Callinectes sapidus*	1	1	no risk					
5	*Caprella mutica*	1	1	no risk					
6	*Corbicula fluminea*	0	0/1	unclear					
7	*Coscinodiscus wailesii*	1	1	no risk					
8	*Crassostrea gigas*	1	1	no risk					
9	*Crepidula fornicata*	1	1	no risk					
10	*Didemnum vexillum*	0	0/1	unclear					
11	*Dreissena polymorpha*	1	1	no risk					
12	*Ensis americanus (syn. E. directus)*	1	0/1	unclear					
13	*Eriocheir sinensis*	1	1	no risk					
14	*Ficopomatus enigmaticus*	1	0/1	unclear					
15	*Gammarus tigrinus*	1	0/1	unclear					
16	*Gracilaria vermiculophylla*	1	0	risk	Zeebrugge	5-60	Teesport	30.9	risk
17	*Grateloupia doryphore*	0/1	0/1	unclear					
18	*Grateloupia turuturu*	0	0/1	unclear					
19	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	10-34	Teesport	30.9	risk
20	*Hemigrapsus takanoi*	1	0	risk	Zeebrugge	7-35	Teesport	30.9	risk
21	*Hemimysis anomala*	0/1	0/1	unclear					
22	*Hydroides dianthus*	0/1 (1)	0/1	unclear					
23	*Hydroides elegans*	0/1 (0)	0/1	unclear					
24	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1	unclear					
25	*Marenzelleria neglecta*	0/1	0/1	unclear					
26	*Marenzelleria viridis*	0/1	0/1	unclear					
27	*Mnemiopsis leidyi*	1	0	risk	Zeebrugge	4-39	Teesport	30.9	risk
28	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0/1	unclear					
29	*Mytilus galloprovincialis*	0/1(1)	0	risk	Zeebrugge	9-'≥38(?)'	Teesport	30.9	risk
30	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
31	*Palaemon elegans*	1	1	no risk					
32	*Palaemon macrodactylus*	1	0/1	unclear					
33	*Phaeocystis pouchetii*	1	0/1	unclear					
34	*Rangia cuneata*	1	0	risk	Zeebrugge	0-33	Teesport	30.9	risk
35	*Rapana venosa*	0/1	0	unclear					
36	*Rhithropanopeus harrisii*	1	0/1	unclear					
37	*Styela clava*	1	0/1	unclear					
38	*Undaria pinnatifida*	1	0/1	unclear					

General

The species distribution analysis for 'Zeebrugge-Teesport' points out that 38 target species (15 of which are questionable[13]) are likely present in, or in the immediate vicinity of, one or both ports (table 16). However, further monitoring is necessary to provide more clarity regarding the questionable occurrences. 9 target species do not pose a threat cf. the HELCOM/OSPAR procedure as they occur in both ports: *Austrominus modestus (Elminius modestus), Callinectes sapidus, Caprella mutica, Coscinodiscus wailesii, Crassostrea gigas, Crepidula fornicata, Dreissena polymorpha, Eriocheir sinensis* and *Palaemon elegans*. However, 7 target species are considered present in only one port and therefore pose an initial threat for the other port. Additionally, the presence/absence of another 22 target species in the ports is questionable. Some of these 22 target species may pose a secondary risk.

Teesport – Zeebrugge

No target species in the port of Teesport are a threat for invasion to Zeebrugge.

Zeebrugge – Teesport

In the port of Zeebrugge, 7 target species are identified as a potential threat for invasion in Teesport: *Acartia tonsa, Gracilaria vermiculophylla, Hemigrapsus sanguineus, Hemigrapsus takanoi, Mnemiopsis leidyi, Mytilus galloprovincialis* and *Rangia cuneata.* Both ports have similar salinities. Based on the latter, all species should be able to survive in Teesport. *Acartia tonsa* can outcompete other copepods. *Gracilaria vermiculophylla* inhibits the growth and survival of native algae through competition. The species negatively impacts the fishing industries through the fouling of nets. *Hemigrapsus sanguineus* can have negative impacts on small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves). The apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* has ecological and economic implications. *Hemigrapsus takanoi* can outcompete the native European green crab *Carcinus maenas* in Europe. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation. High numbers of *Mnemiopsis leidyi* may negatively impact both higher and lower trophic levels through cascading effects. *Mytilus galloprovincialis* can outcompete and displace native mussels and become the dominant mussel species in certain localities. *Rangia cuneata* is a biofouling species and can cause problems in intake pipes used in the power and water industries.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 7 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 14) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (⩾ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Teesport: 30.9 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(0 psu)

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

[13] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 16. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

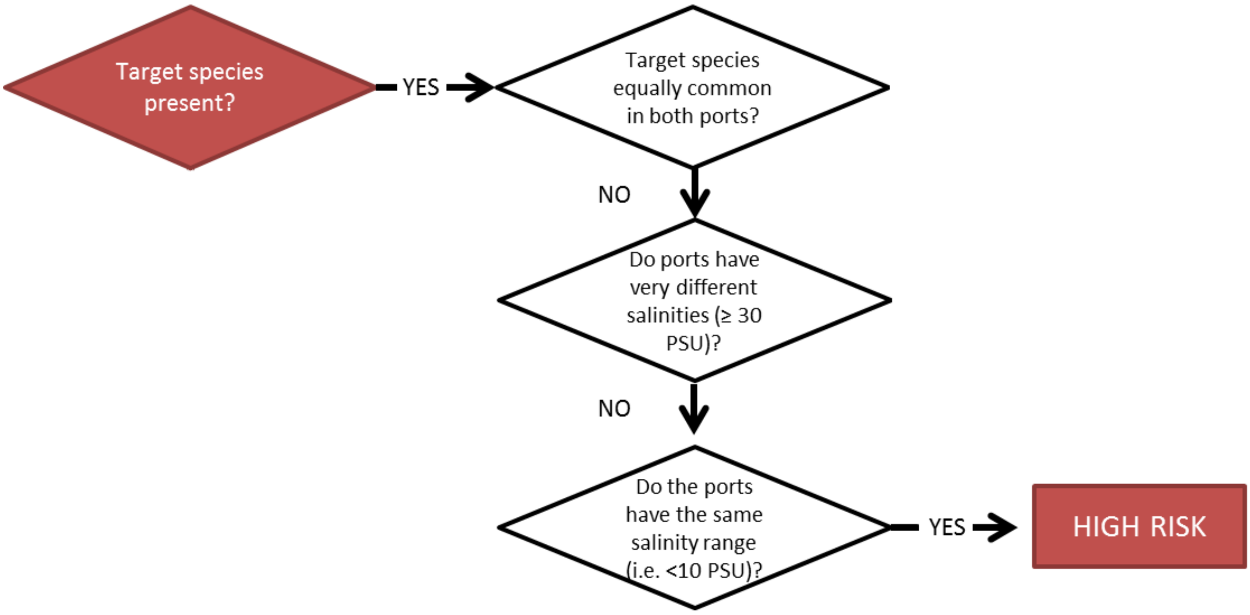

Figure 14. Risk assessment algorithm for the ports of Zeebrugge and Sheerness.

4.14 Zeebrugge (BEL) – Tilbury (UK)

Table 17. Target species present in the port of Zeebrugge and/or Tilbury and their invasion potential, taking into account the species-specific tolerances for salinity and the salinity ranges in the ports of interest.

No.	Species	Zeebrugge	Tilbury	Initial risk	Present in port X	Species-specific salinity tolerance (psu)	Absent in port Y	Salinity port Y (psu)	Species-specific risk based on salinity tolerance
1	*Acartia tonsa*	1	0/1 (0)	risk	Zeebrugge	0-52	Tilbury	12-25	risk
2	*Alexandrium ostenfeldii*	(0/1) 1	0/1	unclear					
3	*Austrominus modestus (Elminius modestus)*	1	1	no risk					
4	*Callinectes sapidus*	1	1	no risk					
5	*Caprella mutica*	1	1	no risk					
6	*Corbicula fluminea*	0	1	risk	Tilbury	0.16-24	Zeebrugge	30.9-33	no risk
7	*Coscinodiscus wailesii*	1	1	no risk					
8	*Crassostrea gigas*	1	1	no risk					
9	*Crepidula fornicata*	1	1	no risk					
10	*Didemnum vexillum*	0	0/1	unclear					
11	*Dreissena polymorpha*	1	1	no risk					
12	*Ensis americanus (syn. E. directus)*	1	1	no risk					
13	*Eriocheir sinensis*	1	1	no risk					
14	*Ficopomatus enigmaticus*	1	0/1	unclear					
15	*Gammarus tigrinus*	1	0/1	unclear					
16	*Gracilaria vermiculophylla*	1	0	risk	Zeebrugge	5-60	Tilbury	12-25	risk
17	*Grateloupia doryphore*	0/1	0/1	unclear					
18	*Grateloupia turuturu*	0	0/1	unclear					
19	*Hemigrapsus sanguineus*	1	0	risk	Zeebrugge	10-34	Tilbury	12-25	risk
20	*Hemigrapsus takanoi*	1	0	risk	Zeebrugge	7-35	Tilbury	12-25	risk
21	*Hemimysis anomala*	0/1	0/1	unclear					
22	*Hydroides dianthus*	0/1 (1)	0/1	unclear					
23	*Hydroides elegans*	0/1 (0)	0/1	unclear					
24	*Karenia (syn. Gymnodinium) mikimotoi*	0	0/1	unclear					
25	*Marenzelleria neglecta*	0/1	0/1	unclear					
26	*Marenzelleria viridis*	0/1	0/1	unclear					
27	*Mnemiopsis leidyi*	1	0	risk	Zeebrugge	4-39	Tilbury	12-25	risk
28	*Mytilopsis (syn. Congeria) leucophaeata*	0/1	0/1	unclear					
29	*Mytilus galloprovincialis*	0/1(1)	0	risk	Zeebrugge	9-'≥38(?)'	Tilbury	12-25	risk
30	*Neogobius (syn. Apollonia) melanostomus*	0/1	0	unclear					
31	*Palaemon elegans*	1	0/1	unclear					
32	*Palaemon macrodactylus*	1	1	no risk					
33	*Phaeocystis pouchetii*	1	0	risk	Zeebrugge	10-40	Tilbury	12-25	risk
34	*Rangia cuneata*	1	0	risk	Zeebrugge	0-33	Tilbury	12-25	risk
35	*Rapana venosa*	0/1	0	unclear					
36	*Rhithropanopeus harrisii*	1	0/1	unclear					
37	*Styela clava*	1	1	no risk					
38	*Undaria pinnatifida*	1	0/1	unclear					

General

The species distribution analysis for 'Zeebrugge – Tilbury' points out that 38 target species (14 of which are questionable[14]) are likely present in, or in the immediate vicinity of, one or both ports (table 17). Future monitoring activities in the ports can provide more information on the species-specific distributions within each port. 11 target species do not pose a threat cf. the HELCOM/OSPAR procedure as they occur in both ports: *Austrominus modestus (Elminius modestus), Callinectes sapidus, Caprella mutica, Coscinodiscus wailesii, Crassostrea gigas, Crepidula fornicata, Styela clava, Dreissena polymorpha, Ensis americanus (*syn. *E. directus)* and *Eriocheir sinensis*. However, 9 target species are considered present in only one port and therefore pose an initial threat for the other port. Furthermore, the presence/absence of another 18 target species in the ports is unclear. Some of these 18 target species may pose an additional risk.

Tilbury – Zeebrugge

In the port of Tilbury, 1 target species may pose a threat for invasion to Zeebrugge: *Corbicula fluminea.* However, *Corbicula fluminea* cannot cope with the salinity levels in the port of Zeebrugge, it is therefore unlikely that the species would survive after the initial introduction.

Zeebrugge – Tilbury

In the port of Zeebrugge, 8 target species can be considered as a potential threat for invasion in Tilbury: *Acartia tonsa, Gracilaria vermiculophylla, Hemigrapsus sanguineus, Hemigrapsus takanoi, Mnemiopsis leidyi, Mytilus galloprovincialis, Rangia cuneata* and *Phaeocystis pouchetii*. The tolerance ranges the species are large enough to survive in Tilbury. *Acartia tonsa* can outcompete other copepods. *Gracilaria vermiculophylla* inhibits the growth and survival of native algae through competition. This species also negatively impacts the fishing industry through the fouling of nets. *Hemigrapsus sanguineus* may negatively impact small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves). The apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* has ecological and economic implications. *Hemigrapsus takanoi* can outcompete the native European green crab *Carcinus maenas* in Europe. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation. *Mnemiopsis leidyi* may impact both higher and lower trophic levels, when occurring in high abundances. *Mytilus galloprovincialis* can outcompete and displace native mussels and become the dominant mussel species in certain localities. *Rangia cuneata* is a biofouling species and can cause problems in intake pipes used in the power and water industries. *Phaeocystis pouchetii* has been found to be toxic to cod larvae in Norway.

Risk assessment

Taking into account the salinity ranges in the ports and the salinity tolerances of the species, 8 species have invasion potential in one of the ports. Therefore, the risk assessment algorithm (figure 15) suggests that it is highly likely that target species are distributed with ballast water and occupy a new habitat. Hence, according to the HELCOM/OSPAR protocol, the risk is unacceptable and an exemption cannot be granted.

The following steps are considered into the risk assessment algorithm:

Target species present?	YES	
Target species equally common in both ports?	NO	
Do ports have very different salinities (≥ 30 PSU) difference?	NO	(Zeebrugge: 30.9-33 psu)
		(Tilbury: 12-25 psu)
Do the ports have the same salinity range (i.e. < 10 PSU)?	YES	(5.9 psu)

[14] 'Questionable occurrences' are not necessarily the same as 'Initial risk = unclear' cf. table 17. If a species is present in one port but its occurrence is doubtful in the other port, the species' occurrence is not considered questionable as its presence is demonstrated in at least one port.

It is highly likely that target species are distributed with ballast water and occupy a new habitat. The risk is unacceptable. An exemption cannot be granted.

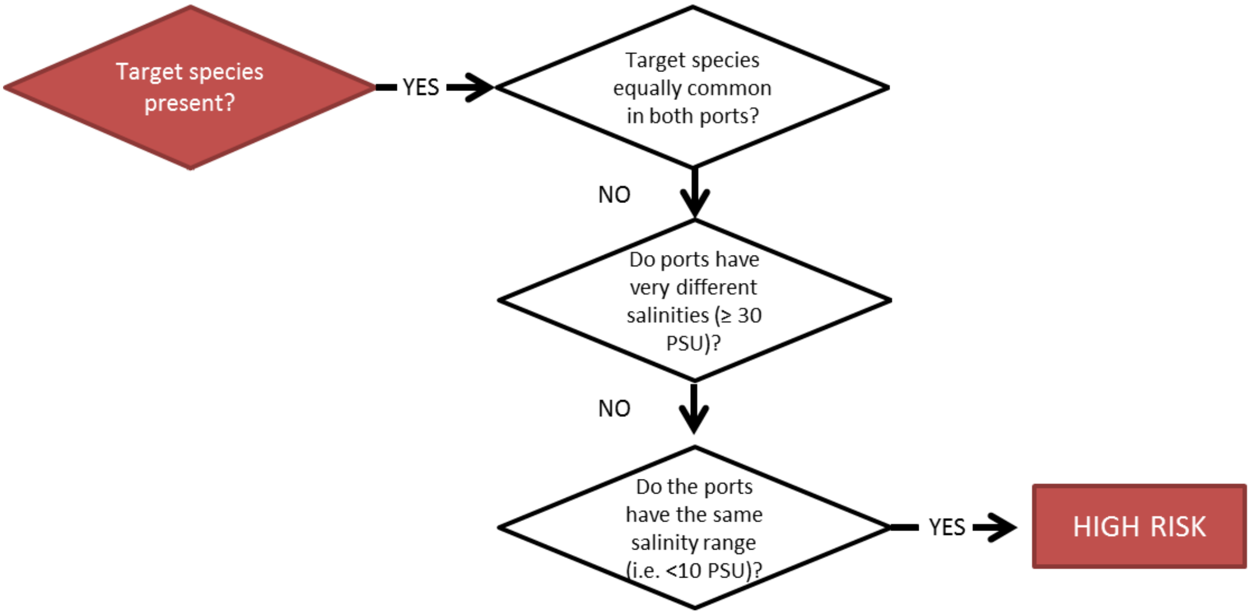

Figure 15. Risk assessment algorithm for the ports of Zeebrugge and Tilbury.

5. Conclusions

Based on the discussions between ship owners and FPS Mobility and Transport, 14 regular shipping lines (i.e. between 2 ports, of which one is Belgian) were identified for which ship owners would like to apply for an exemption under Regulation A-4 of the BWMC. The species compositions in all the relevant ports were analysed using the method described in '3. Methodology', focusing on target species as defined by HELCOM/OSPAR (2015). The available data (database analyses) allows an initial risk assessment under Regulation A-4 of the BWMC for Belgium using the joint HELCOM/OSPAR Harmonised Procedure.

Based on the available data and taking into account the key risk criteria as defined by the HELCOM/OSPAR Harmonised Procedure, all shipping lanes were considered 'high risk', which means that it is highly likely that target species are distributed with ballast water and occupy a new habitat. For each individual shipping route, between 6 and 16 target species were identified which may pose a potential threat for invasion in one of the ports of interest. However, it should be mentioned that, for many additional species, the presence/absence in a particular port was uncertain, so those species may pose a secondary risk.

According to the HELCOM/OSPAR Harmonised Procedure, the chance of survival of an invasive species in another port is mainly based on species-specific salinity tolerances. It is therefore important to mention that for some species other parameters may also play a crucial role in determining the change of survival or reproduction, such as water temperature, oxygen concentration, nutrient availability, light regime, etc. Those latter parameters are not taken into account in the individual risk assessments.

In order to improve the knowledge on species distributions and the species-specific ecological characteristics, future monitoring activities in the ports are encouraged.

6. Annex – Target species of interest

1. *Acartia tonsa*

These copepods are free-swimming, planktonic crustaceans that can tolerate a wide range of temperatures (-1 to 32°C) and salinities (0 to 52 psu) (Danilo *et al.*, 2008; Encyclopedia of Life, Sei *et al.*, 2006). They thrive well in both saline, brackish and almost freshwater environments (Bakker & De Pauw, 1975). However, when temperature is rather low, the presence of the species seems to be restricted to environments characterised by salinity levels below 33 psu (Brylinski, 1981). Both adults and their resting eggs can be transported with ballast water (Remy, 1927; Eno *et al.,* 1997). The species show highest abundances during warmer seasons. In the Scheldt Estuary, this species seasonally outcompetes the other copepod *Eurytemora affinis* (Soetaert & Van Rijswijk, 1993; Bakker *et al.*, 1977). If these copepods overfeed on algae, they may adversely affect the feeding and growth of many other economically valuable marine species such as fish and mollusks (Mauchline, 1998; Teixeira *et al.*, 2010).

Figure 1: Acartia tonsa © IMPAC

2. *Alexandrium ostenfeldii*

A. ostenfeldii is a marine, planktonic dinoflagellate. Generally, it is a cold-water coastal species occurring in low numbers along the West Coast of Europe. The toxic potential of this species has been questioned for a long time (Balech, 1995; Hansen *et al.*, 1992). The species is capable of producing PSP toxins, albeit, it is the least toxic of all the *Alexandrium* species tested for PSP toxins (Cembella *et al.*, 1987; 1988). *A. ostenfeldii* has been associated with shellfish poisoning in Scandinavia (Jensen & Moestrup, 1997) and one report of mussel toxicity (as *Pyrodinium phoneus*) in Belgium (Woloszynska & Conrad, 1939). Recently, a study of aquaculture shellfish from Nova Scotia (Canada) revealed the presence of spirilides, fast-acting neurotoxins, primarily produced by western Atlantic strains of *A. ostenfeldii* (Cembella *et al.*, 2000). Hansen *et al.* (1992) conducted studies with a tintinnid ciliate exposed to high concentrations of *A. ostenfeldii* resulting in an erratic swimming behaviour (backwards) followed by swelling and lysis of the ciliates.

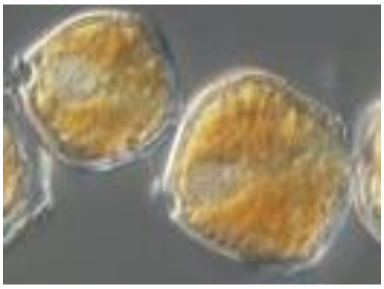

Figure 2: Alexandrium ostenfeldii © Lewis N.

3. *Amphibalanus eburneus (Balanus eburnus)*

The ivory barnacle is a euryhaline species, capable of withstanding a wide range of salinities (6-40 psu; Bacon, 1971). The species tolerates a temperature range from 0 to 30°C, while the optimum condition for free swimming larvae is 14°C (Leppäkoski, 1999). Like other species of barnacles, *B. eburneus* poses an economic threat to several marine-associated industries. Adults and juveniles can attach to ship hulls, creating drag and increasing fuel costs. In addition, intakes of marine-cooled nuclear power plants can become fouled, requiring costly removal. In regions where the ivory barnacle is invasive, *B. eburneus* can alter food webs and have other devastating impacts on local ecosystems. However, in their native habitat, ivory barnacles and their associated fouling organisms can form extensive fouling communities that provide a home and food source for a variety of coastal fishes and invertebrates (Smithsonian Marine Station at Fort Pierce, 2009).

Figure 3: Amphibalanus eburneus (Balanus eburnus) © Sweat H.L.

4. *Austrominus modestus (Elminius modestus)*

The Australasian barnacle can grow rapidly and is resistant to low salinity and water turbidity. The species generally tolerates salinity levels between 19 and 40 psu and temperatures ranging from 4 up to 24°C, but is able to survive temperatures below 0°C (Crisp & Davies, 1955). The initial growth rate of the species is fast. These barnacles can, when the temperature is high enough, produce multiple clutches per year. They compete with a.o. native barnacles, oysters and mussels for food and space, allowing them to pose a threat to the local native fauna. Although oyster spat could overgrow and smother *A. modestus*, they became misshapen and stunted, and so less valuable for the oyster industry. The common barnacle has almost completely disappeared in some areas after the release of the Australasian barnacle. Ships may suffer a less efficient use of fuel and increasing maintenance costs due to fouling (e.g. Schultz *et al.*, 2011).

Figure 4: Elminius modestus © Decleer M.

5. *Callinectes sapidus*

This blue crab supports large valuable commercial and recreational fisheries in the temperate areas of the Atlantic and Gulf coasts of the USA. It is the most widely harvested and consumed crab in the USA. The species can cope with high temperature (3-35°C) and salinity (5-48 psu) ranges, but water temperature should be between 15 and 30°C to allow reproduction (Adema, 1984). *C. sapidus* has been reported to mutilate fish caught in traps and trammel nets and to tear nets. As the species prefers to prey on clams, mussels and oysters, it impacts commercial fisheries and aquaculture. Predation rates can be quite high (575 clams/day) on unprotected shellfish beds (CABI).

Figure 5: Callinectes sapidus © KaveneyW.

6. *Caprella mutica*

C. mutica is one of the largest caprellid amphipods, mature males attain body lengths of >50 mm (Nishimura, 1995). The species is generally observed in environments characterised by salinities between 18 to 35 psu, but may tolerate levels between 11 and 40 psu (Ashton *et al.*, 2007). Its tolerable temperature ranges from -1.8 up to 25°C (Ashton *et al.*, 2007). *C. mutica* is frequently associated with man-made structures and has been observed on boat hulls, buoys, floating pontoons and aquaculture infrastructure. Many of the areas where *C. mutica* has been introduced are located in the vicinity of busy ports suggesting that ballast water transport and/or hull fouling could be involved (Cook *et al.,* 2007). Living *Caprella* spp. have been found in ships' ballast tanks (Carlton, 1985) and in sea-chests in a study in New Zealand (Coutts *et al.*, 2003). Futhermore, the species has the ability to outcompete ecologically similar native species (Boos, 2009 ; Shucksmith *et al.*, 2009 ; Boos *et al.,* 2011). Detailed knowledge on community or ecosystem level impacts of the species is still lacking (Boos *et al.*, 2011; Katsanevakis *et al.*, 2014).

Figure 6: Caprella mutica © Vanderperren, J-P.

7. *Caulerpa cylindracea*

C. cylindracea is a green alga widely distributed in tropical and warm-temperate regions. The species generally lives in warm waters (18 and 24°C), but may survive winter temperatures as low as 10.5°C and maximum water temperatures of 25°C (Verlaque *et al.,* 2000; CABI). The tolerable salinity levels range between 10 and 40 psu (Verlaque *et al.*, 2003). The species forms a dense green carpet with a conspicuous rhizoid development, from 1-70 m depth, on any kind of seaweed (rocky bottoms, concrete, sand and mud), the only exception being unstable sands. The prevention of future introductions is essential because control/eradication programmes are costly and unlikely to succeed (Zaleski & Murray, 2006). The population is able to expand very rapidly in the affected areas due to the fast growth rate, sexual reproduction and vegetative propagation (Zaleski & Murray, 2006). Therefore, a further spread

Figure 7: Caulerpa cylindracea © Dokuz Eylül Üniversitesi

through shipping (ballast water, anchors, fishing nets, etc.) must be prevented. The spread of *C. cylindracea* induces a homogenisation of habitats and a decrease in diversity and invertebrate abundances. The species also produces some metabolites showing phytotoxic effects, and research suggests a possible allelopathic activity of caulerpenyne, which may play a role in the successful competition of the invasive *C. cylindracea* with native macrophytes, such as seagrasses (Raniello *et al.*, 2007).

8. *Cercopagis pengoi*

Figure 8: Cercopagis pengoi

C. pengoi is a predatory cladoceran and is native to the Ponto-Aralo-Caspian Basin. The species tolerates a broad range of salinity, temperature and eutrophication conditions and is highly invasive. In addition, the resting eggs of this water flea can be transported over long distances, and can even survive cold winters on the sea bed. It has become invasive in Eastern Europe, the Baltic Sea and the Great Lakes of North America. In these new habitats, the introduction was characterised by a rapid establishment and a fast increase in abundances. Introductions occur either through the construction of canals between river water basins, ballast water discharge or boat traffic. *C. pengoi* attaches to fishing gear and clogs nets and trawls, causing problems and substantial economic losses for fishermen and fish farms (Leppäkoski & Olenin, 2000; Birnbaum, 2011; Katsanevakis *et al.,* 2014). It is a voracious predator and may notably reduce the density of its prey e.g. small-sized cladocerans. If zooplankton abundance is markedly depleted, higher concentrations of phytoplankton may result, ultimately aggravating problems of eutrophication. Through food competition, *C. pengoi* has the potential to affect the abundance and condition of zooplanktivorous fish, fish larvae and mysids. The species itself becomes important food for the alewife, nine-spined stickleback, bleak, herring and smelt (Uitto *et al.,* 1999; Benoit *et al.*, 2002; Vanderploeg *et al.*, 2002; Bushnoe *et al.*, 2003; Kotta *et al.*, 2004b, 2006; Põllumäe & Kotta, 2007).

9. *Corbicula fluminea*

Figure 9: Corbicula fluminea © van Meerkerk A.

C. fluminea tolerates wide salinity (0-24 psu; Evans *et al.*, 1979; Elliot & zu Ermgassen, 2008) and temperature ranges (2-30°C; Balcom, 1994). The major pathways for introduction include hull attachment and ballast water. In the USA, *C. fluminea* has caused millions of dollars of damage to intake pipes used in the power and water industries (Anon, 2005). The major concern in terms of social impact is the fact that *C. fluminea* may act as a potential vector of diseases. The high abundances of Corbiculidae family and the vast and wide range of organisms that use bivalves as a final or secondary host are responsible for health problems in its native range in humans and animals (Sousa *et al.,* 2008). Pathway transmission is by eating clams raw or barely cooked (Carney *et al.*, 1980; Darrigran, 2002; Sousa *et al.,* 2008).

10. *Coscinodiscus wailesii*

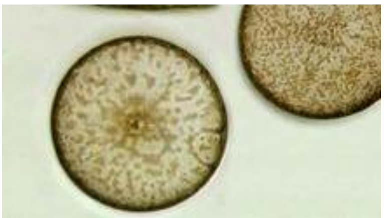

Figure 10: Coscinodiscus wailesii © Hoppenrath M.

C. wailesii is a large solitary diatom found in coastal and oceanic waters between 8 and 32°C and 25 to 35 psu (Rincé & Paulmier, 1986). In Europe, this diatom was first observed in 1977 in the English Channel, forming a bloom producing enormous amounts of slime, which clogged trawls and made fishing difficult by accumulating clay particles (Boalch & Harbour, 1977; Boalch, 1984; 1987; Edwards *et al.,* 2001). The huge slime production may negatively impact recreation. Substantial damage is caused if the copious mucilage sinks and covers the seabed, likely causing anoxic conditions (DAISIE, 2013). During a mass bloom of *Coscinodiscus wailesii*, also other organisms (mainly phytoplankton and macroalgae) are threatened due to competition for space and food. The species is also subject to parasitic infections by the nanoflagellate *Pirsonia diadema*, which is at least partly specific to this diatom (Kühn, 1998).

Fatal infections by the bacterium *Alteromonas* sp. are also known (Nagai & Imai, 1998).

11. *Crassostrea gigas*

C. gigas lives in variable environments, ranging from 5-45 psu and 3-35°C (CABI). However, a minimum water temperature of 16-18°C is needed for reproduction (VLIZ alien species consortium, 2011a). Although highly variable, the invasiveness pattern of *C. gigas* has been demonstrated in several countries and it is therefore considered as a pest or a noxious species in such areas (Orensanz *et al.*, 2002). The introduction of *C. gigas* has had economic side effects in several countries such as Australia (New South Wales), where the native Sydney rock oyster was partly outcompeted by *C. gigas*, leading to the collapse of several businesses. Indirect economic impacts concern increasing coastal management costs to limit *C. gigas* reef expansion, and eradication costs. In other regions, the species poses no problem, being considered of economic interest (McKenzie *et al.,* 1997; Leppäkoski *et al.*, 2002; Escapa *et al.*, 2004). Considering that only about 5.25% of the worldwide production originates from its native range, *C. gigas* overall introduction has had a highly significant economic impact, amounting to US $3,305 million on a yearly basis (FAO, 2004). In several countries, the introduction has resulted in building a sustainable shellfish industry providing direct revenues for thousands of farmers and concomitant activities (e.g., equipment). Moreover, a highly valuable (and unaccountable) indirect economic impact concerns the lasting establishment of coastal communities in otherwise unfavourable rural areas, therefore playing a significant role in coastal management values. As an example, the 1970s oyster crisis in European waters caused by the fast disappearance of disease-impacted *Crassostrea angulata* populations was solved by the introduction of *C. gigas* which saved the collapsing industry (Goulletquer & Héral, 1992; NAS, 2004).

Figure 11: Crassostrea gigas © Yulyfish Copyright

12. *Crepidula fornicata*

C. fornicata can tolerate salinity levels between 20 and 40 psu and water temperatures of 5 to 30°C (CABI). The sea floor can reach densities of up to 10,000 individuals/m^2 as in the bays of Brittany (Blanchard, 2009), causing severe and irreversible impacts on the sediment, the biodiversity and the concentration of suspensed matter. Dense limpet populations disturb fisheries or oyster farming activities to such an extent that in some bays (Scheldt Estuary in Zeeland, Thames estuary and Fal River (Fitzgerald, 2007) in Great Britain, the Norman gulf or the Atlantic Marennes pond in France), cleaning operations are necessary. When limpets are fixed on oysters, oyster farmers must pick off limpets before selling the products, which creates an extra economic burden (Blanchard, 1997). Expensive treatment methods have been developed, often without success. Dense populations of *C. fornicata*, which is a suspension feeder, can have an impact on the available concentrations of phytoplankton and organic matter causing trophic competition with other suspension feeders. This mainly occurs in case of low food levels, causing slower growth in other species (De Montaudouin & Sauriau, 1999; Decottignies *et al.,* 2007a, b).

Figure 12: Crepidula fornicata © Zell H.

13. *Didemnum vexillum*

Figure 13: Didemnum vexillum © Toppin B. (UNH)

D. vexillum, a compound ascidian (tunicate or sea squirt), belongs to the family Didemnidae (Kott, 2002; Lambert, 2009; Stefaniak *et al.*, 2009). Since its identification in 1988 (Kott, 2002), the number of observations have dramatically increased across the globe. The specific vectors for introduction are largely unknown (Coutts & Forrest, 2007), though international shipping, local boat traffic and transport of aquaculture species are likely sources (Carlton, 1989; Dijkstra *et al.*, 2007). Didemnids possess chemical defences (Pisut & Pawlik, 2002) and an acidic tunic (Bullard *et al.*, 2007a), and tolerate a wide range of temperatures (2-28°C) (Bullard *et al.*, 2007a; Dijkstra *et al.*, 2007; Valentine *et al.*, 2007, 2009), salinities (20-45 psu) (Dijkstra *et al.*, 2007; Bullard & Whitlatch, 2009) and nutrients (Carman *et al.*, 2007). Like all ascidians, they produce lecithotrophic larvae that spend less than 24 hours in the water column before settling on suitable substrate and metamorphosing into adult colonies that allow them to build up local populations. In addition, didemnids can disperse through larvae or through fragmentation (Bullard *et al.*, 2007b). They have few known predators (Lambert, 2009) and undergo fast rates of growth (Valentine *et al.*, 2007). All of these characteristics allow *D. vexillum* to successfully occupy new habitats and become a dominant spatial competitor. Coutts and Forrest (2007) examined a variety of eradication techniques and determined that regional eradication is unlikely, but eradication at small-scales may be possible.

14. *Dikerogammarus villosus*

Figure 14: Dikerogammarus villosus © Devin S.

D. villosus, nicknamed the 'killer shrimp', is a freshwater amphipod originating from the Ponto-Caspian region. The species has an upper tolerance limit for salinity of 24 psu (Bruijs *et al.*, 2001) and is able to survive in waters with temperatures between 0-35°C (Bruijs *et al.*, 2001; Wijnhoven *et al.*, 2003). Its range expansion began in the late twentieth century and was associated with reopening of the shipping canal between the Danube River and Main River (Bij de Vaate *et al.*, 2002). Large body size, extremely voracious predatory behaviour, high fecundity and wide environmental tolerance make this amphipod a very successful invader of European waters (e.g. Dick *et al.*, 2002). Invasion of *D. villosus* often results in significant local reduction or even extinction of native amphipods and other macroinvertebrates on which it preys (reviewed in Haas *et al.*, 2002; Grabowski *et al.*, 2007). The species is included on the list of the 100 most invasive exotic species of Europe (Devin & Beisel, 2009), and has been deemed the worst non-native invader of England and Wales's waterways by the Environment Agency (BBC, 2011). In all the European aquatic systems where it has become established, *D. villosus* has largely replaced both indigenous and exotic amphipod species (Kelleher *et al.*, 1999; Dick & Platvoet, 2000; Whitfield, 2000; Dick *et al.*, 2002; Kley & Maier, 2003; Bollache *et al.*, 2004; MacNeil & Platvoet, 2005; Lods-Crozet & Reymond, 2006). In addition, it readily consumes fish eggs (Casellato *et al.*, 2007) and even attacks fish larvae (Schmidt & Josens, 2004). Due to its predatory activities, *D. villosus* significantly changes natural food webs of invaded ecosystems and occupies high trophic levels comparable to fish (Van Riel *et al.*, 2006). However, *D. villosus* is also an omnivorous species able to act as an effective filter feeder on microalgae (Platvoet *et al.*, 2006).

15. *Dinophysis sacculus*

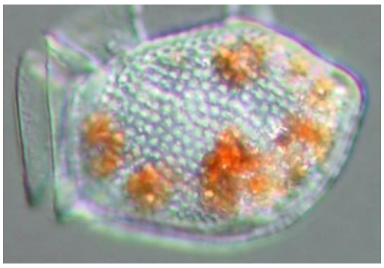

Figure 15: Dinophysis sacculus © Bengt Karlson

D. sacculus is an armoured, marine, planktonic dinoflagellate species. *D. sacculus* has been found to produce okadaic acid (OA) (Masselin *et al.*, 1992; Giacobbe *et al.*, 1995; Delgado *et al.*, 1996). It has been linked to diarrhetic shellfish poisoning (DSP) occurrences along the Mediterranean and Atlantic European coasts (Alvito *et al.*, 1990; Sampayo *et al.*, 1990; Lassus & Marcaillou-Le Baut, 1991; Belin, 1993; Boni *et al.*, 1993; Marasovic *et al.*, 1998; Hallegraeff, 2003; Cembella *et al.*, 2005; Austoni *et al.,* 2006).

16. *Dreissena bugensis*

Figure 16: Dreissena bugensis © Trausel and Slieker

D. bugensis is a sessile filter feeder capable of reaching extremely high densities. Due to these biological traits, *Dreissena* spp. can substantially affect the environment, food webs and biodiversity of the invaded ecosystems (e.g. Karatayev *et al.*, 1997; 2002), and cause tremendous economic damage in raw water-using industries, potable water treatment plants and electric power stations (Pimentel *et al.*, 2005). Furthermore, the mussels negatively impact fire prevention systems, navigation dams, docks, buoys, hulls, recreational activities, etc. (e.g. Molloy, 1998; Minchin *et al.*, 2002; ZMIS, 2006). In the USA alone, the estimated costs associated with *D. bugensis* amounts about 1 billion dollars a year (Pimentel *et al.*, 2005). Invasion of the species results in decreased phytoplankton densities and chlorophyll concentrations (see Karatayev *et al.*, 1997; 2002, 2007; Idrisi *et al.*, 2001; Vanderploeg *et al.*, 2002; Mills *et al.*, 2003; Burlakova *et al.*, 2005). However, the increased nutrient flux from the mussels in combination with selective grazing can facilitate certain algal species, such as cyanobacteria that cause water blooms (Vanderploeg *et al.*, 2001; Pillsbury *et al.*, 2002, Raikow *et al.*, 2004). Zooplankton abundances usually decline after invasion of *D. bugensis*. This decrease may result from competition for food (phytoplankton, planktonic bacteria and other suspended particles), direct filtering of small-sized zooplankton, or from more complex interactions, such as increased predation of zooplankton by fish (see Karatayev *et al.*, 1997; 2002; 2007; Kryuchkova & Derengovskaya, 2000; Wong *et al.*, 2003; Kissman *et al.*, 2010). *D. bugensis* also serves as a host to about 20 taxa of parasites and commensals (Molloy *et al*., 1997).

17. *Dreissena polymorpha*

Figure 17: Dreissena polymorpha © USGS

D. polymorpha has been the most aggressive freshwater invader worldwide. However, the species may cope with salinities up to 11 psu. The upper tolerance limits for temperature are 0 to 32°C, but the optimal temperature measures between 17 and 25°C (Olenin *et al.*, 1999; CABI). *D. polymorpha* causes (1) a decrease of oxygen concentrations from mussel respiration and elimination of phytoplankton, (2) an increase of dissolved nutrients from excretion, (3) accumulation, biosedimentation and deposition of pollutants and trace elements and (4) deposition of organic matter that is contained in faeces and pseudofaeces (invasive species specialist group). The species attaches to crayfish, turtle shells as well as other mussels. The loss of native mussel populations has increased dramatically where *D. polymorpha* are present. Dense colonisation of hard substrates is beneficial to benthic invertebrates, as habitat complexity and the availability of organic matter increases. The species also adversely impact recreational activities such as bathing (foot lacerations) (Minchin *et al.*, 2002).

18. *Ensis americanus (E. Directus)*

The species shows large annual temperature tolerances (6-26°C), but low winter temperatures seem to limit its development (Essink, 1994). Its salinity tolerance is 7-32 psu (Maurer *et al.*, 1974). Therefore, it occurs in both marine and estuarine environments (Beukema & Dekker, 1995). *E. directus* was first found in European waters in 1979 in the German Bight of the North Sea (Von Cosel *et al.*, 1982). The species originates from North American Atlantic waters and is thought to be transported via ballast water tanks of ocean crossing vessels. The species rapidly colonises new areas and causes competition for food and space. The species is fit for human consumption and due to its abundance new shellfish fisheries have developed in European waters.

Figure 18: Ensis americanus © Poppe G.

19. *Eriocheir sinensis*

E. sinensis (mitten crab) is an opportunistic omnivore capable of eating a wide variety of invertebrates as well as fish eggs, algae and detritus (Dittel & Epifanio 2009). The burrowing activity of crabs, especially large numbers of juveniles, accelerates the erosion of dykes, stream banks and levées in European countries. Mitten crabs have affected commercial and recreational fishing by damaging nets/gear and killing netted species. Water intakes were reported to be clogged by mitten crabs during mass developments. Crabs probably damage the aquatic food chain of freshwater and estuarine habitats. They affect other species through competition, overlapping in dietary and habitat preferences. In the UK they may threaten populations of native crayfish (NHM, 2004). This species is a host for lung fluke in Asia, however, the fluke has not yet been reported in the crab's European range (Gollasch, 2006).

Figure 19: Eriocheir sinensis © Herborg Leif-Matthias

20. *Fibrocapsa japonica*

F. japonica is a microalgae belonging to the class Raphidophyceae. The species has an optimal temperature for growth between 10 and 26°C. It can nevertheless tolerate temperatures below 10 and above 26°C, provided optimal temperatures for growth occur during a certain time period within the year (Kooistra *et al.*, 2001). As for salinity, the optimum for growth lies between 11 and 20 psu (Vrieling *et al.*, 1995). The species can be found either in the water column or in the sediment, in the form of cysts, notably during periods of environmental stress (Kooistra *et al.*, 2001; Vrieling *et al.*, 1995). The species produces a neurotoxin – fibrocapsine – leading to harmful algal blooms (Agency, 2011). *F. japonica* is thought to have caused massive fish mortality events in Japan's coastal waters as well as the death of seals in Germany and the Netherlands (Agency, 2011; Vrieling *et al.*, 1995).

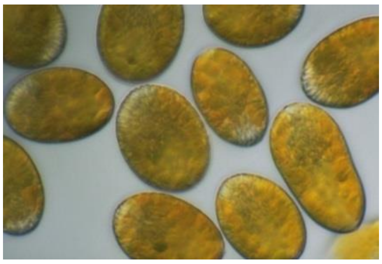

Figure 20: Fibrocapsa japonica © LeRoy C.

21. *Ficopomatus enigmaticus*

F. enigmaticus has a temperature tolerance of 0 to 30°C, mainly occurring between 10 and 20°C. Its salinity tolerance ranges from 0.2 up to 45 psu, with optimal conditions between 10 and 30 psu (CABI). The species is an invasive, ecosystem engineering, brackish-water serpulid polychaete that builds calcareous aggregates in estuarine and coastal environments within subtropical/temperate areas throughout the world. The most important dispersion worldwide is likely to occur via hull fouling and/or in ballast water in large vessels. Within Europe, the species is listed as one of the 100 worst invasive species (DAISIE) but so far, there are no unified strategies for its control or management. This species has a fast growth rate, high tolerance to variable environmental conditions and it is causing important ecological impacts in several regions by modifying the ecological and the physical processes of the ecosystems. In some locations, economic impacts occur due to the prolific growth that can cause blocking of thermal effluents and fouling of aquaculture ponds and leisure crafts. *F. enigmaticus* is one of the major fouling agents on

Figure 21: Ficopomatus enigmaticus © Harris Leslie, NHMLAC

artificial surfaces and has become a nuisance in ports and marinas throughout the Mediterranean (Streftaris & Zenetos, 2006). It impacts both ships and piers but also port structures where it clogs pipes and blocks tide-gates (WGITMO, 2001).

22. *Gammarus tigrinus*

G. tigrinus is highly euryhaline. In its native area, it lives in brackish water with salinities ranging from 4 to 20 psu (Kelly *et al.*, 2006). In Flanders, the species has been observed between 0 and 9.6 psu (Boets *et al.*, 2011b), while some authors put the upper salinity tolerance limit on 29.5 psu (Pinkster *et al.*, 1977). The species has a wide temperature range from 10 to 34.2°C (e.g. Wijnhoven *et al.*, 2003). The species is able to outcompete many native gammarids in oligohaline waters. In any case the original amphipod fauna has been drastically changed in several places in northern Europe (Pinkster *et al.*, 1992; Jazdzewski *et al.*, 2004; Grabowski *et al.*, 2006; Surowiec & Dobrzycka-Krahel, 2008; Zettler, 2008). Life-history traits, such as early maturation, large brood size and short generation time have been identified as possible reasons for the competitive superiority of *G. tigrinus* (Pinkster *et al.*, 1977; Costello, 1993). Parasitism, both in native and invasive species, may also be involved in determining competitive success (MacNeil *et al.*, 2003a,b), whereas differences in microhabitat preference and diel activity patterns have been demonstrated in cases of coexistence (MacNeil & Prenter, 2000; van Riel *et al.*, 2007). *G. tigrinus* is an intermediate host for the eel parasite *Paratenuisentis ambiguus*, in Germany, but as only laboratory reared amphipods were introduced from England to Germany, it is unlikely that the acanthocephalan parasite was brought to Germany with the amphipod (Taraschewski *et al.*, 1987). The parasite has recently been found in eels in Polish coastal waters (Morozińska-Gogol, 2008), and may also occur in other localities within the introduced range of *G. tigrinus*. When occurring in high densities, *G. tigrinus* has had damaging effects on fishing gear and trapped fish (Pinkster *et al.*, 1977).

Figure 22: Gammarus tigrinus © Sareyka J.

23. *Gracilaria vermiculophylla*

G. vermiculophylla is able to grow in a wide range of temperatures (5-35 °C) and salinities (5-60 psu). Optimum growing conditions occur between 15-25 °C and 10-45 psu (Raikar *et al.* 2001; Rueness, 2005). *G. vermiculophylla* inhibits the growth and survival of native algae through competition (Council of Europe, 2009; Hammann *et al.,* 2008). It has been demonstrated to have negative effects on native seagrass beds of *Zostera marina* by decreasing net leaf photosynthesis and survival rates. Negative effects on seagrass are greater at higher temperatures, suggesting that impacts could increase with future ocean warming (Martínez-Lüscher & Holmer, 2010). In high abundance, *G. vermiculophylla* may have dramatic effects on ecosystems. Loose-lying *G. vermiculophylla* populations have the potential to develop into dense mats, particularly in shallow bays, lagoons, harbours and estuaries. These mats can modify the habitat available for the benthic faunal community and bottom dwelling fish. Algal mats can also form physical barriers for settling larvae, decrease light intensity, increase the likelihood of anoxia and change water movement patterns, which in turn affects sedimentation rate and thus food availability for deposit feeders (Nyberg *et al.*, 2009). Additionally, the movement, accumulation and decomposition of the species is likely to have important implications for nutrient cycling and trophic dynamics in areas it invades (Thomsen *et al.,* 2009). *G. vermiculophylla* is also reported to be a problem in fishing industries through fouling of nets (Freshwater *et al.,* 2006).

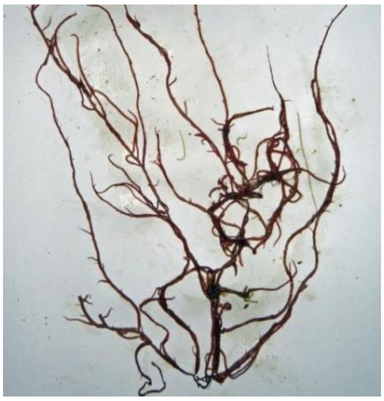

Figure 23: Gracilaria vermiculophylla © Pereira L.

24. *Grateloupia doryphore*

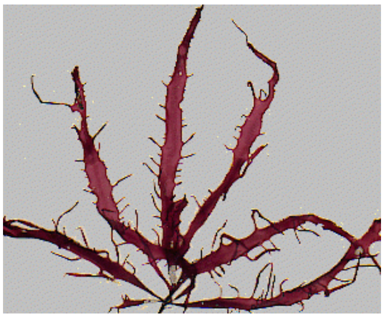

Figure 24: Grateloupia doryphore

G. doryphore is a red macroalgae of the phylum Rhodophyta. The species grows in both sheltered and exposed places and attaches to various hard surfaces. Its thallus is red purple to brown, presents a gelatinous texture and is usually submerged by 15–45 cm seawater. However, thalli measuring 30 cm in length have been found on intertidal rocks (Simon *et al.*, 2001). *G. doryphore* has broad salinity and temperature tolerances and adapts to waters disturbed by eutrophication. *G. doryphore* populations develop normally at water temperatures ranging from 4°C in winter to 28°C in summer and at salinities ranging from 15 to 37 psu. (Simon *et al*., 2001) It can develop to a length of three meters and has been considered the biggest red algae in the world (Simon *et al.*, 2001).

25. *Grateloupia turuturu*

Figure 25: Grateloupia turuturu © Fenwick D.

G. turuturu generally lives in waters between 22 to 37 psu salinity, but can survive 12-52 ppt and 4-29°C (Simon *et al.*, 1999; 2001). *G. turuturu* is a nuisance organism that can outcompete many native seaweeds within the low intertidal and shallow subtidal zones due to its large size and ability to reproduce quickly via sporic and vegetative reproduction (Barillé-Boyer *et al.*, 2004; MIT Sea Grant Coastal Resources, 2009). Thus, it can alter typical trophic patterns and cause a loss of habitat (Vitousek *et al.*, 1997; Walker & Kendrick, 1998; Marston & Villalard-Bohnsack, 1999; Simon *et al.*, 2001; Torbett *et al.*, 2004; Wallentinus & Nyberg, 2007). The plant is known as an effective invader (Farnham, 1980; Harlin & Villalard-Bohnsack, 2001; Balcom, 2009), as it grows fast and has a high reproductive output. As *G. turuturu* has broad patterns of growth, reproduction and physiological tolerances, it is considered to be one of the five most-threatening introduced species with respect to its potential to become invasive (Nyberg & Wallentinus, 2005; Inderjit *et al.*, 2006). Researchers have found that, in the presence of light, this alga has an inhibiting effect on bacteria (Pang *et al*., 2006).

26. *Hemigrapsus sanguineus*

Figure 26: Hemigrapsus sanguineus © Altieri A.

H. sanguineus is a relatively small intertidal shore crab. The species tolerates a wide range in salinity (10-34 psu, e.g. Boets *et al.*, 2013) and water temperature (5-30°C, CABI). In September 1988, this species is found to be invasive in Europe (Dauvin *et al.*, 2009). It is able to achieve extremely high densities with apparent negative impacts on small recruits and juveniles of several native species (barnacles, littorine snails, brachyuran crabs, mytilid bivalves) (Lohrer & Whitlatch, 2002a,b). The apparent replacement of *Carcinus maenas* (European green crab) by *H. sanguineus* has ecological and economic implications. The invasion by *H. sanguineus* probably represents a net negative influence on blue mussel populations in the rocky intertidal zone (Lohrer, 2001).

27. *Hemigrapsus takanoi*

Figure 27: hemigrapsus takanoi © van Bragt Peter H.

H. takanoi is a small crab native to the rocky coasts of northwest Pacific regions (Asakura & Watanabe, 2005). In its native range, *H. takanoi* can be commonly found in bays and estuaries, including areas where salinities and temperatures fluctuate highly (7-35 psu and 12.5-20°C, respectively) (Mingkid *et al.*, 2006). Possible vectors of introduction in Europe include accidental transport in hull fouling, ballast water and oyster shipments. In Europe, the species outcompetes the native European green crab *Carcinus maenas* in rocky shore habitats, particularly where it occurs in high densities. Its recent invasion and establishment in the coastal and delta waters in the Netherlands is thought to impact especially upon newly settled shellfish, such as mussel and oyster splat through predation (van den Brink, 2013).

28. *Hemimysis anomala*

H. anomala is a small mysid shrimp native to the Ponto-Caspian region. In the 1950s and 1960s it was used to stock reservoirs in Eastern Europe to promote fish production (Grigorovich *et al.*, 2002). Following successful population establishment in these reservoirs, *H. anomala* was passively transported to the Baltic Sea, where the first accidentally introduced invasive populations were reported in the Curonian Lagoon off the Lithuanian coast in 1962 (Gasiunas, 1964). Further range expansion has been facilitated by their wide salinity (0.5-18 psu) (Janas & Wysocki, 2005; Ellis & MacIsaac, 2009) and temperature tolerance (2-28°C) (Wittmann, 2007), which has enabled the mysid to be transported over great distances in ballast water and to become established in a wide variety of habitat types. It has now been observed in numerous countries across mainland Europe, the United Kingdom and North America. It can reach high population densities in newly invaded habitats (Ketelaars *et al.*, 1999; Holdich *et al.*, 2005; Borcherding *et al.*, 2006; Pothoven *et al.*, 2007; Wittmann, 2007) and may outcompete species with similar dietary requirements (e.g. Verslycke *et al.*, 2000). The species acts as a top-down regulator of the plankton community and can therefore alter community structures at multiple trophic levels, potentially lowering the number of trophic levels and thus reducing ecosystem stability (Salemaa & Hietalahti, 1993; Ketelaars *et al.*, 1999). It can therefore have a significant impact on the ecology of a receiving environment (Ketelaars *et al.*, 1999). The economic impacts of *H. anomala* populations is still relatively minor and localised, and may be either positive or negative. The species is known to consume the blue-green algae (cyanobacteria) responsible for toxic algal blooms (Ketelaars *et al.*, 1999). *H. anomala* has also established populations in drinking water reservoirs (Ketelaars *et al.*, 1999), and if the mysid can indeed reduce the abundance of cyanobacteria, this could potentially reduce drinking water production costs.

Figure 28: Hemimysis anomala © Pothoven S.

29. *Hydroides dianthus*

This species originates from the East Coast of North America and was probably introduced from there, or possibly from the Mediterranean, where it is widespread within harbours and lagoons (Zibrowius, 1971). The salinity tolerance range for the species is 28-50 psu (Zibrowius, 1971), while the recorded range for temperature is 11-24°C (Encyclopedia of Life). It was possibly introduced as a fouling organism, transported on ships hulls, while larvae could be transported in ballast water. Nelson & Stauber (1940) reported that *H. dianthus* may kill young oysters by overgrowing them in its native area of eastern North America. It is also the host of certain nematode stages in eastern North America.

Figure 29: Hydroides dianthus

30. *Hydroides elegans*

H. elegans is a small tube-forming serpulid polychaete worm commonly found in hard-bottom coastal and estuarine fouling communities. Ship hull fouling is widely suggested as the most important transport vector in the spread of *H. elegans*, with accidental transport in shipments of harvested wild or cultured bivalves noted as a secondary source of introduction (NIMPIS, 2015). The species competes with co-occurring fouling community species for space, food, and possibly other resources. For example, NIMPIS (2015) reports that competition by *H. elegans* for food and oxygen has been implicated in up to 60% mortality for cultured oysters in Japan. The native North American congener *H. dianthus* has been similarly implicated in the mortality of juvenile oysters from smothering. Additionally, tube-forming species like *H. elegans* are considered to be "ecosystem engineers" capable of modifying the habitats in which they occur. Architectural habitat modification due to the presence of calcareous tubes would be expected to affect community structure at local

Figure 30: Hydroides elegans © Granitch G.

scales. Direct economic impacts of these tube-dwelling biofoulers include the cost of cleaning ship hulls, aquaculture gear and other submerged structures. Other costs include decreased operational efficiency of fouled vessels due to drag and of water intake pipes due to clogging (NIMPIS 2015; Smithsonian Marine Station at Fort Pierce).

31. *Karenia (*syn*. Gymnodinium) mikimotoi*

Figure 31: Karenia mikimotoi © University of Liverpool

K. mikimotoi is a dinoflagellate with an oval shape. The species tolerates water salinity levels from 5 to at least 35 psu (e.g. Shikata *et al.*, 2014). Although the species is non-toxic to humans (Hallegraeff, 2003), this dinoflagellate produces haemolytic cytotoxins and has caused harmful algal blooms (HABs) that resulted in massive aquatic life mortality (Yamaguchi *et al.*, 1997; Hopkins, 2001; Gomez, 2008; Davidson *et al.*, 2009; ICES, 2009; Reid *et al.*, 2009; Schultz & Kiorboe, 2009, Chang, 2011; Agency, 2011, O'Brien *et al.*, 2012). The release of exotoxins enables *K. mikimotoi* to gain competitive advantage over other phytoplankton species, particularly dinoflagellates and diatoms (Vanhoutte-Brunier, 2008).

32. Lophocladia lallemandii

Figure 32: Lophocladia lallemandii © www.biomare.it

L. lallemandii is a marine filamentous red algae up to 15 cm in height. The pathways of introduction are still under discussion, but dispersal via shipping and other maritime activities is suspected. The species possess very successful strategies for dispersal. It reproduces sexually only during summer and autumn, while its vegetative reproductive activity occurs throughout the year, with minimal growth during late autumn and winter. Moreover, besides reproducing vegetatively through spore dispersal, it can spread by fragmentation. This species is easily broken and free-floating filaments produce small, disc-like holdfasts that are able to attach to a large variety of floating substrates (Cebrián & Ballesteros, 2010). Due to its high invasive potential, it is able to cover most kinds of substrate causing homogenisation of the benthic landscapes (Boudouresque & Verlaque, 2002). The species has an aggressive behaviour when colonising *P. oceanica* meadows, causing a major decrease in seagrass density and growth that can lead to plant mortality (Ballesteros *et al.*, 2007). This species completely overgrows macroalgal assemblages and also affects the benthic invertebrate community (Cebrián & Ballesteros, 2010). Currently, little is known about the biology of this species and its invasion mechanisms. However, recent studies point to negative effects of *L. lallemandii* colonisation, and stress the need to address interaction effects across natural communities and invaded systems before associated and irreversible effects are caused (Ballesteros *et al.*, 2007, Deudero *et al.*, 2010; Peireira & Neto, 2014).

33. Marenzelleria neglecta

Figure 33: Marenzelleria neglecta © Andrius Siaulys

M. neglecta competes with native benthic macrofauna for food and space. It can change the structure of a native benthic community and influence the balance of organisms in a particular ecosystem when occurring in high abundances (e.g. Kotta *et al.*, 2001; Kotta & Olafsson, 2003). The burrowing activity of this worm has a high impact on fluid-exchange rates between bottom water and sediments, especially in muddy sediments. The burrow walls make good substrates for aerobic degradation of organic matter (HELCOM, 1996; Olenin, 2006).

34. Marenzelleria viridis

M. viridis is an annelid worm of the class Polychaeta which is common in fine-grained substrate, both in marine and brackish nearshore waters. The larvae of the species are unable to complete their development to metamorphosis at salnities below 5 psu (Bochert *et al.*, 1996). Individuals can reach a length of 10 cm and its diameter ranges from 3 to 4 mm (Schiedek, 1997). The polychaete makes burrows in the sediment (Quintana *et al.*, 2007; 2011). It produces a large number of planktonic larvae that remain in this stage during a relatively long period. Therefore, the species can be easily transferred through ships' ballast waters (Bastrop *et al.*, 1998; NORSAS). The red-gilled mud worm competes with native benthic macrofauna for food and space. Being numerically dominant it can change the structure of a native benthic community.

Figure 34: Marenzelleria viridis © Kirstensen Erik

35. Microcosmus squamiger

M. squamiger is a relatively small (up to 4 cm) solitary ascidian. It its native range the species lives on both rocky and artificial substrates. In the introduced range the species is found mostly inside marinas, harbours and aquaculture facilities forming dense aggregates. It can, however, colonise adjacent natural communities, forming dense crusts that can outcompete native species (e.g. Turon *et al.*, 2007). Lowe (2002) pointed at the ability of *M. squamiger* to withstand reduced salinity conditions to 15 psu, while it tolerates a maximum salinity of 36 psu. The species shows a marked northern limit in its geographical distribution (Lambert & Lambert, 2003), being absent in case of water temperatures below 10°C. The maximum tolerable temperature is 30°C. The economic impact of *M. squamiger* is mainly related to its interference with oyster cultures, where it competes for food and space (e.g. Kott, 1985). The fouling capacity of *M. squamiger* can also have an impact on immersed structures, pipelines and refrigeration filters, although this has never been formally reported.

Figure 35: Microcosmus squamiger © Griffiths and Rius

36. Mnemiopsis leidyi

The ctenophore *M. leidyi* is a native species along the Atlantic coast of North and South America. It can live over a broad range of salinity (0.1-40 psu; for reproduction >6 psu) and temperature (0-32°C; for reproduction >12 °C) conditions (Kremer and Reeve, 1989; Purcell *et al.*, 2001; Shiganova *et al.*, 2004a; Fuentes *et al.*, 2010; Lehtiniemi *et al.*, 2011; Vansteenbrugge, 2015). It may reach high numbers in conditions of abundant prey (zooplankton concentrations) under optimal salinity and temperature conditions**.** *M. leidyi* is a real ecosystem engineer. It affects physical conditions of several recipient productive ecosystems. After *M. leidyi* invasions, cascading effects occurred at the higher trophic levels, from a decreasing zooplankton stock to collapsing planktivorous fish to dolphins (bottom-up). Similar effects occurred at lower trophic levels: from a decrease in zooplankton stock to an increase in phytoplankton, relaxed from zooplankton grazing pressure (top-down) and from increasing bacterioplankton to increasing zooflagellata and infusoria (Shiganova *et al.*, 2004 a,b).

Figure 36: Mnemiopsis leidy © Marco Faasse

37. Mytilopsis (syn. Congeria) leucophaeata

Figure 37: Mytilopsis leucophaeata © Trausel and Slieker

M. leucophaeata is euryhaline and has been recorded from salinities of 0-25 psu with an optimal range of 0.75-20.9 psu (Verween *et al*, 2010). It is also fairly temperature tolerant and may tolerate temperatures from 6.8 to 37°C, but its optimum range, in which reproduction occurs, is between 15°C to 27°C (Verween *et al*., 2010; Rajagopal *et al*., 2005; NOBANIS, 2010). It is a biofouling species which commonly disturbs coolant water systems of industrial and power plants. Its rapid reproduction in such an ideal environment may result in extremely dense populations that clog water intakes and may damage or cause failure to systems (Rajagopal *et al*, 2002a; Kennedy, 2010; Verween *et al*, 2006b). Specific examples of its biofouling have been reported from Belgium, Finland, and the Netherlands with densities ranging from tens of thousands to even millions of individuals/m^2 (Verween *et al.*, 2007; Laine *et al.*, 2006; Rajagopal *et al*, 2002b). *M. leucophaeata* also fouls boats, ropes, cages and other marine equipment (Bergstrom, 2004). Aside from biofouling, dense populations *M. leucophaeata* alter ecosystems and likely have significant ecological effects similar to that of the more widely researched dreissenid Zebra mussel, (*Dreissena polymorpha*).

38. Mytilus galloprovincialis

Figure 38: Mytilus galloprovincialis © Storey Malcolm

The Mediterranean mussel, *M. galloprovincialis*, has been unintentionally introduced to various regions around the world outside of its native Mediterranean range, both through shipping and cultivation (e.g. Wonham, 2004). The species tolerates temperatures between 10 and 28°C (e.g. Crăciun, 1980; Mancebo *et al.*, 1991) and salinity levels between 9 and 38 psu (Hamer *et al.*, 2008). It is known that *M. galloprovincialis* is able to outcompete and displace native mussels and become the dominant mussel species in certain localities. This is because *M. galloprovincialis* may grow faster than native mussels, be more tolerant to air exposure and have a greater reproductive output compared to indigenous species (Branch & Stephanni, 2004).

39. Neogobius (syn. Apollonia) melanostomus

Figure 39: Neogobius melanostomus © Eric Engbretson

A recent study of Hempel & Thiel (2015) pointed out that this species is able to survive salinity levels between 0.1 and 30 psu. The species has also been observed at salnity levels of 40.5 psu, however, this is very exceptional and problably due to another chemical compositions of the salt in that area (Kornis *et al.*, 2012). Laboratory experiments demonstrated that the species is not able to survive in sea water of 35 psu (Ellis & MacIsaac, 2009). The main pathway for introduction is ballast water (Corkum *et al.*, 2004). Round gobies are typical bivalvevorous. Arthropods are also an important food resource for young and small individuals, or in the case of lower bivalve abundances (Skóra & Rzeżnik 2001; Wandzel, 2003).

40. Palaemon elegans

Figure 40: Palaemon elegans © Malcolm Storey

P. elegans is a euryhaline species that is native to the Atlantic and Mediterranean (including the Black Sea) coasts of Europe, ranging from Norway to South Africa. According to CABI, the species may tolerate salinity levels between 1 and 40 psu and water temperatures from 5 to 31°C. The distribution of *P. elegans* in the Baltic was, until recently, limited to its westernmost part (Köhn and Gosselck, 1989). In the eastern and southern Baltic, the species was observed for the first time between 2000 and 2002 (Zettler, 2002; Janas *et al.*, 2004; Grabowski, 2006). Currently, the species is the most abundant palaemonid shrimp along the Polish Baltic coast. *Köhn & Gosselck* (1989) hypothesised that the species could have been transported by ballast water. *P. elegans* is known to outcompete and replace native palaemonid shrimps from inshore, lagoon and estuarine habitats. Some positive impact may be related to the species forming abundant populations that may possibly enrich food base of various bird and fish species (Gruszka & Wiecaszek, 2004).

41. Palaemon macrodactylus

P. macrodactylus can tolerate 0.6-48 psu and water temperatures from 2-26°C, with an optimum of 14-26 °C (e.g. Newman, 1963; CABI). It is a large edible crustacean native to northeast Asia (Li *et al.*, 2007). Once established in a region *P. macrodactylus* spreads to other nearby areas with apparent ease. Shipping has been suggested as a pathway facilitating further spread (Newman, 1963). The species has comparatively long breeding seasons and high fecundity (e.g. Siegfried, 1980). It is largely carnivorous but can exploit a wide variety of food sources and can be cannibalistic in crowded laboratory conditions (Newman, 1963). In San Francisco Bay it is thought to be outcompeting native *Crangon* species but evidence for its impact on native species in other regions is lacking. In China, it is listed in their Red Data Book as a threatened species.

Figure 41: Palaemon macrodactylus © Melissa Frey, Royal BC Museum, Canada

42. Paralithodes camtschatica

The crab tolerates water temperatures between -1.7 and 11°C, little is known about salinity tolerances, but the species has been observed in Alaska between 22 and 34 psu (Hansen, 2002; DAISIE). It is native to the Okhotsk and Japan Sea, the Bering Sea and the Northern Pacific Ocean, but since 1992 the crab became abundant in Northeast Norwegian waters. The economic value to the Norwegian fisheries on the red king crab has increased almost by a factor 60 between 1994 and 2004. But the concurrent increase in the red king crab stock in recent years has also resulted in bycatch problems, particularly in the gillnet fisheries. The crabs impact the longline fisheries by removing bait from hooks, thereby reducing catches of targeted fish (Sundet & Hjelset, 2002). In order to compensate for the loss of fishery and equipment (trawl-, net, and long-line fishing) caused by the invasion of the red king crab, the criterions for participation in the annual crab fishery are set in favor of the local small-scale fishermen. This is generally acknowledged by fishermen from other parts of Norway, since the presence of the crab directly influence the conditions of the local fishermen (e.g. Jørgensen, 2013). The nature of the food consumed by *P. camtschatica* varies. The pelagic larvae consume both phytoplankton and zooplankton (Bright, 1967), while, once settled, they feed on the dominant epifaunal component of the refuge substrate (Tsalkina, 1969). Dew (1990) reported that small crabs feed on sea stars, kelp, molted king crab exuvia, clams, mussels, nudibranch egg masses and barnacles. Adults are opportunistic omnivorous feeders according to what is most readily available in the benthos (Cunningham, 1969).

Figure 42: Paralithodes camtschatica © The Childrens Museum of Indianapolis

43. Pfiesteria piscicida

P. piscicida is an estuarine species with a wide temperature (10-32°C) and salinity (2-35 psu) tolerance (NJ Health, 2000). It is a prey generalist that feeds on bacteria, algae, microfauna, finfish and shellfish, and may well represent a significant estuarine microbial predator (e.g. Burkholder *et al*., 1995; Burkholder & Glasgow, 1997; Glasgow *et al.,* 1998). *P. piscicida* is lethal to fish at relatively low concentrations (> 250-300 cells/ml). At lower levels (~100-250 cells/ml) ulcerative fish disease results. Similar ulcers have been reported from shellfish as well. *P. piscicida* and possibly other *Pfiesteria*-like species are suspected to be responsible for a number of major fish and shellfish kills in the North Carolina Albemarle-Pamlico Estuary and in the Maryland Chesapeake Bay (Burkholder *et al.* 1995; Burkholder & Glasgow, 1997). The ever changing morphology of this species may give answers to a number of mysterious fish kills along the southeast coast of the United States (Steidinger *et al.,* 1996). This species was initially linked to serious health problems in humans who had come in direct

Figure 43: Pfiesteria piscida © Steidinger et al., 1996

contact with it (narcosis, respiratory distress, epidermal lesions, and short-term memory loss); however, a study sponsored by the Centers for Disease Control (CDC) has revealed no such relationship (Swinker *et al.,* 2001).

44. Phaeocystis pouchetii

P. pouchetii is an important colony-forming marine phytoplankton species in the northern hemisphere cold waters (Verity *et al.*, 2007). A study on *Phaeocystis* sp. by *Sini* (2012) found a tolerance level for salinity of 10-40 psu. Its temperature range is -2 to 14 °C (Jahnke & Baumann, 1987). The species has been found to be toxic to cod larvae in Norway (Moestrup, 2015). This species is included in the IOC-UNESCO Taxonomic Reference List of Harmful Micro Algae.

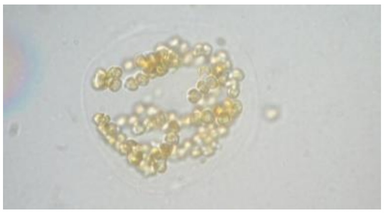

Figure 44: Phaeocystis pouchetii © Hanna Mossfeldt

45. Pseudochattonella verruculosa

Yamaguchi *et al.* (1997) demonstrated the tolerable salinity and temperature ranges of *P. verruculosa*, corresponding to 12-35 psu and 12-22°C respectively. Over recent decades, the species has not only increased in abundance in coastal waters of Japan, but has also been observed in tidal estuaries and lagoons on the eastern coast of the United States, and off the coasts of Germany and New Zealand. Red tides have significant impact on the fishing and aquaculture industry (e.g. Murayama-Kayano *et al.*, 1998). Blooms of *P. verruculosa* have been associated with the mortality of fish (Yamamoto & Tanaka, 1990; Baba *et al.*, 1995; Yamaguchi *et al.*, 1997). The related species, *P. farcimen*, caused the deaths, on the coast of Norway, of 350 tons of farmed salmon in 1998 and 1,100 tons in 2001 (Edvardsen *et al.*, 2007), and deaths of garfish, herring, sandeel and mackerel on the west coast of Denmark (Aure *et al.*, 2001; Bourdelais *et al.*, 2002). The mechanism of icthyotoxicity is still uncertain and no toxins have been isolated or characterised from either *Pseudochattonella* species (Riisberg & Edvardsen, 2008).

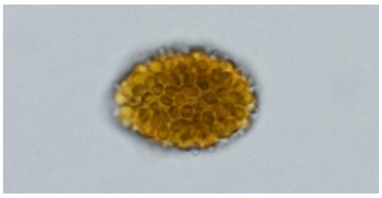

Figure 45: Pseudochattonella verruculosa © Cawthron institute

46. Rangia cuneata

R. cuneata can tolerate a wide salinity (0-33 psu) and temperature (8-32°C) range (Cooper, 1981). The species is native in the Gulf of Mexico, but has most likely been introduced to Europe, and spread within Europe, through ballast water (e.g. Carlton, 1992; Verween *et al.*, 2006; Rudinskaya & Gusev, 2012; Warzocha & Drgas, 2013). It inhabits low salinity estuarine habitats (Parker, 1966) and is as such most commonly found in areas with salinities from 5-15 psu (Swingle & Bland, 1974). *R. cuneata* possess both extracellular (blood and body fluid) and intracellular mechanisms of osmoregulation, which enables them to respond to sudden salinity changes in many estuaries (Bedford & Anderson 1972). They can cross the 'horohalinicum', the 5-8 psu salinity boundary which usually divides fresh and salt-water invertebrates, making them one of the few freshwater clams to become established in brackish water (Ladd, 1951) as such thriving in a zone unfavourable for many animals. Competition and predation may explain its scarcity in high salinity environments (Cooper, 1981). Verween *et al.* (2006a) describe *R. cuneata* as a biofouling species, causing problems in industrial cooling water systems.

Figure 46: Rangia cuneata © Verween Annick

47. Rapana venosa

Figure 47: Rapana venosa

R. venosa is considered as one of the worst invaders worldwide. It has a high ecological fitness as evidenced by its high fertility, fast growth rate and broad tolerance to salinity (12-32 psu, Golikov, 1967; ICES, 2004), temperatures (4-27°C, CABI), water pollution and oxygen deficiency, giving it all the characteristics of a successful invader (Kerckhof *et al.*, 2006). In areas where it has been introduced it has caused significant changes to the ecosystem (ISSG, 2007). In the past decades, its biogeographical range has extended towards Europe and America due to shipping (ballast water and aquaculture transfer) (Savini *et al.*, 2007). *R. venosa* is an active predator of epifaunal bivalves and its proliferation is a serious limitation to natural and cultivated populations of oysters and mussels (Zenetos *et al.*, 2004). It is internationally considered a serious menace to bivalve fisheries, being preferentially acclimated in estuarine/brackish water of coastal regions, where intensive bivalve harvesting usually takes place (Savini *et al.*, 2007). In the North Sea, the regional industries for edible bivalves such as mussels *Mytilus edulis*, Pacific oysters *Crassostrea gigas* and cockles *Cerastoderma edule* may be at risk (Kerckhof *et al.*, 2006; ISSG, 2007). *R. venosa* has become established in the Black Sea with significant damage to native benthos (e.g. bivalves) (Mann & Harding, 2003). It has occupied an empty ecological niche exerting a significant predatory pressure on the indigenous malacofauna. Impact on bivalve populations is variable ranging from rather mild along the Romanian coast, moderate in Bulgarian and Turkish Black Sea, and severe along Russian and Ukrainian coasts where this species has been blamed for local extermination/major decline of a number of bivalves (BSEPR, 2007). In the North Sea, the possible establishment of *R. venosa* would exert severe competition pressure to the native whelk *Buccinum undatum*, a species already suffering from organotin water pollution and heavy fishing pressure (Kerckhof *et al.*, 2006).

48. Rhithropanopeus harrisii

6Figure 48: Rhithropanopeus harrisii

R. harrisii is a small brackish water crab which belongs to the superfamily Xanthidae. It is native to the Atlantic coast of North America but has been introduced accidentally in over 20 different countries spanning both North and South America, Europe, northern Africa and Asia (Roche and Torchin, 2007; Roche *et al.*, 2009). Possible vectors of introduction include accidental transport in vessel fouling, ballast water and oyster shipments (Cohen & Carlton, 1995), as well as with fish stocking (Keith, 2008). *R. harrisii* tolerates a broad range of environmental conditions, mainly salinity (0.2-40 psu, e.g. Christiansen & Costlow, 1975; CABI) and temperature (0-35°C, Christiansen & Costlow, 1975), which facilitates its success as a global invader (Williams, 1984; Petersen, 2006). The species may alter species interactions and cause some economic damage, notably through competition with native species (such as crabs and fish feeding on benthos), spoiling fishes in fill nets, alteration of food webs and fouling of water intake pipes (Marchand & Saudray, 1971; Turoboyski, 1973; Jazdzewski & Konopacka, 1993; Cohen & Carlton, 1995; Zaitsev & Öztürk, 2001; Roche & Torchin, 2007; Keith, 2008). According to *Payen and Bonami* (1979), *R. harrisii* can also be a potential host of white spot baculoviruses, which can be transmitted to co-occurring native crustaceans.

49. *Styela clava*

S. clava, the clubbed tunicate, is a fouling organism native to the Pacific Coast of Asia (Millar, 1960; Eno *et al.*, 1997). Because of its ability to withstand salinity (22-35 psu; Lützen, 1999; Davis *et al.*, 2007; Krone *et al.*, 2007; Davis & Davis, 2008) and temperature (-2-23°C; Lützen, 1999; Minchin, 2009) fluctuations, *S. clava* has established a widespread non-native distribution. Its global spread is further facilitated by human-assisted dispersal, such as shipping (hull fouling, ballast water) (Eno *et al.*, 1997; Davis *et al.*, 2007) and oyster culture (Lützen, 1999; Davis *et al.*, 2007). The green crab (*Carcinus maenas*) may also facilitate *S. clava* invasion (Locke *et al.*, 2007). The species is fast-growing, a prolific breeder and an efficient suspension feeder. It can therefore reach extremely high densities and outcompete native organisms for food in the water column. *S. clava* also predates on the larvae of native species causing population declines. It fouls on vessels, aquaculture species, fishing equipment, moorings, ropes, etc. In Japan it has been known to impact upon human health causing an asthmatic condition in oyster shuckers when hammering open *Styela* fouled oysters in poorly ventilated areas (NIMPIS, 2015).

Figure 49: Styela clava © Luis A. Solórzano

50. *Stypopodium schimperi*

This flat brown algae is considered a Lessepsian immigrant, originally described from the Red Sea coast of Egypt. Its thin thalli with a large surface area usually have rapid uptake rates for nutrients, with a negative impact on competing algae. It functions as an ecosystem engineer, it can foul submarine infrastructure and seasonally huge quantities are observed on the Syrian beaches (i.e. impact on recreational activities) (e.g. Streftaris & Zenetos, 2006). Habitat modification could be either positive, by creating substrate for small epiphytes, or negative by occupying space.

Figure 50: Stypopodium schimperi

51. *Undaria pinnatifida*

U. pinnatifida is an annual kelp native to northeast Asia and Russia. The species forms the basis of a large aquaculture industry in Japan, Korea and China. In the early 1970s, *U. pinnatifida* expanded into non-native areas, and is now found in Europe, North America, South America and Australasia. It appears that the species was introduced in Europe primarily by 'hitchhiking' on other aquaculture species (e.g. *Crassostrea gigas*) (Eno *et al.*, 1997). Probably, secondary introductions took place through fouling on boat hulls (VLIZ alien species consortium, 2011b). Based on the results of Martin & Cuevas (2006) and *Peteiro & Sánchez* (2012), the salinity tolerance range has been estimated around 11-34 psu. Discontinuous populations occur if seasonal water temperature exceeds 25°C (Hay & Villouta, 1993; Castric-Fey *et al.*, 1999a, b; Stuart *et al.*, 1999; Curiel *et al.*, 2004). Their growth is best when the seawater temperature is between 5 and 13°C. The ability of microscopic stages to go dormant at high temperatures may allow this species to persist during transport. The ecological impact of *U. pinnatifida* can be negative in some regions (decrease of native species diversity through competition) and neutral/positive in others (e.g. Valentine & Johnson, 2003; 2004; Hewitt *et al.*, 2005; Farrell & Fletcher, 2006).

Figure 51: Undaria pinnatifida © Yann Fontana

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