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ABSTRACT

The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) aims to mitigate the introduction risk of harmful aquatic organisms and pathogens (HAOP) via ships' ballast water and sediments. The BWM Convention has set regulations for ships to utilise exceptions and exemptions from ballast water management under specific circumstances. This study evaluated local and regional case studies to provide clarity for situations, where ships could be excepted or exempted from ballast water management without risking recipient locations to new introductions of HAOP.

Ships may be excepted from ballast water management if all ballasting operations are conducted in the same location (Regulation A-3.5 of the BWM Convention). The same location case study determined whether the entire Vuosaari harbour (Helsinki, Finland) should be considered as the same location based on salinity and composition of HAOP between the two harbour terminals. The Vuosaari harbour case study revealed mismatching occurrences of HAOP between the harbour terminals, supporting the recommendation that exceptions based on the same location concept should be limited to the smallest feasible areas within a harbour.

The other case studies evaluated whether ballast water exemptions could be granted for ships using two existing risk assessment (RA) methods (Joint Harmonised Procedure [JHP] and Same Risk Area [SRA]), consistent with Regulation A-4 of the BWM Convention. The JHP method compares salinity and presence of target species (TS) between donor and recipient ports to indicate the introduction risk (high or low) attributed to transferring unmanaged ballast water. The SRA method uses a biophysical model to determine whether HAOP could naturally disperse between ports, regardless of their transportation in ballast water. The results of the JHP case study for the Baltic Sea and North-East Atlantic Ocean determined that over 97% of shipping routes within these regions resulted in a high-risk indication. The one route assessed in the Gulf of Maine, North America also resulted in a high-risk outcome. The SRA assessment resulted in an overall weak connectivity between all ports assessed within the Gulf of the St. Lawrence, indicating that a SRA-based exemption would not be appropriate for the entire study area.

In summary, exceptions and exemptions should not be considered as common alternatives for ballast water management. The availability of recent and detailed species occurrence data was considered the most important factor to conduct a successful and reliable RA. SRA models should include biological factors that influence larval

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dispersal and recruitment potential (e.g., pelagic larval duration, settlement period) to provide a more realistic estimation of natural dispersal.

1. Introduction

1.1. Background

The movement of ballast water by international shipping is a dominant pathway for the introduction of harmful aquatic organisms and pathogens (HAOP), including non-indigenous species (NIS) (Ruiz et al., 1997; David and Gollasch, 2015; Bailey et al., 2020). HAOP can have severe ecological or socio-economic impacts at local and regional scales (Carlton et al., 1990; Reise et al., 1998; Bax et al., 2003; Colautti et al., 2006; Strayer, 2010).

The International Maritime Organization's (IMO) International Convention for the Control and Management of Ships' Ballast Water and Sediments, or in short, the Ballast Water Management Convention (BWM Convention) was the first international treaty to mitigate the introduction of HAOP attributed to the movement of ballast water (IMO, 2004). Specifically, Regulation D-2 of the BWM Convention sets maximum allowable viable organism limits in discharged ballast water separately for ≥50 μm organisms, ≥10 to <50 μm organisms and indicator microbes (*Escherichia coli*, intestinal enterococci and toxicogenic *Vibrio cholerae*) (IMO, 2004). In general, ships are expected to adhere to the D-2 standard by treating ballast water using an approved onboard ballast water management system, utilising one or more physical and/or chemical treatment processes to eliminate most viable organisms. Requirements to meet the D-2 standard are being phased in on a specified timeline, with all ships expected to meet the standard by September 8, 2024 (IMO, 2018).

Since the installation and maintenance of ballast water management systems can be costly (Wang et al., 2020), some ship operators have started to seek exceptions or exemptions from ballast water management requirements under Regulations A-3 and A-4 of the BWM Convention, respectively (IMO, 2004). Regulation A-3 states that ships are excepted from ballast water management requirements in emergency and safety situations or when ballast operations (both uptake and discharge) occur on high seas or within the same location. Regulation A-4 enables Member States to grant exemptions from ballast water management to ships transporting ballast water between specified ports or locations, provided a scientifically robust risk assessment (RA) consistent with the 2017 Guidelines for Risk Assessment under Regulation A-4 of the BWM Convention (G7) (G7 Guidelines) indicates an acceptable low risk of introducing or spreading HAOP (IMO, 2004; 2017).

The BWM Convention entered into force in September 2017 — more than ten years after it was adopted in 2004 — following prolonged negotiations between stakeholders and experts (Gollasch et al., 2007; David and Gollasch, 2015). As a result, ballast water management regulations are being implemented only recently, and there is a need to better understand the feasibility, efficacy and limitations associated with these procedures (Wright, 2018). Exceptions from ballast water management based on the same location concept have not been clearly defined by IMO (Gollasch and David, 2012; David et al., 2013a). In addition, there has been uncertainty among the associated parties on a systematic manner (IMO, 2017) for granting exemptions (Gollasch et al., 2007; David et al., 2013a, 2013b, 2013b; Olenin et al., 2016).

1.2. Objectives

The objective of this study was to use local and regional case studies to provide an ecological evaluation of exceptions and exemptions from ships' ballast water management, to support harmonised implementation of the BWM Convention. Additionally, this study provides clarification of terms (e.g., same location, Same Risk Area [SRA]), regulations and guidelines of the BWM Convention towards a more unified interpretation. For exceptions under Regulation A-3.5, a case study was assessed to determine whether an entire harbour may be considered as the same location. For exemptions under Regulation A-4, the methodology of two existing RA approaches was examined to evaluate how exemptions from ballast water management should be assessed in different situations.

1.3. Context for exceptions and exemptions

1.3.1. Exceptions from ballast water management: same location concept

The BWM Convention does not require ships to manage their ballast water when it is loaded and unloaded in the same location (IMO, 2004). The history of the same location concept and its purpose within the framework of the BWM Convention has been described in detail by Gollasch and David (2012) and David et al. (2013a). The concept was initially introduced during the drafting of the BWM Convention in 1990s to include ballast operations that are always conducted in the same location (Gollasch and David, 2012). These relatively rare situations may include fixed ferry traffic with ballast water operations only in one of the ports they connect, or cargo ships that always load and unload ballast water in the same harbour.

Regulation A-3.5 of the BWM Convention states that ships may be excepted from ballast water management *"in the case of the discharge of ballast water and sediments from a ship at the same location where the whole of the ballast and those sediments originated and provided that no mixing with unmanaged ballast water and sediments from other areas has occurred"* (IMO, 2004). The only definition for same location provided by IMO is included within the Guidelines for Ballast Water Management Equivalent Compliance (G3) (G3 Guidelines): "*In the context of these Guidelines, same location shall be taken to mean the same harbour, mooring or anchorage*" (IMO, 2005). However, the G3 Guidelines only apply to relatively small (maximum 50 m in length and ≤8 m^3 of ballast water capacity) leisure and search-and-rescue crafts and do not include larger commercial ships. Additionally, IMO does not provide any guidance on how to determine the appropriate spatial extent for same location.

Therefore, same location could be interpreted as a single anchorage within a harbour, an entire harbour, or possibly even larger than a harbour. For smaller ports with limited number of berths, the entire port may be considered a single same location. However, larger ports (e.g., Port of Rotterdam, David et al., 2013a) with many terminals and diverse environmental conditions (fresh, brackish and marine water) may have a same location for each terminal or anchorage.

1.3.2. Exemptions from ballast water management

Three methods are described in IMO's G7 Guidelines to assess the risk of transferring HAOP between ports or locations: environmental matching RA, species' biogeographical RA and species-specific RA (IMO, 2017). The G7 Guidelines state that these RA types can be used either individually, or in combination to assess the risk of transporting unmanaged ballast water.

Environmental matching RA provides an indication of species establishment based on a comparison of environmental conditions between the ballast water donor region and recipient port. The environmental conditions typically assessed are water temperature and salinity but may also include other relevant parameters (Gollasch and Leppäkoski, 2007; Stuer-Lauridsen et al., 2018). The overlap in environmental conditions between the donor region and recipient port is used as a proxy for the likelihood of survival or establishment of species introduced by ballast water, based on the assumption that species will have a higher probability of survival and establishment in similar environments. Individual point measurements should be avoided when conducting environmental matching RA, since environmental conditions such as temperature or salinity often fluctuate depending on depth, season or year.

The G7 Guidelines recommend assessing the environmental conditions of the biogeographical regions of donor and recipient ports, since aquatic species are typically distributed beyond the location of a single port. It is recommended to use the Large Marine Ecosystem schema to categorise biogeographical regions (Sherman, 2005). Environmental matching RA is typically insufficient to comprehensively assess the introduction risk alone but has been considered as an important component of a successful RA (van der Meer et al., 2016; David and Gollasch, 2019).

"*Species' biogeographical RA compares the biogeographical distribution of non-indigenous, cryptogenic and harmful native species that presently exist in the donor and recipient ports or biogeographic regions*" (IMO, 2017). Cryptogenic species are species that cannot be categorised as indigenous or non-indigenous due to uncertainty about their endemic distribution (Carlton, 1996). The amount of shared species indicates that the environmental conditions are sufficiently similar so that a high likelihood of survival and establishment of species introduced from the donor to recipient port occurs. Species' biogeographical RA can also be used to identify species of concern for the species-specific RA or biogeographical regions that have been major sources of NIS (IMO, 2017).

Species-specific RA evaluates the probability of arrival, survival, establishment and impact of target species (TS) based on life history traits and physiological tolerances. The IMO defines TS as "*species identified by a Party that meet specific criteria indicating that they may impair or damage the environment, human health, property or resources and are defined for a specific port, State or biogeographic region*" (IMO, 2017). TS lists should include any harmful species (indigenous, non-indigenous, cryptogenic or pathogens) that may be transported via ballast water, including species with evidence of prior introductions (IMO, 2017; Gollasch et al., 2020). The occurrence of species may be identified by conducting port surveys or literature reviews (e.g., NIS databases). The TS with the highest risk are species that have a high probability of arriving (via ballast water), surviving, establishing, or impacting to the recipient port ecosystems (David et al., 2013b; Stuer-Lauridsen et al., 2018).

Species-specific RA can be also conducted using the SRA approach (IMO, 2017). The G7 Guidelines define a SRA as "*an agreed geographical area based on a completion of a risk assessment carried out in line with these Guidelines*" (IMO, 2017). The SRA assessment is conducted by modelling the unassisted dispersal of TS within the waterbody to determine the natural connectivity between ports. The G7 Guidelines state that a SRA assessment could be deemed low risk if either: 1) the TS are present in all ports or locations; or 2) the TS have a high probability of dispersing (unassisted) to all locations within the timeframe agreed by the involved parties (IMO, 2017).

However, biophysical modelling often attempts to evaluate the dispersal of larvae (or other pelagic life stages), and not their effective recruitment in local populations (Giménez et al., 2020). The likelihood of establishment for a species depends on a variety of factors related to for example abiotic factors and habitat suitability. Dispersal modelling studies thus assess putative dispersal rather than realised dispersal (Pineda et al., 2007). Therefore, models with such limitations can predict two locations being connected through propagule dispersal, where the settlement of the larvae or the establishment of a pelagic population (e.g., American comb jelly *Mnemiopsis leidyi* in the northern Baltic Sea, Lehtiniemi et al., 2012) would never occur by natural means.

2. Methods and case studies

2.1. Terminology and acronyms

This study uses terminology of the BWM Convention and the associated guidelines (Table 1). In addition, the present case studies relied on existing approaches that have been previously used to assess the introduction risk of HAOP or agreed upon by several nations in international cooperation.

2.2. Same location case study: vuosaari harbour

Vuosaari harbour in Helsinki, Finland, was assessed to determine whether the entire harbour or smaller areas within the harbour should be considered the same location, based on similarity in salinity and composition of HAOP between the two harbour terminals. The case study followed the definition of the G3 Guidelines for same location, as it is the only definition provided by IMO.

Vuosaari harbour is operated by the Port of Helsinki and it manages traffic for containers and roll-on/roll-off passenger (ROPAX) ships (Port of Helsinki, 2020a). Vuosaari harbour has two main terminals: 1) ROPAX terminal, consisting of quays C, F and G; and 2) container terminal, consisting of quays B, D and E (Fig. 1). The salinity range and species composition were determined based on field surveys completed for each terminal in 2018. The survey included two sampling events (spring and summer), and the terminals were surveyed on the same days with identical sampling effort, following the HELCOM and OSPAR

Table 1

Acronyms and definitions. The acronyms and definitions are based on international and regional legislative and guidance documents (IMO, 2004, 2005; 2017; HELCOM and OSPAR, 2020a).

Acronym	Definition
BWM Convention	Ballast Water Management Convention. International Convention for the Control and Management of Ships Ballast Water and Sediments.
G3 Guidelines	Guidelines for Ballast Water Management Equivalent Compliance (G3)
G7 Guidelines	2017 Guidelines for Risk Assessment under Regulation A-4 of the BWM Convention (G7)
HAOP	Harmful aquatic organisms and pathogens. Aquatic organisms or pathogens which, if introduced into the sea including estuaries, or into freshwater courses, may create hazards to the environment, human health, property or resources, impair biological diversity or interfere with other legitimate uses of such areas.
HELCOM	The Helsinki Commission. The Baltic Marine Environment Protection Commission.
IMO	International Maritime Organization
JHP	Joint Harmonised Procedure. The Joint Harmonised Procedure for the Contracting Parties of OSPAR and HELCOM on the granting of exemptions under the BWM Convention, Regulation A-4
NIS	Non-indigenous species. Any species outside its native range, whether transported intentionally or accidently by human activities.
OSPAR	Oslo and Paris Commissions. The Convention for the Protection of the Marine Environment of the North-East Atlantic
RA	Risk assessment. A logical process for assigning the likelihood and consequences of specific events, such as the arrival, establishment, or spread of harmful aquatic organisms and pathogens.
ROPAX	Roll-on/roll-off passenger ship for private and commercial vehicles.
SRA	Same Risk Area. An agreed geographical area based on the completion of a risk assessment conducted following the G7 Guidelines.
TS	Target Species. Species identified by a Party or Parties that meet specific criteria indicating that they may impair or damage the environment, human health, property or resources. Target species can be defined for a specific port, State or biogeographic region.

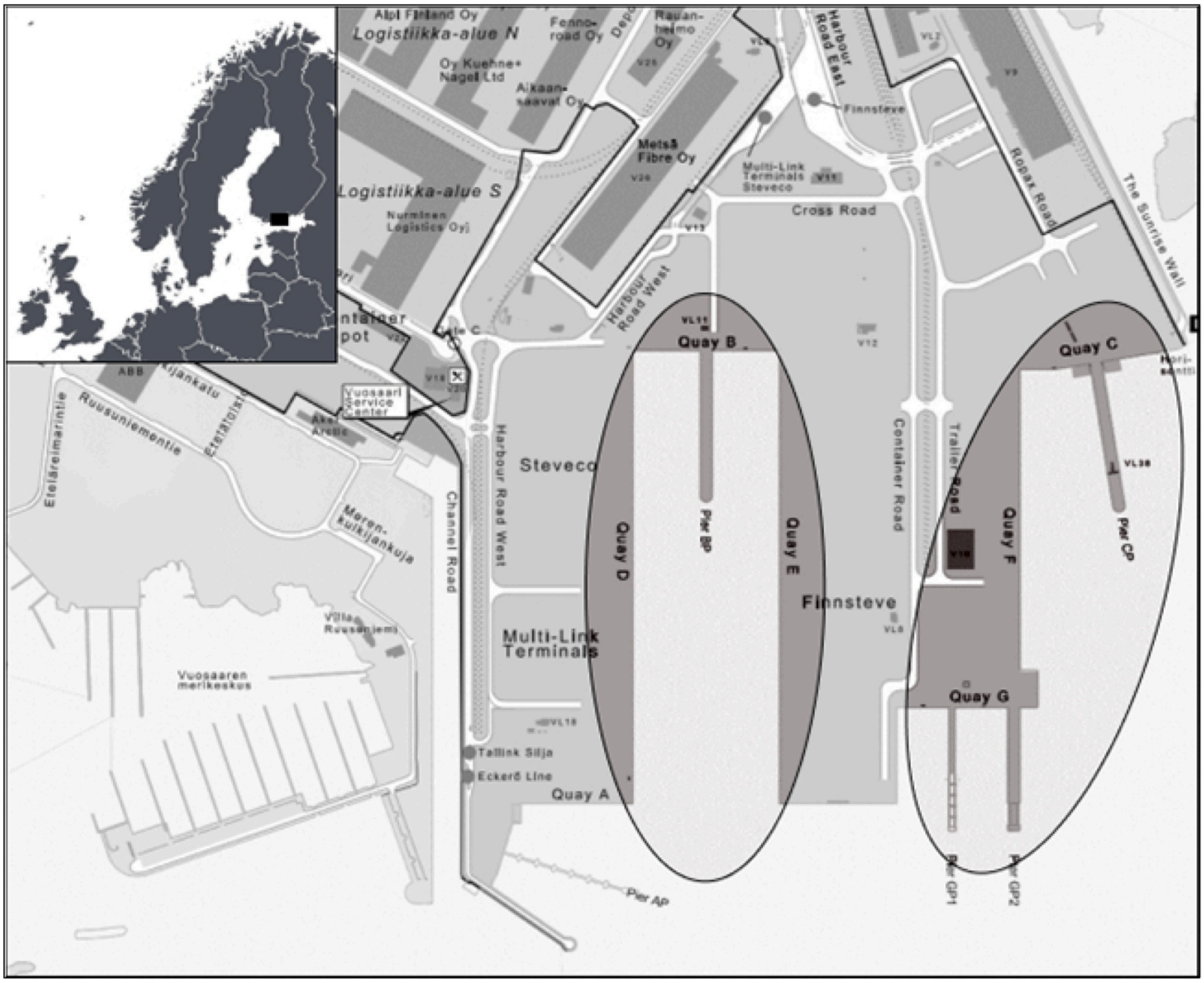

Fig. 1. Terminals in Vuosaari harbour, Finland. The container terminal quays are on the left and ROPAX terminal quays are on the right (Port of Helsinki, 2020b).

(2020a) sampling requirements. The similarities in salinity range and composition of HAOP between the terminals were compared using an existing approach from David and Gollasch (2019), which determines the risk of spreading HAOP via ballast water by comparing the salinity range and presence of HAOP between two ports or locations. The HAOP comparison in Vuosaari harbour included harmful algae (ICES, 2007), indicator microbes (IMO, 2004), and potentially harmful native, cryptogenic and non-indigenous taxa identified during the port survey, as the aim of the BWM Convention is to prevent, minimise and ultimately eliminate the risks of introduction of HAOP through ships ballast water and sediments.

2.3. *Joint Harmonised Procedure*

2.3.1. *Methodology*

The Helsinki Commission (The Baltic Marine Environment Protection Commission, HELCOM) and Oslo and Paris Commissions (The Convention for the Protection of the Marine Environment of the North-East Atlantic, OSPAR) developed the Joint Harmonised Procedure for the Contracting Parties of OSPAR and HELCOM on the granting of exemptions under the BWM Convention, Regulation A-4 (Joint Harmonised Procedure, JHP) to ensure that exemptions from ballast water management are granted in a standardised manner across the Baltic Sea and North-East Atlantic Ocean (HELCOM and OSPAR, 2020a). The methodology includes a port survey protocol and an online RA tool (HELCOM and OSPAR, 2020a,b), and it follows the G7 Guidelines by combining environmental matching and species-specific RA types. The development of the JHP was based on preliminary RA studies (e.g., Gollasch et al., 2011; David et al., 2013b) that thoroughly examined the G7 Guidelines and identified key risk criteria to consider before issuing exemptions (HELCOM and OSPAR, 2020a). The key risk criteria include comparing the differences in salinity and presence of TS between the ports of interest (David et al., 2013b). Since the adoption of the JHP in 2013, the JHP has undergone several amendments and updates by the Contracting Parties of HELCOM and OSPAR and the Joint HELCOM/OSPAR Task Group on Ballast Water Management Convention and Biofouling. The JHP RA tool was updated in 2020, reducing the number of RA steps from nine to two and the number of possible outcomes from three (low, medium or high risk) to two (low or high risk). The online RA tool is an open access resource (https://maps.helcom.fi/website/RA_tool/) that provides a preliminary risk indication, which is followed by a detailed review in the second step of the RA (see below).

JHP includes also a port survey protocol and an agreed TS list for the Baltic Sea and North-East Atlantic Ocean. First, port surveys are conducted for both, the donor and recipient ports following a standardised port survey protocol (HELCOM and OSPAR, 2020a). The protocol has minimum requirements for representative port surveys, including measurements for abiotic parameters (e.g., salinity) and sampling of phytoplankton, zooplankton, fouling organisms, mobile epifauna and benthic infauna. The organisms sampled in each port are identified and the data are entered into the RA tool. TS for the Baltic Sea and North-East Atlantic Ocean regions have been pre-selected by NIS experts from HELCOM and OSPAR regions in 2013 (HELCOM and OSPAR, 2020b). The TS selection criteria have been updated since (Gollasch et al., 2020), but have not been applied yet to this list. In short, following the new criteria, it is a prerequisite that TS have a pelagic life stage and may therefore be transported in ballast water. All species fulfilling this prerequisite are considered TS if: 1) the species has potentially unacceptable impacts on human health, environment, or economy; 2) the species has history of prior introductions outside its' native range, or; 3) the current distribution status of the species indicates that it has wide biogeographical or habitat distribution (see the detailed TS selection criteria in Gollasch et al., 2020).

The port survey data are valid for a maximum of five years and potential five-year exemptions must include intermediate reviews, based on any newly available data on introduction events or changes in invasion pathways or environmental conditions within the associated ports. Once the regional TS have been identified and the ports of interest have been surveyed, the JHP online RA algorithm (Fig. 2) can be used to determine the risk indication of transporting unmanaged ballast water between the donor and recipient ports based on the salinity match and presence of TS between ports.

Since the JHP is only intended to guide the decision-making process, exemptions need to be granted by the port State of the recipient port(s) for each exemption application. As the first step of the RA approach (the RA algorithm) only provides an indication of whether routes are high or low risk, each exemption application must be reviewed in detail to complete the second step of the RA. The second step of the RA considers the full scope of introduction risk attributed to ballast water before granting an exemption (HELCOM and OSPAR, 2020a).

The detailed review should include examining additional information on NIS, conducting species-specific assessments or applying mitigation measures on discharged ballast water (HELCOM and OSPAR, 2020a). Furthermore, additional species data (e.g., from species databases or monitoring programmes) may be reviewed to determine the occurrences of TS in areas adjacent to ports, differences in TS abundances between ports, presence of human pathogens or whether TS are managed in the recipient port. As the occurrences of human pathogens may have significant seasonal variation (Oberbeckmann et al., 2011), their presence also documented in other studies should be considered before making the final decision. The presence of TS in both, the donor and recipient ports cannot alone be the basis for granting an exemption, if ongoing eradication measures are being undertaken in the recipient port (HELCOM and OSPAR, 2020a). Exemptions may be granted also with conditional mitigation measures such as setting seasonal limitations or designate specific areas to ballast operations. As an example, a low-risk indication may not lead to an exemption due to eradication measures being conducted on the concerned TS in the recipient port environment. In a similar manner, an exemption may be considered for a specific port terminal (regardless of the high-risk indication), if the donor port has several distinct terminals with varying environmental conditions (e.g., Port of Rotterdam, David et al., 2013a), and the ship does not load ballast water in the terminal, where the concerned TS were detected (Outinen, 2016).

2.3.2. *Baltic Sea and North-East Atlantic Ocean case study*

The JHP RA method was applied to a case study in the Baltic Sea and North-East Atlantic Ocean to determine the likelihood of shipping routes resulting in a low-risk indication, potentially enabling an exemption from ballast water management. The JHP online tool had data on 27 ports across nine countries in the HELCOM and OSPAR regions (see Table 2 in supplementary materials; Figs. 3 and 4). All port surveys were conducted between 2012 and 2019. The RA algorithm can be applied to two ports at a time, and the data analyses included all potential route combinations in the RA tool ($n = 702$). Sixteen ports either did not have adequate data for all required taxonomic groups (data were not collected following JHP guidelines), or port surveys were conducted more than five years ago. The remaining 11 ports (Hull, Brofjorden, Hamburg, Kiel, Gdansk, Helsinki, Muuga, Swinoujscie, Szczecin, Cuxhaven and Jade-Weser) had valid data for all required taxonomic groups. While all potential routes were evaluated (610 international and 92 national routes), the results focused on routes with valid (2015–2019) biological data for all required taxonomic groups ($n = 110$, 92 international and 18 national routes).

2.3.3. *Boston–Saint John case study*

The JHP methodology may also be applied to ports outside of Europe. JHP was applied to a case study assessing the risk of transporting ballast water from Boston, USA to Saint John, Canada (Fig. 5). This international shipping route was selected since there is a small fleet of ships operating between these ports.

First, a NIS list was created for each port based on existing species distribution data (Fofonoff et al., 2018), since conducting biological port surveys was beyond the scope of this case study. If the occurrence of a species in a harbour was not explicitly stated in the literature, the species was considered absent. Species were considered as TS, if they met all of the following requirements: 1) species has been detected in ballast tanks or has a pelagic life stage that is likely to be transported by ballast water (pelagic larvae or planktonic adult); 2) species is present in part but not the entire region (in this case, Boston and Saint John); and 3) species has

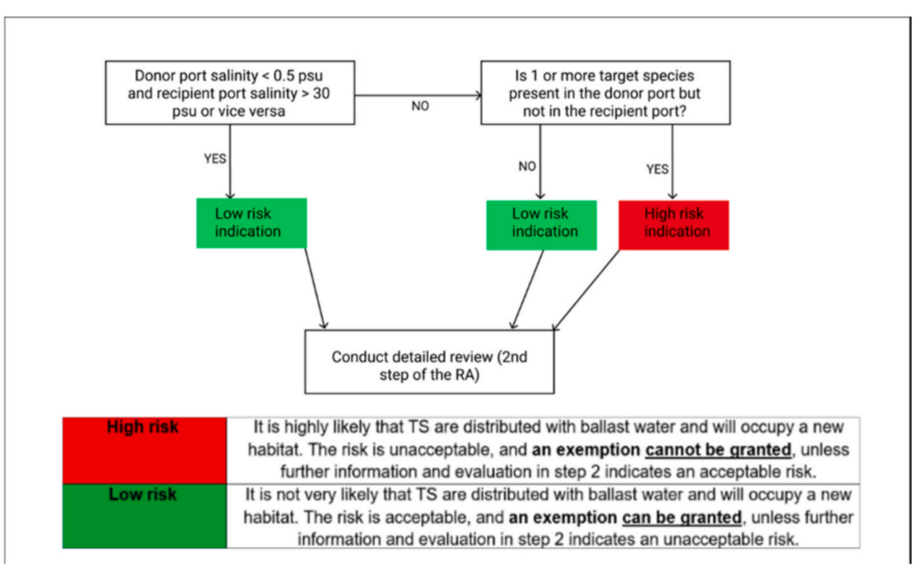

Fig. 2. The JHP RA algorithm. The RA approach and risk level definitions (modified after HELCOM and OSPAR, 2020a).

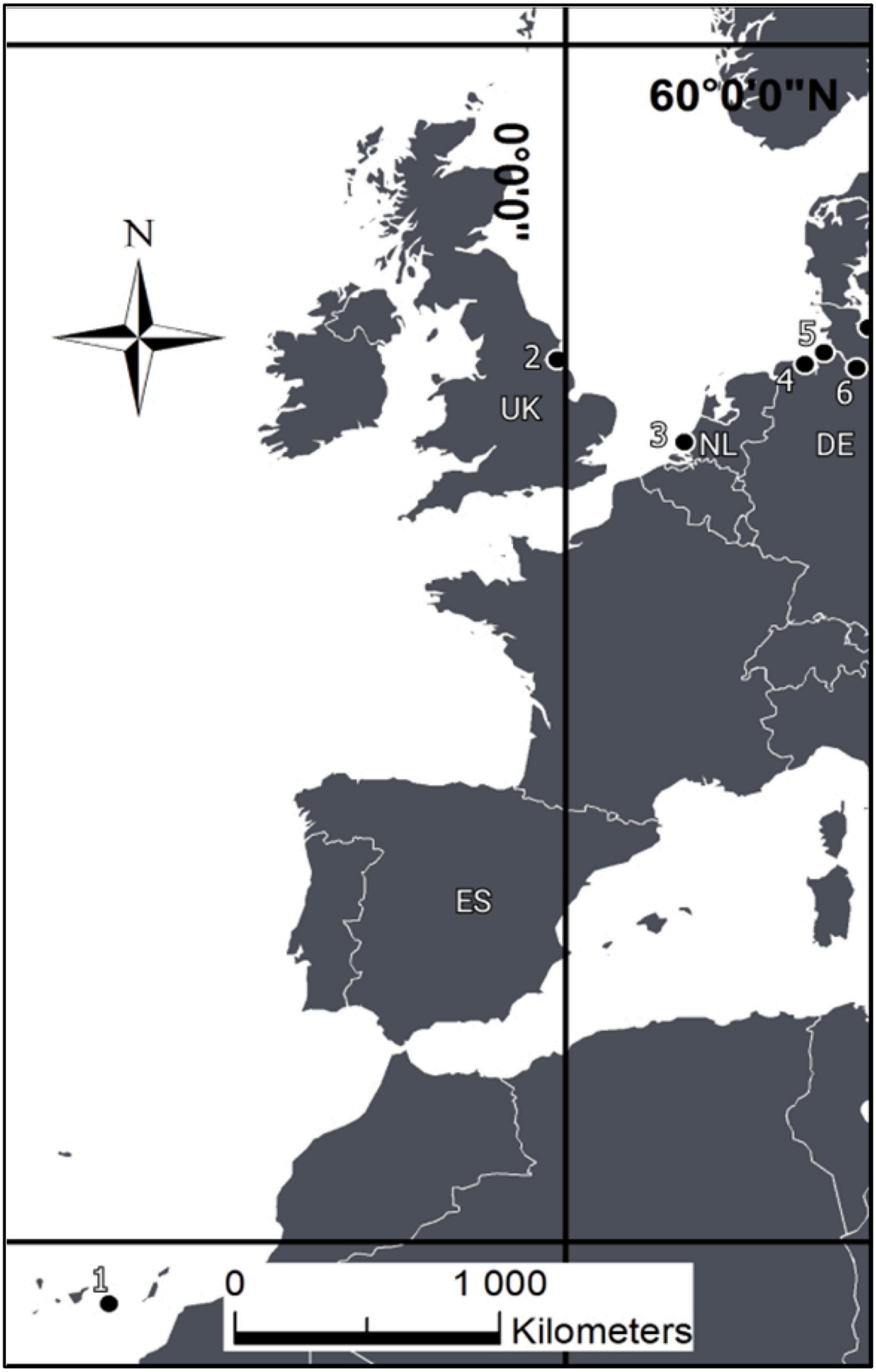

Fig. 3. Surveyed ports within the North-East Atlantic Ocean. The surveyed ports included Las Palmas (1), Hull (2), Rotterdam (3), Jade-Weser (4), Cuxhaven (5) and Hamburg (6).

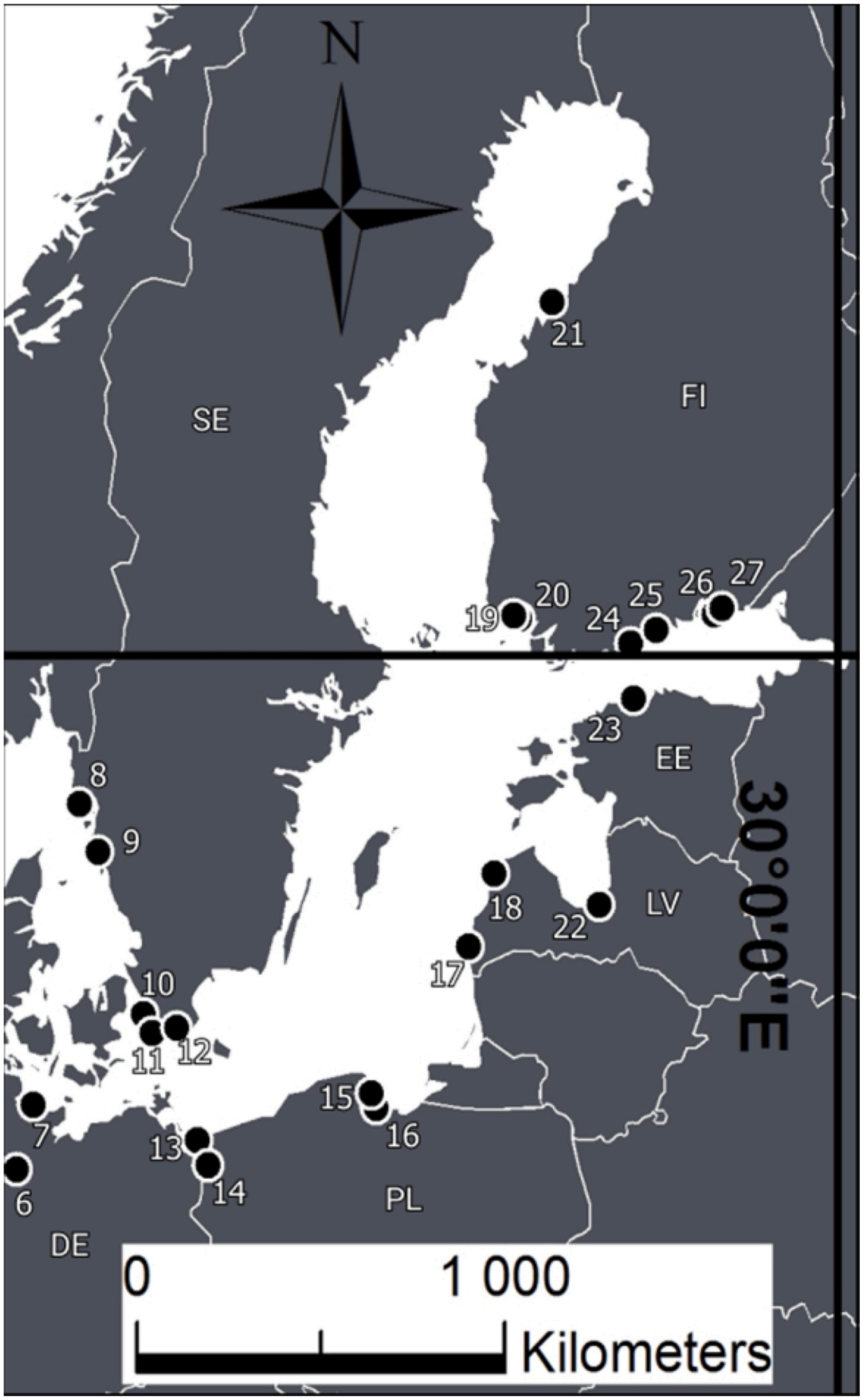

Fig. 4. Surveyed ports within the Baltic Sea. The surveyed ports included Kiel (7), Brofjorden (8), Gothenburg (9), Malmö (10), Trelleborg (11), Ystad (12), Swinoujscie (13), Szczecin (14), Gdynia (15), Gdansk (16), Liepaja (17), Ventspils (18), Naantali (19), Turku (20), Kokkola (21), Riga (22), Muuga (23), Helsinki (24), Skoldvik (25), Kotka (26) and Hamina (27).

measurable negative human health, economy, ecological impact. This TS selection method deviated from the JHP, since TS were selected for a single shipping route rather than a broader biogeographical region.

Once the TS were selected, the risk of the shipping route was assessed using the JHP RA algorithm (Fig. 2). The salinity ranges were obtained through existing literature for Boston harbour (Shiaris, 1989) and Saint John harbour (Hachey, 1935). This case study did not evaluate the shipping route in the opposite direction (Saint John-Boston), as in this case the port State of the recipient port (USA) would have had to identify TS separately for Boston harbour, and this input was not included in the present study.

2.4. Same Risk Area

2.4.1. Methodology

The SRA approach has been previously applied by the Danish

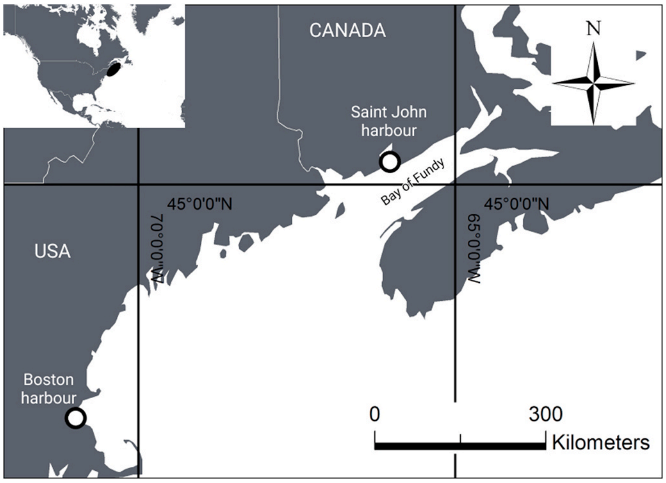

Fig. 5. Map of Boston, USA, and Saint John, Canada. The JHP RA was applied to the shipping route of Boston–Saint John.

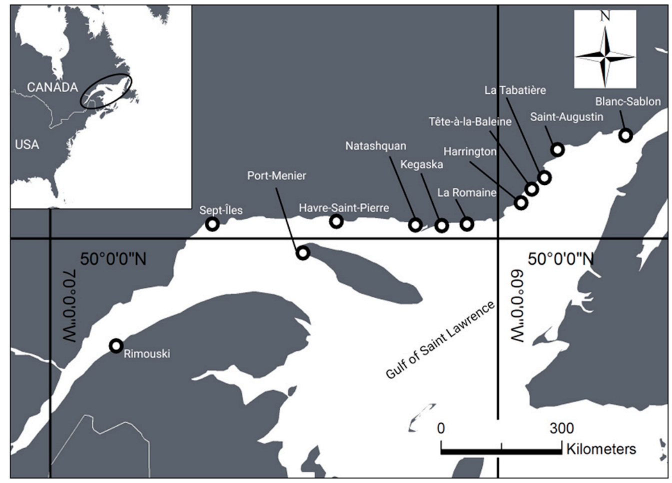

Fig. 6. Ports of interest within the Gulf of the St. Lawrence.

government in 2014 (Stuer-Lauridsen and Overgaard, 2014), as well as Singapore and Belgium (IMO, 2016; Baetens et al., 2018; Hansen and Christensen, 2018). Essentially, a SRA is an area where the TS established in one port are highly likely to disperse (unassisted) to all other ports or locations in the SRA within an agreed timeframe, regardless of their transport in ships' ballast water. The delineation of the SRA is determined by using a biophysical model to assess the natural dispersal of organisms within a waterbody (Stuer-Lauridsen et al., 2018). Biophysical models simulate organism dispersal by combining a hydrodynamic model with a biological, individual-based model (Cowen et al., 2007). The hydrodynamic model simulates a water circulation regime governed by tide and wind forces. The individual-based model estimates organism dispersal within the hydrodynamic model based on relevant life history traits (e.g., pelagic larval duration, swimming behaviour, depth preference or reproduction period; Cowen and Sponaugle, 2009; Stuer-Lauridsen et al., 2018). Species dispersal modelling is a well-established field of research, as biophysical models have been used for decades to examine natural dispersal patterns of species, determine population connectivity, guide Marine Protected Area designations or manage endangered or exploited species (Cowen et al., 2007; Cowen and Sponaugle, 2009; Storlazzi et al., 2017).

The SRA assessment can be conducted using either a species-specific or trait-based approach, modelling either individual TS or a range of life history traits across a suite of species, respectively (Stuer-Lauridsen et al., 2018). The extent of the SRA should be based on the TS or trait combinations that have the lowest capacity to disperse, since an exemption should not undermine the purpose of the BWM Convention by spreading any TS via ballast water further distances than they can disperse unassisted (IMO, 2016; Stuer-Lauridsen et al., 2018). A detailed, standardised protocol does not currently exist for the SRA approach, as modelling methods may differ depending on the biogeographical region assessed or the availability of detailed NIS distribution data (trait-based vs. species-specific approach). Consideration should be given to the number of generations of stepping-stone dispersal to be modelled (IMO, 2016). Previous case studies on the SRA approach have modelled between one to five years of species dispersal (Baetens et al., 2018; Hansen and Christensen, 2018).

2.4.2. *Gulf of the St. Lawrence case study*

A SRA assessment was applied to a shipping route within the Gulf of the St. Lawrence, Canada, spanning the ports of Rimouski, Sept-Îles, Port-Menier, Havre-Saint Pierre, Natashquan, Kegaska, La Romaine, Harrington harbour, Tête-à-la-Baleine, La Tabatière, Saint-Augustin and Blanc-Sablon (Fig. 6).

The SRA case study utilised the validated, trait-based biophysical model from Daigle et al. (2016), who modelled the propagule dispersal of marine benthic invertebrates in St. George's Bay, Canada (see Daigle et al., 2016 for details on the biophysical model). The biophysical model simulated the dispersal of larvae within the Gulf of the St. Lawrence by combining the circulation model designed by Brickman and Drozdowski (2012) with the particle tracking model developed by Chassé and Miller (2010). A trait-based approach was pursued to assess a broad range of traits applicable to a variety of NIS. The domain of the model includes the Gulf of the St. Lawrence, Scotian Shelf, and Gulf of Maine. The model has a horizontal spatial resolution of 1/24° and a vertical resolution with 46 layers (6 m near the surface, with increasing layer thickness with depth). Currents were averaged over 2-h intervals to capture the effect of tides on the dispersal of larvae. Three years of hydrographical data (2009, 2011, and 2013) were utilised to examine broad dispersal patterns across multiple years.

A range of pelagic larval durations were examined (one week, four weeks, eight weeks, and four months), and larvae were considered competent to settle during the final week of the pelagic larval duration (McEdward, 1995). Two reproduction periods of spring (April–June) and summer (July–September) were considered, based on the typical reproduction period of marine invertebrates in Atlantic Canada (Fish and Johnson, 1937; Lacalli, 1981). Three vertical swimming behaviours were modelled: 1) diel migration, where larvae rise to the surface at night and sink during the day; 2) no swimming behaviour (passive) and; 3) tidal migration, where larvae rise to the surface during high tide and sink during low tide (Daigle et al., 2016). It was assumed that larvae vertically migrated to stay within 0–100 m depth and could only settle at depths $\leq$100 m. Larvae had a vertical swimming speed of 1 mm s^{-1} (Daigle et al., 2016).

For each combination of pelagic larval duration, reproduction period, and swimming behaviour, 1000 larvae were released every 2 weeks at each port. Larvae were recorded reaching a recipient port when they travelled within 3 km of a port. Only a single generation of propagule dispersal was assessed in this case study. The connectivity metrics used in the SRA assessment were: 1) the maximum probability of larvae reaching a port; and 2) the probability that larvae are present at a port during the competence period. The maximum probability of larvae reaching a port was calculated by dividing the number of larvae in a recipient port by the number of larvae released. This connectivity metric was based on a single release event with largest number of larvae reaching a port at a given dispersal time to avoid double-counting larvae. The probability that larvae are present at a port during the competence period was estimated by dividing the number of days that larvae were present at a port by the competence period of seven days. The port connectivity results were averaged across the three years (2009, 2011 and 2013) to evaluate the general patterns of larval dispersal within the study area.

The effects of pelagic larval duration, reproduction period, swimming behaviour, and release site on the connectivity between ports were assessed by conducting 4-way ANOVA tests. The Cohen's f value was calculated for each factor and interaction to estimate their relative effect size on connectivity (Cohen, 1988). Factors and interactions were considered to be ecologically significant when their Cohen's f value was either >0.1 for a small effect, >0.25 for a medium effect, or >0.4 for a large effect (Cohen, 1988). Effect size determined the importance of statistically significant differences. The final connectivity value for each port pair was calculated based on the lowest value across all trait combinations, since the focus of SRA-based exemptions is on highly connected ports.

3. Results

3.1. Same location case study: vuosaari harbour

The salinity conditions were not a limiting factor for the extent of the same location, as the range of salinometer readings were between 3.3 and 4.7 g kg^{-1} across both terminals at the Vuosaari harbour. Even though the terminals are within immediate proximity and had similar salinities, the comparison of taxa between the terminals revealed several dissimilarities in the presence and abundance of HAOP (Table 3). The results indicate that at least each terminal should be considered as a separate location within the Vuosaari harbour. Furthermore, ROPAX ships only use the ROPAX terminal, and container ships only use the container terminal, due to different-sized facilities and equipment required for their loading operations (A Perttilä, 2020; personal communication, 18 May; Finnsteve, 2020), supporting the delineation of distinct same locations within the harbour.

Table 3
Harmful aquatic organisms and pathogens (HAOP) at Vuosaari harbour. Harmful algae were based on the list of potentially harmful algal species in the Baltic Sea (ICES, 2007). The abundances refer to number of individuals detected in all samples from Vuosaari, during the 2018 Helsinki port survey (using multiple methods in the port survey protocol), and 'P' refers to species presence. **A. improvisus* densities were counted from settlement plate samples. [+]The *Vibrio cholerae* analyses did not include a detailed description whether the detected strains were toxicogenic.

Category	HAOP	ROPAX terminal	Container terminal
Potentially harmful cryptogenic and non-indigenous taxa	*Acartia tonsa*	7800	10,790
	*Amphibalanus improvisus**	175/cm^2	68/cm^2
	Cercopagis pengoi	89	693
	Cordylophora caspia	P	P
	Gammarus tigrinus	1	–
	Marenzelleria spp.	43	86
	Mytilopsis leucophaeata	–	1
	Neogobius melanostomus	8	–
	Palaemon elegans	11	40
	Sinelobus vanhaareni	1	6
Harmful algae	*Nodularia spumigena*	P	P
	Aphanizomenon flosaque	P	P
	Planktothrix agardhii	P	–
	Dinophysis norvegica	P	P
	Chrysochromulina spp.	P	P
	Chaetoceros danicus	P	P
	Woronichinia naegeliana	–	P
	Akashiwo sanguinea	P	–
Indicator microbes	*Escherichia coli*	P	P
	Intestinal enterococci	–	P
	Vibrio cholerae[+]	P	–

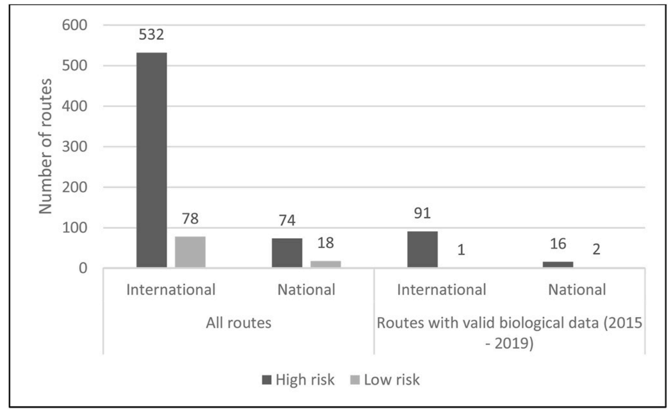

Fig. 7. The JHP RA algorithm results for routes within the Baltic Sea and North-East Atlantic Ocean.

3.2. Joint harmonised procedure

3.2.1. Baltic Sea and North-East Atlantic Ocean case study

The 702 routes in the JHP RA tool included 610 international and 92 national routes, for which 78 (~13%) and 18 (~20%) indicated low risk, respectively (Fig. 7). For ports with valid data for all taxonomic groups, one out of 92 (~1%) international routes and two out of 18 (~11%) national routes produced low-risk outcomes. The low-risk routes included two national routes (Cuxhaven–Jade-Weser, Germany, and Szczecin–Swinoujscie, Poland) and one international route (Muuga, Estonia–Helsinki, Finland). These routes were low risk because all TS at the donor port were already present at the recipient port. Overall, the results of the RA algorithm indicate a low probability that exemptions would be granted for international routes within the Baltic Sea and North-East Atlantic Ocean, whereas the probability was modestly higher for national routes.

3.2.2. Boston–Saint John case study

Seven out of 28 NIS detected in Boston harbour were selected as TS, including *Ascidiella aspersa*, *Agarophyton vermiculophyllum*, *Carcinus maenas*, *Grateloupia turuturu*, *Hemigrapsus sanguineus*, *Membranipora membranacea* and *Mytilopsis leucophaeata*. The JHP RA algorithm resulted in a high-risk indication due to the overlap in salinity between Boston (26.2–33.2 g kg^{-1}) and Saint John (5–30 g kg^{-1}), and the presence of TS at Boston harbour (donor port) that were absent at Saint John harbour (recipient port).

3.3. Same Risk Area case study

The lowest maximum probability of larvae reaching a recipient port ranged from 0 to 14.77% (1-week pelagic larval duration), 0–1.3% (4-week duration), 0–0.70% (8-week duration), or 0–0.10% (4-month duration; Tables 4–7 in supplementary materials) for the 12 ports within the Gulf of the St. Lawrence, across all combinations of swimming behaviour (passive, diel, and tidal) and reproduction period (spring or summer). The minimum probability that larvae are present at a recipient port during the competence period ranged from 0 to 85.71% (7-day duration), 0–24.14% (4-week duration), 0–21.84% (8-week duration), or 0–6.01% (4-month duration). The connectivity between ports was negatively correlated with pelagic larval duration, as propagules with a longer pelagic stage had a lower probability of reaching recipient ports. Therefore, the results of the biophysical model indicate that the overall connectivity within the study area was relatively low across all ports and species' traits. The factors of pelagic larval duration and release site, and their interaction, had ecologically significant effects on both connectivity metrics, as their Cohen's f value ranged between 0.17 and 0.41 (see Table 8 in supplementary materials). Reproduction period and swimming behaviour, and their interactions, did not have ecologically significant effects on connectivity between ports (Cohen's f value ranging between 0.01 and 0.04).

4. Discussion

4.1. Same location concept

The purpose of the same location case study was to illustrate how a same location under Regulation A-3.5 of the BWM Convention can be delineated not only within the Vuosaari harbour, but also how this method can be applied to other ports and harbours. Although IMO has not provided a formal RA method to assess the extent of same location, the mismatch in the composition of HAOP between the terminals suggests that even relatively small harbours like Vuosaari should not be automatically considered as the same location. The discrepancy in HAOP between the terminals could be due to differences in microhabitat at the docks within each terminal, rather than their occurrence within the general area, as the terminals were in immediate proximity and had nearly identical salinities. The dissimilarity may also be due to differences in vessel types, ballast operations, and shipping routes between the two terminals. There would likely be greater overlap in HAOP composition if the terminals provided facilities for multiple ship types (e.g., ROPAX and container ships).

In summary, same location-based exceptions should be limited to the smallest feasible areas within a harbour, such as a single anchorage or terminal, which supports the findings of previous same location studies by Gollasch and David (2012) and David et al. (2013a). This recommendation also follows the definition of same location from the IMO's G3 Guidelines, which states that the same location should represent the same harbour, mooring or anchorage (IMO, 2005). However, it is recommended that a definition of same location is added to BWM Convention when its amendments will be discussed, since the G3 Guidelines do not apply to large commercial ships.

4.2. Joint Harmonised Procedure

The JHP case studies included several hundred shipping routes in the Baltic Sea and North-East Atlantic Ocean, and a route in North America. Thus, the outcomes can be considered representative for the Baltic Sea and North-East Atlantic Ocean, but the methodology should be further tested on shipping routes within and across other Large Marine Ecosystems. The small proportion of shipping routes that produced a low-risk outcome indicated that exemptions under Regulation A-4 should not be considered common alternatives to comply with the BWM Convention. This finding was in line with previous route-specific RA studies (Gollasch et al., 2011; Olenin et al., 2016; David and Gollasch, 2019), concluding that environmental matching and species-specific RA for international shipping routes often results in a high-risk outcome.

The low-risk routes included two national routes (Szczecin–Swinoujscie, Poland and Cuxhaven–Jade-Weser, Germany) and one international route (Muuga, Estonia to Helsinki, Finland). The two national routes could be low risk due to similar habitats and secondary spread of the associated TS across the national waterbodies between the donor and recipient ports. The single low-risk international route from Muuga (Estonia) to Helsinki (Finland) presented an opportunity to conduct international shipping across the Gulf of Finland without the burden of ballast water management. However, a detailed review must be conducted before granting an exemption for the route (IMO, 2017; HELCOM and OSPAR, 2020a). The regional TS list used in the RA tool is considered a living document according to the JHP, but the list has not been reviewed since the JHP was adopted in 2013. Therefore, updating the Baltic Sea TS list may reveal new TS that are present in the donor port of Muuga but not in the recipient port of Helsinki. This issue has been acknowledged among the Contracting Parties of HELCOM, and the Baltic Sea TS list will be updated in 2021. It is highly recommended to include a protocol to update TS lists, where species could be proposed by the concerned parties and added to the list if they meet the TS selection criteria (Gollasch et al., 2020). Continuous updates would ensure that the TS lists are indeed living documents.

The Boston-Saint John case study provided an example of the application of the JHP approach to a shipping route outside of the Baltic and North-East Atlantic regions. This route was an interesting example, as even though several NIS occurrences have been reported from the Bay of Fundy area in Canada as well as Boston (e.g., *Carcinus maenas*, Fofonoff et al., 2018), there was no evidence of these species in the Saint John harbour. This is most likely due to tidal mixing in the Saint John river estuary that seasonally flips the salinity entirely from oceanic to near-freshwater conditions very quickly (Hachey, 1935). The detailed review step in the JHP methodology includes seasonal consideration for exemptions, but it would be very difficult to support granting a seasonal exemption for this route, as the TS for this route included euryhaline species (Fofonoff et al., 2018) that could establish to the Saint John harbour regardless of the season. It is essential to note that the existing species distribution data did not meet the minimum requirements of the JHP port survey protocol. For future exemption applications, it would be expected to conduct port surveys following the JHP port survey protocol even if species distribution data are available for the ports of interest.

Up-to-date port survey data are of paramount importance for the JHP approach. The five-year expiration date for TS presence data is aligned with the IMO's G7 Guidelines, and it is the maximum recommended time interval between surveys following the JHP guidelines. After all, half a decade can be a relatively long time considering that several introductions occur in the coastal waters of the North and Baltic Seas each year (AquaNIS Editorial Board, 2015). The JHP port survey protocol ensures that data are collected in a standardised manner, providing comparable datasets between ports surveyed by organisations across multiple nations and geographical regions. It would be beneficial for the online RA tool to have minimum data requirements, rather than accepting all data entries, as any RA should be based on best available scientific information (IMO, 2017). However, the HELCOM Secretariat stated that all data entries are accepted because the JHP RA tool is not a decision body and recipient port administrations need to evaluate the data quality for each exemption application (M Sala-Perez, 2020; personal communication, 3 April). Overall, the tool sets a clear framework combining environmental matching and species-specific RA methods and enables exemption assessments within and between biogeographical regions. Nevertheless, as the first step of the RA algorithm provides only an indication of risk based on a comparison of salinity and presence of TS between ports, the detailed review in the second step of the RA should include further evaluation on the presence of euryhaline organisms that can tolerate salinities of <0.5 g kg^{-1} and >30 g kg^{-1}.

4.3. Same Risk Area

While the G7 Guidelines indicate that the SRA approach may include a species-specific evaluation (IMO, 2017), a trait-based approach was selected for this case study as trait-based models evaluate a variety of life history traits applicable to a broad variety of known or unknown NIS that may be introduced to a recipient port over time. Species-specific models assess the likelihood of TS arriving and surviving at the recipient port, providing greater certainty in the results for the selected TS. However, the results of species-specific assessments may be difficult to extrapolate to the introduction risk of unknown species, such as species missed during port surveys or those introduced after port surveys. Furthermore, trait-based assessments do not require port- or region-specific species occurrence data that may not be readily available for the ports or regions of interest.

Overall, the outcomes of the SRA case study presented that the biophysical connectivity within the study area was relatively low. In a similar manner, other relevant SRA case studies (Baetens et al., 2018; Hansen and Christensen, 2018) concluded that SRA-based exemptions are unlikely to be granted for large waterbodies with low connectivity. More specifically, the modelling results determined that both pelagic larval duration and release site had an ecologically significant effect on the connectivity between the ports within the Gulf of the St. Lawrence. Thus, a range of relevant pelagic larval durations should be modelled when conducting a trait-based SRA assessment to consider species with short, average and long pelagic larval stages. The ecologically significant effect of release site suggests that the underlying hydrodynamic model and the spatial distribution of donor and recipient ports within this model were essential in estimating connectivity, an obvious; but important outcome.

On the other hand, reproduction period and swimming behaviour did not have an ecologically significant effect on connectivity. However, other studies have concluded that these factors can play an important role in the dispersal of propagules (Daigle et al., 2016; Baetens et al., 2018). Most marine invertebrates, such as molluscs and crustaceans conduct some type of vertical swimming behaviour during pelagic larval stages to feed, avoid predation, or migrate to a suitable habitat (McEdward, 1995; Cohen et al., 2015; Daigle et al., 2016). For example, the larvae of certain brachyuran species coordinate their vertical swimming pattern with the tidal cycle to remain in the estuary throughout their entire developmental stage, whereas the larvae of other brachyurans initially migrate offshore and return to the estuary during their final developmental stage (Cohen et al., 2015). As marine benthic invertebrate species have varied reproduction periods in response to various environmental cues (e.g., tidal cycle, water temperature or light; McEdward, 1995), it is recommended to include a variety of relevant reproduction periods and swimming behaviours when conducting a SRA assessment.

The appropriate biophysical model to be used in a SRA assessment depends on the type of assessment being conducted (trait-based vs. species-specific approach), geographical scale (e.g., spatial distribution of the donor and recipient ports), and the factors (biological and environmental) that influence larval dispersal within each region. For example, mortality rate of larvae was not considered in the case study, but a larval mortality factor would have obviously reduced the number of larvae reaching a recipient port even more (Cowen et al., 2000). Additionally, a single depth preference (0–100 m) was used in the case study to cover a variety of species, while managing the number of trait combinations. However, most larvae remain in the mixed upper layer that generally has higher velocities than below the thermocline, dispersing larvae further (Brennan et al., 2019). Future trait-based SRA assessments should consider either using multiple depth preferences or the depth preference that covers the majority of pelagic larvae within the study area (e.g., mixed upper layer).

The SRA case study served as a useful example to assess the SRA method in practice, as it included several important inputs to assess the biophysical connectivity for the area. One of the most important findings of this case study was related to methodology, as there has been criticism that biophysical modelling is limited to assessing only hydrodynamical connectivity and not settlement potential (Giménez et al., 2020). The present case study aimed to partially tackle this issue by focusing on percentage of propagules reaching a recipient port, as well as probability of propagules being present at a recipient location during the competence period. If the connectivity between the ports of interest is reported in the number of days, it means that the ports are hydrodynamically connected within this time window by a single propagule. Further, pelagic larvae are competent to settle only at the end of their development, which may take several days or even longer (McEdward, 1995). For example, a species that has a pelagic larval duration of 14 days would never settle to a recipient port environment on the third day of the larval duration. These aspects in the model represent a much more realistic probability for competent propagules to reach and settle into a port by natural means and were the main reasons the study area was considered having poor connectivity.

The IMO's G7 Guidelines state that the outcome of the SRA assessment is low risk if the TS (or in this case, trait combinations) have a high probability of dispersing to all locations within the area. However, the threshold to distinguish between high and low probability of larval dispersal has not been defined by these guidelines. Nevertheless, a highly connected waterbody (i.e., high probability of dispersal across all ports) would have had a large number of larvae dispersing from the donor to recipient ports across all trait combinations examined. Lastly, an overall disadvantage of the SRA approach is that it does not assess the risk of organisms in (ballast tank) sediments, whereas the introduction risk of benthic species without a pelagic larval stage can be evaluated using the JHP RA method.

5. Conclusions

The understanding gleaned from this study should be used as a guide to help regulators and managers undertake their own assessments on exceptions and exemptions for the ports and shipping routes under their responsibility. The key value of the present study is to summarise that exceptions and exemptions should not be considered as common options for ballast water management. Applying these regulations should not undermine the primary objective of the BWM Convention, to mitigate the introduction of HAOP attributed to the movement of ballast water by the international shipping industry. After all, new introductions of HAOP are extremely difficult to predict and even though ballast water has been transported globally for over hundred years without restrictions, new introductions are recorded in coastal regions every year, with an increasing trend in many regions. Therefore, all exception and exemption scenarios should be viewed with caution and continuously re-evaluated.

Although economic considerations were not included in this study, limiting exception and exemption alternatives to rare situations with a low risk of new HAOP introductions can be considered also less risky economically. The overall costs of complying with the BWM Convention are relatively low on a national and global scale (Wang et al., 2020). However, the annual costs of new HAOP introductions are unpredictable and can raise up to e.g., millions of Canadian dollars (Colautti et al., 2006), or a dozen of billion euros (Shine et al., 2010), which would be a remarkable stressor to any local or national industry. In addition, this study highlighted the importance of documenting NIS occurrences and their potential link to shipping in order to determine the likely risks of proposed port developments on becoming hubs for future species spread. In these cases, work undertaken to implement the BWM Convention could contribute to wider policy themes, such as spatial planning and strategic environmental impact assessments.

The present case studies relied on IMO guidelines and existing RA methods. The JHP and SRA approaches have been developed extensively since the beginning of the 21st century and provide fundamental framework to assess the introduction risk related to exemption applications. However, comprehensive and up-to-date species occurrence data, as well as continuously updated TS lists are the cornerstones of a scientifically robust RA for route-based exemptions that utilise environmental matching and species-specific comparisons. Further, the SRA case study showed that an exemption would not be appropriate for the area under consideration. This case study also demonstrated that to assess the extent of natural dispersal in a realistic manner, the percentage of propagules that would be competent to settle into the recipient ports should be included in the assessment. The same location assessment suffered from the lack of associated IMO guidelines, which are inevitably needed to assess the risk related to same location-based exceptions in a transparent manner. Regardless, the environmental and ecological characteristics and harbour structure of the Vuosaari harbour indicated that same location-based exceptions should be confined to the smallest feasible area within a harbour, if the harbour consists of distinct areas or terminals. This recommendation follows the definition of same location described in the G3 Guidelines, which currently only addresses smaller ships. The definition should be included to the BWM Convention to cover also commercial ships.

Even though the current study included the evaluation of four different case studies and hundreds of route combinations across several biogeographical regions, further research on exemption and exception alternatives is highly encouraged. Many international shipping routes were not assessed in this study and the outcomes can be somewhat limited to the regions examined. Further studies should concentrate on combining different RA approaches, since all RA methods have their advantages and disadvantages.

Author statement

Outinen was responsible of leading of the research, planning of the case studies, conducting port of Helsinki survey and analyses in 2018 and same location case study, as well as the final layout of the manuscript. Bailey Contributed to the writing and planning of the manuscript and was responsible of the Canadian Same Risk Area case study. Broeg has been involved in the original development of the Joint Harmonised Procedure and contributed to the writing of the MS. Chasse was responsible of the Same Risk Area case study analyses and contributed to the writing of this section. Clarke contributed to the writing of the manuscript and planning of its' layout. Daigle was responsible of the Same Risk Area case study analyses and contributed to the writing of this section. Gollasch has been involved in the original development of the Joint Harmonised Procedure and contributed to the writing of the MS and to the planning of the same location case study. Kakkonen contributed to the writing of the manuscript and planning of its' layout. Lehtiniemi has been involved in the original development of the Joint Harmonised Procedure and contributed to the writing of the MS. Normant-Saremba has been involved in the original development of the Joint Harmonised Procedure and contributed to the writing of the MS. Ogilvie was responsible of the completion of the Same Risk Area case study and contributed to the writing of the manuscript. Viard contributed to the writing of the manuscript and planning of its' layout.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.112823.

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