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ABSTRACT

Same Risk Area refers to an area-based approach for the risk assessment of aquatic invasive species that considers the extent of natural dispersal. It is a new addition to the Guidelines on Risk Assessment (G7) under the International Convention for the Control and Management of Ships' Ballast Water and Sediments. The method outlined here to define the extent of a Same Risk Area assesses the connectivity of species of concern within a wider area by combining information from simulated hydrodynamic data and agent-based modelling with the biological traits and habitat preferences of the selected target species.

1. Introduction

Invasive species, including pathogens, are viewed as a major threat to aquatic ecosystems worldwide and have been reported to affect local economies and societies [5,37,40]. The shipping industry has been identified as a major vector for the unintentional transport of exogenous species across ecosystems with about a third of all introductions of non-indigenous species due to fouling on the ship hulls and another third due to ballast water exchanges [15,18,19].

Nearly all vessels including bulk cargo carriers, oil tankers, container ships and cruise ships use ballast water as a safety measure to ensure structural integrity and stability of the vessel depending on the weight of cargo that has been loaded and unloaded between successive ports of call. Ballast water is taken up from the coastal waters of a region, along with a variety of other biological material, including plants, animals, viruses, and bacteria, and then may be discharged at another port in an entirely different coastal region. These materials may be non-native to the new region and may cause extensive ecological damage to the aquatic ecosystems there as well as economic impacts on aquatic based industries such as aquaculture [10,37].

To address this issue, the International Maritime Organisation (IMO) in 2004 adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments [25], otherwise known as the Ballast Water Management Convention (BWMC). In 2016, the convention surpassed its mandatory number of 30 ratifying Member States representing more than 35% of the world gross cargo tonnage, thereby entering into force on the 8th September 2017. After this date,

over a course of seven years, the vast majority of ships in international trade must meet stringent discharge criteria that *de facto* requires the vessels to disinfect their ballast water before discharge using an on-board Ballast Water Management System (BWMS). These treatment systems, which represent an *a priori* risk reduction measure, must undergo comprehensive testing before they are granted a Type Approval and can be fitted on-board vessels. An original type approval process were found to present flaws (e.g. [9]) and a successful revision of the testing requirements has been completed through a revision of the G8 Guidelines [27].

1.1. Risk assessment for exemption

The convention recognizes that ships trading in certain locations and on voyages between certain ports may be considered as a non-significant risk regarding transport of invasive species via ballast water and therefore the use of a BWMS may not be necessary. Acknowledging this fact, regulation A-4 of the BWMC allows for such ships to be granted an exemption to the ballast water management requirement (i.e. compliance with the discharge criteria which necessitate to have a BWMS installed). To ensure that exemptions are granted with due consideration of the specific occurrence and potential transport of invasive species, the convention requires that a risk assessment is carried out according to its Guidelines on Risk Assessment (G7) [26] and that the risk of transfer of invasive species is found to be acceptable. While the guidelines are not binding, they do outline the standards and best practice that member states should follow in establishing the level of

environmental risk from ballast water exchange.

The UN-funded international programme on ballast water, GloBallast has published a series on Monographs in which risk is defined as "the probability that a hazard will lead to loss, or injury/damage to life, property or the environment; it requires knowledge of the extent of exposure to the hazard concerned" [3]. The G7 Guidelines proposes three risk assessment methods, which may be more or less appropriate depending on the ship's route for which the risk assessment is to be carried out. Generally, the *environmental matching* risk assessment focuses on the similarities and dissimilarities of the abiotic factors (e.g. temperature and salinity) between bioregions and therefore might be used appropriately for ships trading between ports very distant from one another and located in very distinct biogeographic regions. The *species biogeographical* risk assessment approach compares the general presence/absence of species between the ports of origin and arrival of the ship, when traversing different biogeographical zones. The *species-specific* risk assessment of the G7 focuses on identifying target species which 'may impair or damage the environment, human health, property or resources and are defined for a specific port, State or biogeographic region' [26], and subsequently applying information on such organism's life history and physiological tolerances to assess the risk of an invasion by these target species.

In particular, the *species biogeographical* risk assessments require comprehensive knowledge of the natural baseline of the biota in each location; currently largely unavailable because monitoring of invasive or non-indigenous species in ports and other locations is not part of the environmental monitoring effort in most countries. GloBallast has published a monograph on Port Biological Baseline Surveys [2] and guidance assessment procedures by the North Sea and Baltic Sea environmental organisations, respectively OSPAR and HELCOM, also promotes port surveys based on spot sampling as a key part of obtaining and comparing incidence data on invasive species [24].

1.2. Challenges for short sea shipping

Since the guidelines do not offer a mechanism to extend knowledge on invasive species from one port basin to the next, let alone other ports in the proximity, establishing the data set necessary for a risk assessment requires a considerable number of surveys to be conducted in any sizeable port, and makes it cumbersome both for exemption issuing authorities and the shipping industry to implement. In particular, the short sea shipping sector as defined by European Commission [11], may face considerable challenges employing the exemption regime. The short sea shipping sector carries cargo and passengers in local areas and is key to efforts to decrease rates of carbon dioxide emissions by moving heavy cargo traffic off roads [12]. These vessels may regularly call at several ports in an area, or may occasionally use alternative berths in the same port, or even call ports not included in their original schedule, often separated by only short distances. The costs of sourcing the data needed to underpin a risk assessment for each individual ship and route to allow such common local trading patterns would be prohibitive, effectively excluding the option of exemptions for the short sea shipping sector.

1.3. An area-based approach

The G7 guidelines as originally released did not propose to account for natural dispersal of organisms (i.e. that not mediated by shipping). Mobile aquatic species, pelagic life stages of marine organisms (meroplankton) and holoplankton may disperse naturally across international borders, irrespective of other vectors of transfer such as ship's ballast water. Ships that take short sea voyages within such an area of natural dispersion may be unlikely to greatly alter the consequences from the natural transfer of potentially harmful and invasive species.

To address these issues, an area-based approach taking natural dispersal into account was proposed as early as 2014 [45]. The so-
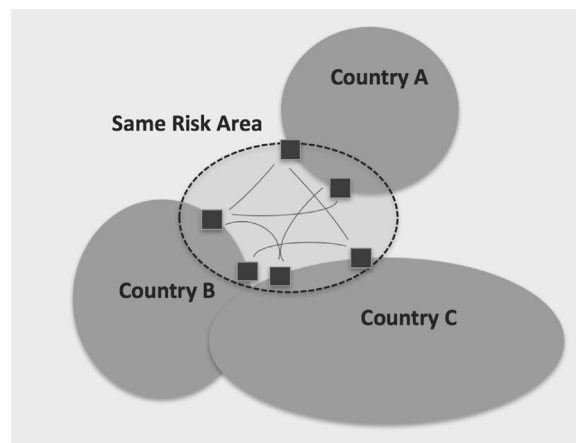

Fig. 1. An area-based approach delineating a conceptual Same Risk Area (SRA) between ports and locations in a defined area.

called Same Risk Area (SRA) approach matured over the successive submissions of member states to the IMO [28–34]. The IMO eventually concluded that a SRA should be defined as: "an agreed geographical area based on a completion of a risk assessment carried out in line with these Guidelines [33]. The terminology decided by IMO differs slightly from proposals previously published and therefore only the most recent as mentioned above should be applied. The concepts behind the SRA approach are illustrated in Fig. 1 where there are a number of ports across different States or countries, with their waters connected hydrodynamically in all directions.

The primary advantage of an area-based approach is that it can be used by administrations as a decision-support tool to grant area-based exemptions to ships trading in short sea shipping. This allows a key underlying dataset and model to be shared between administrations and the ship-owners to use one coherent environmental assessment as the common basis for the exemption of individual vessels. A secondary benefit is that ship-owners and others may conduct initial simple modelling of a potential area to check the feasibility of undertaking a full modelling and exemption process.

In the present paper, the definition proposed by the IMO is used and approaches to define target species characteristics and model their dispersion is provided with the objective of generating information to carry out a risk assessment using an area-based approach. The detailed risk assessment itself is not the focus of the present contribution and should be completed according to the G7 Guidelines as an expert-driven process.

2. Proposed methodology supporting the prediction of data for an area-based approach to risk assessment

2.1. Overview of the proposed approach

One of the key tasks when applying an area-based risk assessment in an effort to define an SRA, is the evaluation of the natural dispersal of species in an area governed by unique hydrographic characteristics. The authors consider that the area-based risk assessment proposed for such studies should be based on a species-specific risk assessment under the G7 guidelines in that it should start with a decision on which identified target species should be used to carry out the modelling exercises. The modelling assessment necessitates that a proper and calibrated hydrodynamic model is setup and used as a basis upon which individual-based biological models (also known as Agent Based Models – ABM) are coupled/combined [7,46,50]. This combination of modelling approaches is also referred to as biophysical modelling (e.g. [44]), particle tracking (e.g. [38]) or Lagrangian modelling (e.g. [50]).

The data required is not limited to but may include:

- Hydrodynamic data on the area including environmental and meteorological features, e.g. the historic and seasonal pattern of currents, tidal regime, salinities, temperature and wind patterns, which provides the mechanism driving the movement and dispersal.
- Biological and physiological traits of the organism to be modelled, e.g. the occurrence and duration of egg or larval stages, foraging and mobility, spawning characteristics, settling rate, mortality, and behavioural aspects, which will govern the ability to survive during the dispersal.
- Habitat occurrence and preference, e.g. the occurrence of soft or hard bottom environs, corals, river banks, littoral and high energy zones.

2.2. Gathering the adequate hydrodynamic data

For a proper simulation of natural dispersal the hydrodynamic model developed needs to be calibrated and validated, which is conventionally done by comparing model predictions with observation data to ensure that the model produces realistic results. The costs associated with developing robust hydrodynamic models are very high but calibrated and validated model results have been produced for most marine areas world-wide by universities, authorities and companies for various purposes (e.g. www.coopernicus.eu; https://www.infoatsea.com/secure/home), and can be used as input to the dispersal simulation.

2.3. Gathering the adequate biological data

2.3.1. Target species

In order to proceed with a species-specific risk assessment using an area-based approach, it is important to define a list of species which will be used to carry out the modelling tasks. The target species are defined based on existing biological information on the ports and the expected area of study and/or based on educated assumptions. A target species for instance must be one that can be transported through ballast water, survive the voyage, settle in a recipient port, grow and form a viable population of the species. Information on the exposure pressure (magnitude), the vulnerability of the recipient environment as well as an estimation of the consequences, are necessary to evaluate the risks posed by such target species. Under Article 6 of the BWMC, States are encouraged to undertake scientific and technical research and monitoring including "observation, measurement, sampling, evaluation and analysis of the effectiveness and adverse impacts of any technology or methodology as well as adverse impacts caused by such organisms that have been identified to have been transferred through ships' ballast water". Port Biological Baseline Surveys as proposed by Awad et al. [2] are not a mandatory requirement under the BWMC. However, the biological records obtained by the surveys are of immense value as part of a global archive that can assist in risk assessments studies that are central to ballast water management. Yet, in many areas around the world consolidating existing information should be the first step to take.

Various internet portals already provide lists of existing and potential marine non-indigenous species in different regions and references to species life history traits and biology. An example is the joint HELCOM and OSPAR online ballast water management tool for the North Sea and the Baltic Sea [23], which also provides access to an invasive species database. In other areas where limited information exists, the target species may be decided on alternative approaches based on the reporting of previously described invasive species [43]. This methodology has been proposed for example by the Singapore Tropical Marine Science Institute [39] and assumes that invasive species reported from one location have life history traits necessary to be invasive elsewhere [42]. Using existing databases it is possible to generate a list of target species, which present a risk for the marine environment (Fig. 2) and benchmark this list to whatever data is existing locally to define species presenting a high or low risk.

2.3.2. Life history traits

Once a list of target species is generated, the parameters governing the ABM must be setup using the most important life history traits of the target species in the context of their natural dispersal (Table 1). To do this, an extensive review of the literature describing the target species should be carried out.

2.4. Gathering information on habitats

In order to assess the likelihood that a species will actually establish itself in a new area, the required ecological niche must be present, e.g. a suitable substrate to allow the settling of sessile species. Maps of the occurrence of relevant habitats are required to be included in the ABM to account for habitat fragmentation, coverage and distribution. Holoplanktonic species follow the hydrodynamics and are not often restricted by 'habitat', but in case of specific requirements, e.g. regarding temperature, salinity, food access, concentration of mates, these should be included as barriers to their distribution.

2.5. Existing softwares

A number of software programmes exists linking agent-based modelling and simulated hydrographic data: MIKE 21/3 ABM Lab [21], IBM LIB [6], Ichthyop [36] and TRACMASS (Döss et al. [8]). Numeric and statistical methods are used to analyze the dispersal modelling results to delineate areas where the natural dispersal within the areas are high (~ highly intra-connected areas), and where the natural dispersal to neighboring areas are low (~ divided by dispersal barriers) [35,50]. Recently, Hansen and Christensen [20] have developed a prototype tool for carrying out area-based assessment of dispersal ("Same Risk Area Assessment Model"or SRRAM). The results from the developed tool can be presented as a connectivity matrix which is in turn analysed using cluster analysis techniques using graph theory as proposed by Vincent et al. [50]. The connectivity analysis of dispersal modelling results can be carried out using statistical software packages like R (R [41]) and previous studies have developed libraries for R specifically for supporting the delineation and segregation of well connected areas using graph theory and information theory approaches [35,50]. Results from the analyses can be displayed as map layers including various connectivity statistics for further risk assessment.

2.6. Simulating the dispersal of marine invasive species

Ideally, the simulation of the dispersal of each of the target species should be carried out, but several target species may share the same traits and they may be addressed together under a single model entry, i.e. it may in practice not be necessary to run a separate model for each target species. In selecting species at least those with characteristics or traits limiting the extent of dispersal should be modelled.

An alternative to simulating dispersal of each individual species, a trait-based approach can be adopted, simulating individual traits or combinations of traits (e.g. [22,38]). A review of all target species and the ranges of each individual trait these species occupy can be used to systematically decide and design the necessary number of simulations to describe the variability of dispersal patterns and connectivity within a study area. The benefit of this approach is that the variability of traits observed across species can be more systematically analysed and a trait-based approach can limit the work load. This approach allows to cover more target species in the risk assessment.

2.7. Technical consideration and limitations

The technical requirements for the input data to the model as outlined below should be clarified and settled in advance amongst the involved parties.
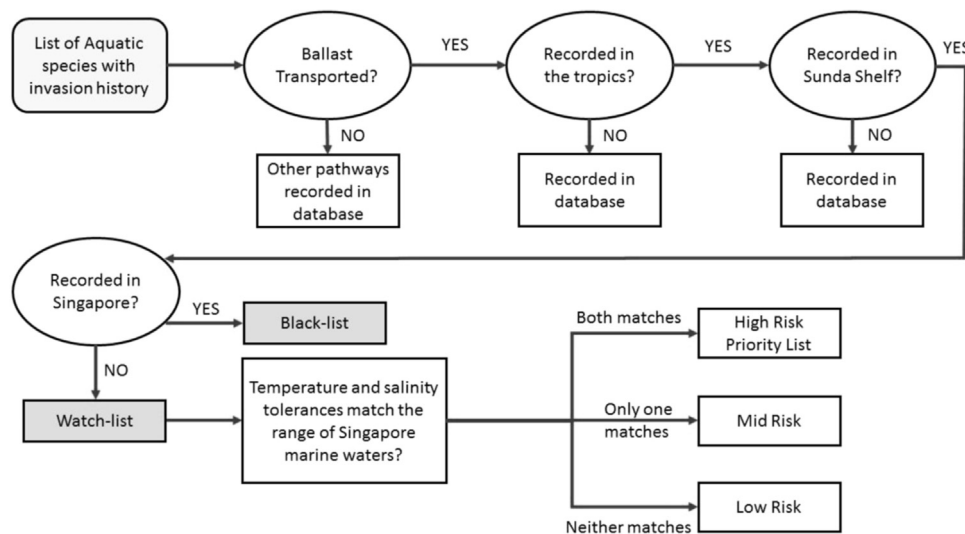
Fig. 2. Flowchart of data mining processes relevant to create a blacklist and watch list of potentially invasive and harmful species for Singapore [39].

Table 1
Example of life history traits and units of measure which a target species may be defined against in the view of its natural dispersal aptitude.

Trait	Unit
Mortality	1/day
Temperature tolerance	Celsius
Salinity tolerance	PSU
Vertical position or movement behavior in the water column	m or m/day
Horizontal swimming behavior	m or m/day
Habitat preference	Selection
Duration and timing of free swimming life stages	Days or hours
Seasonal life events, e.g. spawning	Date interval
Time to maturation	Months or years
Lifetime expectancy	Months or years

2.7.1. Hydrodynamic considerations

Hydrodynamic modelling of an area relies on historic data and the availability and choice of data sets may influence the output if representative data is not included. It is proposed from consultation with oceanographers that two hydrographic years covering the area in question are chosen as base data for the modelling: one typical and one extreme year. It is obviously of importance to consider the degree of conservatism intended to be applied as one may find different output if based on scenarios including 100-year events.

The hydrodynamic data quality and coverage may potentially affect the outcome of the dispersal modelling and hence potentially the identification of areas with high natural dispersal and dispersal barriers. The implication of limitations in the hydrodynamic data for the dispersal modelling and connectivity analysis must be at least qualitatively evaluated. Considerations may include the range of parameters listed in Table 2 with their definitions, responses and limitations.

2.7.2. Biological considerations

The species-specific risk assessment of the G7 guidelines emphasises selecting the target species and this is also of utmost importance in the SRA since the modelled dispersal and the risk assessment will be specific to these target species. Identified target species may already be available through regional or bilateral cooperation organisations, identified by specific monitoring exercises or by scrutinising of the scientific literature.

Once the relevant target species have been decided between parties and their scientific experts, the number and type of traits that are necessary to model a certain species or a group of organisms should be identified or decided from the literature. This should be done with parsimony but should include important traits that will likely affect the survival and therefore the dispersion of organisms.

Examples of traits for meroplankton could include the pelagic larval stage duration, spawning period, temperature and salinity requirements, habitat preference, vertical positioning in water column and survival. Other parameters may be included depending on the required complexity and resources available.

2.7.3. Habitat consideration

An important input to the modelling is the habitat preference of the target species. For certain organisms, particular substrate types are required for settlement, for example, hard substrate is required for barnacles and mussels to settle. Spatial information on habitat occurrence therefore is crucial for identifying barriers to the natural dispersal or the presence of stepping stones aiding the dispersal of a target species. Information may include for example, the occurrence of soft or hard bottom environs, corals, river banks, littoral zones and high productivity zones.

The quality and availability of such data is often limited and almost inevitably in a different resolution than the hydrodynamic data to which it is to be combined in a model framework. Thus it is important to establish model uncertainties with regards to the assumptions made on substrate availability.

Habitat information also includes the physico-chemical characteristics of the water column for holoplankton which is used in the BWMC in the application for the D-1 ballast water exchange standard where coastal species are considered less likely to survive open oceans and vice-versa.

It is also important to consider man-made habitats and their distribution and longevity. Hard substrates in soft-bottom areas may develop from oil rigs, windmills, bridges etc. or barriers may be developed through dredging operations. Such structures may form stepping stones facilitating the dispersal of invasive species [1].

2.8. Evaluation of model outputs

Ports in close proximity may exhibit a high probability of exchanging species among them as a result of natural dispersal mechanisms. Natural dispersal may be driven by species moving by their own means, by passive drift with water currents or by wind-induced drift, or as a combination of these. In Fig. 3, conceptual diagrams of the natural dispersal pattern in a theoretically acceptable SRA are presented under three different scenarios. The analyses of potential dispersal allows the identification of ports or locations that may be considered to be within

Table 2
A range of hydrodynamic data parameters with definition, response and limitations presented, where the quality and coverage may affect the outcome of the dispersal modelling and consequently the identification of areas with high natural dispersal and dispersal barriers.

Definition	Response	Limitations
The spatial resolution: The horizontal and vertical resolutions of the computational grid.	Models with 1–10 km grid resolution will often be applicable with the finer resolution in areas of hydrodynamic complexity (e.g. straits, sounds, coastal regions). The computational grid may be organized in a fixed grid (equally spaced) or a flexible grid (varying space). Vertical resolution of a computational grid typically ranges from 1 m up to 100 m with a constant or flexible layer thickness. Optimally, apply models with grid spacing that resolve the important hydrodynamic processes such as major eddies and hydraulic fronts (in the horizontal plane) and any important vertical stratification of the water column.	The finer the resolution the more details of the hydrodynamic processes will be included. However, the amount of data increases dramatically, and this affects the computation time, data storage and data download requirements. Ideally test different data sets with different spatial resolution to test the limitation of the data you choose.
Time coverage: The period covered by the hydrodynamic data.	Should cover at least the duration of the spawning period of the organism(s) plus the pelagic larvae duration (~ time to settlement). Hydrodynamic data covering more than one year or season should be included to reflect year to year variation of the hydrodynamic processes. Typically, 2–3 years are used representing a "normal", and 1 or 2 "extreme" years. Selections of years very much depend on local conditions and which parameters that are known to vary between years, e.g. dominating winds, regional currents, or temperatures.	Too many years may require too many simulations or too long simulation times, which may not be practical. The aim is to limit the number of years at the same time capturing the year-to-year variability observed in important hydrographic parameters.
Time resolution: Time duration between time steps in the hydrodynamic data available.	The time step is often stored on an hourly, daily or weekly basis. The time step of the original simulation will typically be much lower, e.g. minutes. In systems with significant tidal influence hourly time steps are preferred. For systems with limited on no tidal gauge, daily time steps may be sufficient.	Using large time steps in a highly fluctuating system may introduce undesired errors or biases in the dispersal modelling. Ideally test data sets with different time resolution to evaluate this error on the modelling endpoints (~ overall dispersal pattern, area subdivision using cluster analysis etc.).
Time step: Time step used for the dispersal modelling.	The time is typically minutes or hours. The time step should be adjusted to ensure its appropriate scaling to the grid resolution and the current speed. A rule of thumb is that the maximum distance travelled by any passive drifter in one time step should not exceed the minimum horizontal spatial resolution of the computational grid.	Too small time steps may result in an undesired increase in computational time, while too large time step may result in unrealistic dispersal patterns.
Duration of the simulation: The duration of the dispersal simulation	The duration of a simulation should be assessed relative the dispersal time of the target species. In case of one generation of meroplankton it should cover as a minimum the period from the onset of spawning until most of the settling has been accomplished (may be several months). Multiple generational dispersal can be simulated through a continuous hydrographical period of multiple years, or more conveniently by iterative procedures analyzing the connectivity matrix based on one (or more) representative years.	Not limited
Number of simulated individuals: Number of "agents", "individuals" or "particles" included in the simulation, each representing a free drifting/swimming life stage.	The number of individuals simulated should be aimed at using enough "individuals" to achieve robust and reproducible results (i.e. overall dispersal pattern, areal subdivision using cluster techniques etc.), while at the same time limit the computational effort (i.e. simulation time, result storage, post-processing time of dispersal simulation results etc.). A starting number may be 10,000 but often simulations will require considerable larger numbers to achieve robust and reproducible results (e.g. 50,000 or 500,000). The effect of varying the number of individuals in a simulation and how it affects the endpoint should be tested prior to the main simulations.	A test of reproducibility and robustness of the influence on the endpoint result of different numbers of simulated individuals will limit the risk that results are biased and lack credibility. Note that when simulation organisms that are associated with a very fragmented habitat with limited coverage, only a minor faction of the simulated individuals will successfully settle within the habitat, and thus there may be a need to increase number of simulated individuals accordingly.

an SRA, as well as any directionality to be considered. Available data from surveys, existing databases or published studies may support the modelling results as indicators of an SRA.

An example of delineations of well-connected areas based on dispersal modelling results is presented in Fig. 4.

As another example of model output, the information presented in Fig. 5 illustrates the effects of larval dispersal from coral reef sites in Singapore 45 days after a "spawning event" (from [43]). It shows the cumulative density of competent larvae across to Indonesia to the south and Malaysia to the east and west. The effect of the strong tidal currents in the Singapore Straits is illustrated in the lower cumulative larval density in Indonesia, i.e. the majority of larvae are transported east towards Malaysia.
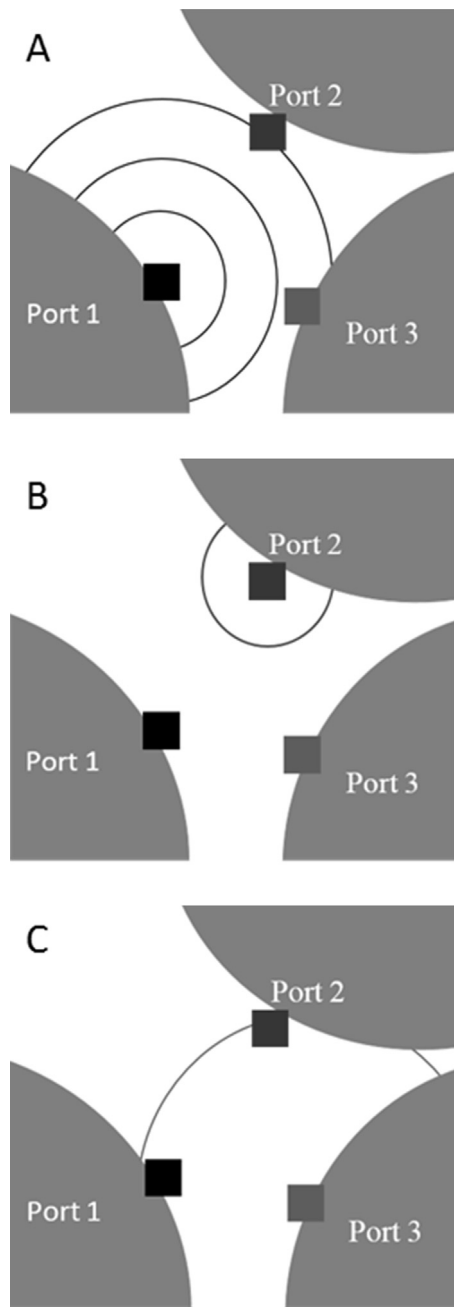
Fig. 3. Conceptual diagram of three situations relevant for delineation of SRAs in an area with three ports (squares) in different countries. Three different invasive species are considered. Grey: Land masses. White: marine area. Solid concentric lines: dispersal distance per generation. Panel A: Data exists on a target species in Port 1. The species has a medium dispersal capability. Analysis of species dispersal reveals that the species after a few generations will reach Port 2 and Port 3 through natural dispersal. All three ports may be perceived as belonging to the same SRA. Panel B: Data exists on a target species in Port 2. The species has no pelagic larval stage and slow dispersal. Analysis of the species' dispersal data show that the species is incapable of spreading to Port 1 or Port 3 within the timeframe considered. Port 2 is not perceived as belonging to an SRA including Port 1 and/or port 3. Panel C: Data exists on a target species in Port 3. The species has a large dispersal capability. Analysis of species' dispersal reveals that the species after one generation will reach Port 1 and Port 2 through natural dispersal and provided all three ports are both sources and sinks they will belong to a SRA for this species.

3. Discussion

3.1. Adequacy of the proposed approach

With the acceptance of the SRA as part of risk assessment in the G7 Guidelines, a new tool has been added to assist in the management of exogenous and potentially invasive species transferred in ballast water. This as such increases the applicability of the IMO's Ballast Water Management Convention. The use of agent-based modelling as proposed here is by no means new to environmental management and is a common tool in the assessment of connectivity of marine parks (e.g. [35]), local biomes [50], and recruitment in fisheries (e.g. [16,38]). There are, as described previously, some important technical limitations to be aware of and choices to be made regarding hydrodynamic, biological and habitat information when using agent-based modelling for risk assesments in an area-based approach. However, including modelling of natural dispersal does provide the benefit of accounting for an everpresent component in the risk of invasive species and allows for the assessment of an area rather that multiple isolated points.

It is advocated here that the focus of dispersal modelling should be on the sessile or bottom dwelling species with time-limited free-drifting stages (meroplankton) since the dispersal capabilities of these species will be the primary limiting factor for delineation of well-connected areas and dispersal barriers. Holoplankton, as represented by many zooplankton and phytoplankton, are assumed to disperse more widely because they reside uniquely in the water column. Note that phytoplankton and zooplankton with resting stages are generally assumed to be part of the holoplankton even though they have benthic stages as part of their life history strategies. However, for some of these holoplankters, limitations in environmental tolerances such as salinities, temperature or light e.g. in an estuarine system may imply the existence of dispersal barriers, and such should be included in the simulation scenarios. Mobile organisms such as fish with an autonomic behavioural pattern may disperse independently or partly independently of hydrographic conditions and these types of organisms are not suitable for the modelling approach proposed here.

It is also possible to take into account multiple generations of species dispersal, and how species may migrate from habitat patch to habitat patch in a fragmented marine landscape where habitats are sparsely and unevenly distributed. This type of analysis may be used to support the risk assessment addressing the identification of an SRA where the target species have long reproduction time or very distinctive requirements for regeneration success. An important caveat is that an area-based approach such as SRA is not a tool to model discrete events such as an outbreak of cholera, accidental untreated sewage discharge, conditional algae blooms or similar for which remidative actions would be described by authorities under the BWMC Regulation C-2, regardless of the type of exemption granted to vessels operating in the area.

Fig. 6 illustrates the importance of barriers and habitat distribution in an area for the dispersal of a target species.

A recent study by van der Meer et al. [49] addresses the environmental homogeneity of the North Sea based on a review of existing data and questionnaire responses. The study concludes that the North Sea is 'far from homogenous in terms of hydrological and biological conditions'. While this may very well be the case, the emphasis on hydrological net transport patterns are in our opinion not a proof of absence of risk of natural dispersal, which are strongly influenced by the prevailing seasonal conditions during critical life stages for each of the selected target species. The SRA method proposed here provides a framework for a quantitative type of analysis of risk of dispersal for use in risk assessments.

### 3.2. Other potential applications of an area-based approach

While the concept of SRA was developed in response to a an international and cross border issue with management of invasive species,
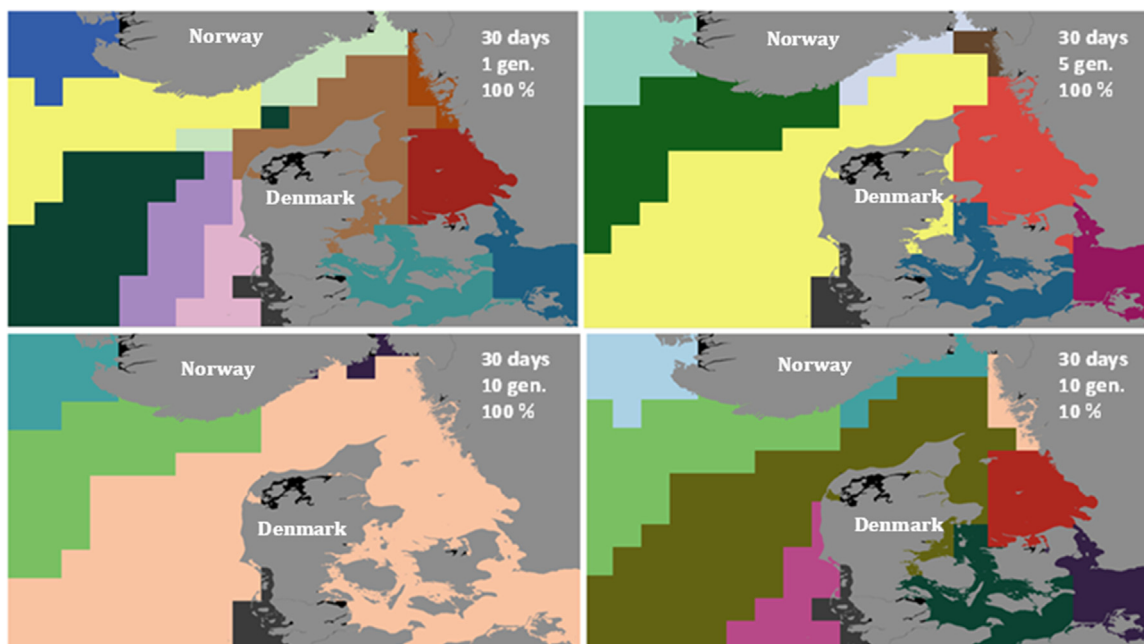
Fig. 4. Four examples of delineations of theoretical well- connected areas based on 30 days dispersal modelling with continuous spawning using SRAAM [20]. Same colors in each example represent areas that are well connected. The hydrographic data used was from Berg and Poulsen [4]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

it is clear that countries with long coastlines spanning several biozones may also find the area-based approach valuable to reduce spread of invasive species domestically. There are examples of countries subdividing their aquatic environment into zones within which vessels may discharge ballast water of the same zone without meeting any treatment criteria, e.g. captain of the port zones in the US [48].

Also, we consider that this approach should be recommended in aquaculture zone management programmes because of the importance of pathogen dispersal between production areas. Shipping has been considered as a potential threat for this $160 billion global industry [10] but the links between shipping and aquaculture are very strong (Drillet et al. in press) and the aquaculture industry itself lacks
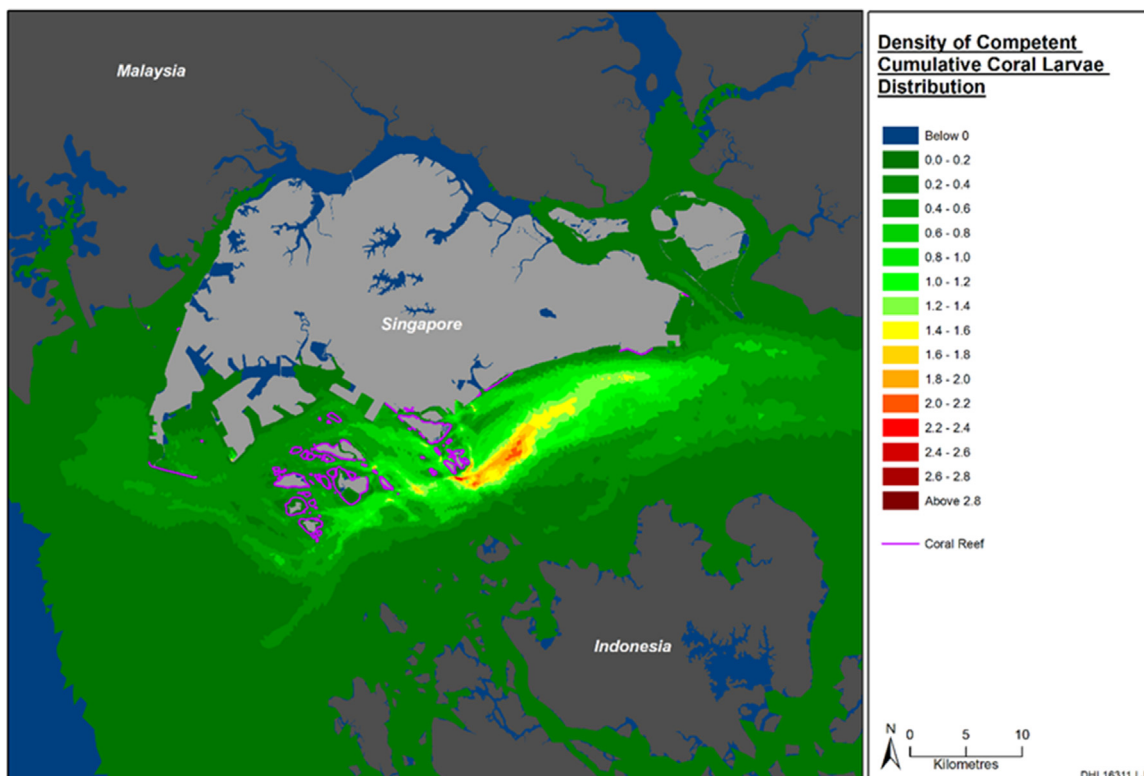
Fig. 5. Temporal model snapshot of the cumulative density of competent larvae dispersed from all coral reef sites in Singapore 45 days after a spawning event using MIKE Software [43].
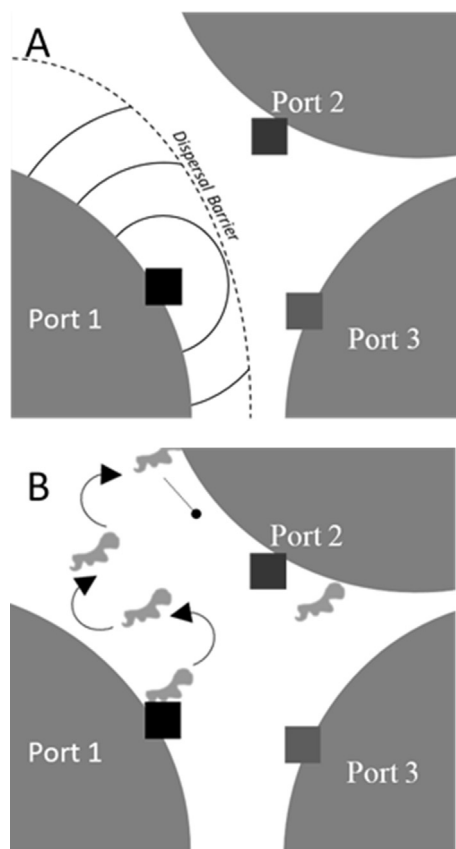
Fig. 6. Conceptual diagram showing two situations relevant for delineation of SRAs in a marine area with three harbours (squares) in different countries. One invasive species registered in Port 1 is considered. Grey: Land masses. White: marine area. Light grey: habitat patches. Solid concentric lines: dispersal distance per generation. Hatched line: Dispersal barrier. Panel A: Data exists on the presence of an invasive species in Port 1. The species has a medium dispersal capability. Analysis of species dispersal reveals that the species after multiple generations will not reach Port 2 and Port 3 through natural dispersal. Despite medium dispersal capability a dispersal barrier, e.g. a salinity gradient, is identified between Port 1 and the two other ports. Port 1 will not be perceived as belonging to an SRA including Port 2 and/or Port 3. Panel B: Data exists on the presence of an invasive species in Port 1. The species has a medium dispersal capability. Analysis of species dispersal reveals that the species after multiple generations will not reach Port 2 or Port 3 through natural stepping-stone dispersal because of habitat fragmentation. Port 1 will not be perceived as belonging to an SRA including Port 2 and/or Port 3.

enforcement of zone management practices. New introductions in this industry are governed by guidance documents [13,47] but no international convention exist that is globally applicable. Yet, we advocate that the use of the present tool could help site selection of off-shore cages areas to ensure a limited connectivity and decrease the pressure from parasites such as sea lices and other pathogens. It could also be used to design water intake points for landbased farms such as shrimp farms where disease outbreak have caused dramatic impacts in the past [14].

4. Conclusions

The IMO has included the Same Risk Area, an area-based approach, to the organisation's risk assessment guidelines. However, the description of the methodology to be used for such work is limited except for partial descriptions reported in submission from member states to the IMO. The present contribution describe how the modelling part of a SRA could be applied to risk assessment under the existing G7 guidelines of the BWMC. We recommend the SRA approach should include hydrodynamic modelling, biological characteristics of target species,

habitat information combined in agent-based modelling to support more robust risk assessment of invasive species. Modelling tools for the application of risk assesments is not new and it has been strongly emphasized in the sphere of ecotoxicological impact assessment (Galil and Forbes, [16]).

While this approach will support the management of bio-invasion risks from short sea shipping there are limitations to the use of the SRA. This tool is currently only applicable to planktonic organisms or organisms presenting a planktonic life form. Natural dispersal of neston (organisms with the capability of swimming against currents) should not be evaluated using the presented approach. The contribution of mobile organisms to the identification of highly connected areas and dispersal barriers may be evaluated qualitatively based on data on species life histories and recorded dispersal capabilities in native and introduced regions.

There are many parameters that must be carefully considered, agreed, and used regarding the hydrodynamic and biological environment in question when employing the SRA approach. These considerations are not new to invasive species risk assessment but in SRA they are incorporated in a transparent modelling mechanism. We conclude that this approach is adequate for the application of the species specific risk assessment as described in the G7 guidelines and advocate that the same methodology could be applied at the national scale and used for other industries including aquaculture.

Acknowledgements

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