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Risk assessments for new bioinvasions for the North Sea Region

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1   INTRODUCTION

This deliverable is a compilation of summaries of four scientific papers that cover different aspects of risks connected to marine bioinvasions in the North Sea Region. One of the papers looks deeper into global shipping and adds several factors to shipping density to describe hotspots for potential invasions and invasion routes. Two of the papers dig into concerns of regional perspective (the Wadden Sea), one developing a model of a specific kind of water body's vulnerability to non-native, the other dealing with questions related to when a species should be stated as a non-native and when it has become part of the native "natural" ecosystem. Finally, one paper is on risk assessment for exemptions of ballast water treatment (also see David, M. and Gollasch, S, 2010, for risk assessment focussing on intra North Sea shipping). All these articles contribute to the understanding of how the risks of bioinvasions must be tackled on a larger geographic scale. Other important risk reduction measures are modelling approaches considering biology and geology of the oceans and monitoring approaches, for example the building of databases on marine invasive species. Here, knowledge about the biology and ecology of the species is important, as well as the abiotic and biotic circumstances of the area of origin, as such information may for example be used to assess whether or not water bodies comply with the ecological demands of the non-natives or to predict scenarios in various kinds of models (e.g. Leewis and Gittenberger, 2011).

2   BALLAST WATER AND MARINE INVASIVE SPECIES

Ballast water has been shown to be a major facilitator of the global transfer of aquatic organisms, including human pathogens (e.g., Carlton, 1985; Ruiz et al., 2000; Gollasch et al., 2002; David et al., 2007). Introduced species may further spread by natural means or be transferred as secondary introductions by e.g., coastal or local shipping, boating, fisheries etc. (e.g., Minchin et al., 2005; Simkanin et al., 2009; Rup et al., 2010; Bailey et al., 2011; Darling et al., 2012; David et al., 2013a) Indeed, invasive species are recognized as one of the greatest threats to biodiversity. However, on a global scale, the pathways for species dispersal remain poorly understood.

There are many obstacles to climb before a non-native species in a ballast tank becomes an invasive and established in a new area. It first must enter a ballasting vessel, survive the physical stress during the ballasting process, survive the unfavourable conditions in the tank during a voyage, become discharged and survive the de-ballasting process (David et al., 2013). Importantly, these events need to coincide with opportunities in the recipient area for the non-native species to survive and reproduce. This is termed the 'invasion windows'.

Normally the establishment of an invasive species must follow three phases (Crooks et al., 2005; Van der Weijden et al., 2007):
   (1) the introduction/first phase of establishment: The species is introduced into an area for the first time and establishes itself as a small and often unobtrusive population.
Sometimes this is immediately followed by a considerable increase in the population, but more often this next phase follows:
   (2) the "lag-phase". This is the period of time between the species' introduction to the area until the moment (often many years later) that the population starts to increase exponentially where the invasive species is present only as a small and unobtrusive population. In a stable water body an invasive species can maintain itself solely as a small population longer than it could in an unstable water body.
   (3) The exponential increase is the final phase where the population of the species increases exponentially and suddenly. This happens usually immediately after an unusually large fluctuation or disaster, such as an extremely cold winter that killed many of the indigenous species in the area. This would consequently decrease the threat of predators to the invasive species, allowing it to then quickly expand its populations, using the niches that have become empty. After an invasive species has established itself in a stable ecosystem, it can thus maintain itself better than in an instable ecosystem.

Ones established non-native species can have various impacts, from ecological to economical. By threatening the biodiversity or food web structure in a water body they may have effects on public health, safety, and the economic functions of the water bodies. It could however also be that a species finds a niche without severely altering the natural ecosystem (Lewis and Gittenberger, 2011).

3   ORIGIN AND SPREAD OF MARINE INVASIVE SPECIES BY WAY OF SHIPPING

Summary of Seebens et al. 2013

In a recent article Seebens et al. (2013) explore "the risk of invasion" with a modelling approach. The few previous attempts to understand patterns of ship-associated bioinvasions have focused on explicitly incorporating data of shipping networks to predict invasion dynamics (Drake and Lodge, 2004; Tatem et al., 2006; Keller et al. 2010). Given that the likelihood of new invasions also depends on ecological and environmental factors (i.e. environmental matching between source and destination and biogeographic dissimilarity), Seebens et al. (2013) combine such factors with global shipping patterns (AIS-based data). Furthermore, the paper considers the full trajectory of marine vessels by considering all ports previously called by a ship as potential sources for non-native species and also estimates the likelihood of a new, previously unknown species from a large pool of potential invaders and not of a particular species. Thus, the model can quantify the probability that a non-native species is successfully introduced and establishes a population for every port and shipping connection worldwide – the risk of invasion. The authors aggregated risks at the level of large-scale marine eco-regions to be able to compare model predictions to empirical data and then classify these according to their aggregated invasion risk.

The paper has several interesting results. A main result is that most ports are unlikely to receive new primary introductions via ballast water, and that high invasion risks are concentrated to hotspots ((South) East Asia, the Middle East and the USA with Singapore, the Suez Canal, Hong Kong and the Panama Canal). The North Sea Region is thus not among the hotspots, which has been the case for the busiest North Sea ports in previous analyses only considering shipping density. Another interesting result is that for some ecoregions the major invasion pathways are concentrated on relatively few highways of bioinvasion, while for other regions, e.g. North-West Pacific, there is a high diversity of high risk routes. As the Northern European Seas are most strongly connected to tropical and subtropical ecosystems, which have very different e.g. climatic conditions, the invasion risk in turn becomes low.

Yet another finding is that the field data, confirmed by model predictions, show that most introduced species originate from sites of intermediate geographic distances to destination ports (8000 - 10 000 km). At short distances the similarities are larger and the probability for the introduction of non-native species is small, while for large distances the shipping density is reduced and also surviving the voyage becomes an issue. Transportations at intermediate distances ensure both a high chance for the introduction of non-native species and their survival during transportation.

The authors also tested the effect of reducing the invasion probability by a fraction every time a ship enters a port. Such a uniform risk reduction for all ships may be an approximation of the debated ballast water treatments, it however revealed that already moderate effects of ballast water treatment can yield substantial results. Interestingly, overall invasion probabilities can be reduced by 56 or 82% if ballast water is treated according to the treatment effort of 25% or 50%. This is due to the fact that successive risk reductions at single ports multiply during the voyage of a ship. When considering a treatment effort of 25% at the 10 ports of highest invasion risk would reduce the invasion risks by 24.8% on the whole shipping network.

The paper further mentions the seasonality of invasion risk with e.g. the highest risk in North America was achieved in the west coast in winter but at the east coast in summer and that invasion dynamics is also associated with ship type; e.g. container ships show a diverse pattern of high-risk routes connecting almost all continents, whereas oil tankers, bulk carriers and ro-ro cargo ships exhibit only a few routes with a high invasion probability.

4   VULNERABILITY OF WATER BODIES AND NON-NATIVE SPECIES

Summary of Leewis and Gittenberger, 2011

High biodiversity is one of several factors determining good ecological quality and functioning of an ecosystem. As a result, non-native species can greatly influence the ecosystem. Other factors include environmental parameters such as chemistry, hydrology and morphology. Leewis and Gittenberger (2011) introduce a new approach to assess the vulnerability of Dutch water bodies to non-native species

by combining features from several methods developed in other countries (Arbačiauskas et al., 2008; Cardoso and Free, 2008; Olenin et al. 2007). Their approach focusses on the system where the alien species are introduced into rather than only on the alien species. The aim is to provide a tool that can be used by water managers to comply with the European Water Framework Directive (WFD) and that is relatively easy to use and gives solid, consistent results. The results can be translated into classes of vulnerability, which are represented on geographical maps with colour codes to indicate different degrees of vulnerability in the different water bodies (see Leewis and Gittenberger, 2011). This readily corresponds to the way countries are required to report to the European Union in the context of the WFD. The method can also be generalized using functional groups of non-native species instead of particular species.

They propose an equation that combines threats to and in water types with effects of particular species (observed or prognosticated). The values used in the formula were found by scoring a number of properties in different water types and species, which are specified in questionnaires (see Leewis and Gittenberger, 2011). The results of the calculations are given as relative vulnerability scores (scale 1–10). They tested 8 water types and 13 species to demonstrate that the method is flexible and easy to use for water managers. The water bodies and species were selected in a workshop by a team of Dutch experts in such a way to best represent situations in fresh, brackish and marine waters.

The vulnerability of areas to exotic species in general depends on a number of properties of those areas, including the measure of isolation (connectivity), species richness, spatial and temporal variation in environmental circumstances, and measure of disturbance, as well as the aspects within the area that may be threatened. The vulnerability of a water body to exotic species further depends on the effects that those species may exert onto the water body. The expression below combines these threats and effects, and leads to a relative value of the vulnerability of a water body to exotic species. The equation used for calculating the vulnerability of water bodies is:

V = (T+ E)/2

V = the vulnerability of a water body to non-native species, giving an indication of how easy non-native species are introduced into the area combined with the severity of the problems that they can cause.
T = the total number of threats of a water body (or water type), divided into "what can threaten the water body" (e.g. pollution, import vectors, number of non-native species already present in the area), and "what can be threatened in the area" (e.g. tourists, drinking water extraction plants, endemic species).
E = the effect a non-native species or group of species can have.
E is split into habitat-suitability **H**, damage done in other areas **D**, and potential damage **P.**

T and E were determined on the basis of questionnaires (see Leewis and Gittenberger, 2011). If the Vulnerability value resulting from the presented method here is not comparable with the resulting values for methods used outside of The Netherlands, the formula V = (T + E) / 2 can be changed into parameters that are more compatible and therefore comparable. The method can be used as a starting point in setting up an early warning system for non-native species and their impacts on water bodies, which may enable an environmental manager to act before an invasive species in a water body reaches its exponential increase phase.

5   NON-NATIVE MACROBENTHOS IN THE WADDEN SEA ECOSYSTEM
Summary of Buschbaum et al. 2012

The Wadden Sea is under joint nature protection by its surrounding countries and listed as a World Heritage Site based on its unique geomorphology, ecological and biological processes and biodiversity (CWSS, 2008). However, the introduction of non-native species proceeds almost unchecked which undermines the conservation target of the trilateral Wadden Sea Plan (CWSS, 2010) to keep the ecosystem as natural as possible. In 2012 there was no evidence of any extinction in marine ecosystems as a result of alien invasions, nevertheless, the biota may lose their integrity by the chronic infiltration of alien species, resulting in a global homogenization of ecosystems (e.g. Olden et al. 2004). An inventory of the Dutch-German-Danish Wadden Sea revealed a total of 66 non-native taxa including 17 tentative

cryptogenics in the brackish-marine macrobenthos until 2010 (Gittenberger et al., 2010), which is close to average compared with similar inventories from other coasts. Most aliens were fouling at harbour walls, pontoons in marinas, at hard structures for coastal defence but also in epibenthic mussel and oyster beds.

The paper by Buschbaum et al. (2012) describes a rapid assessment at suspected hotspots of alien introductions in the German sector combined with a survey in the Dutch sector (Gittenberger et al. 2010) and critically examined published records of alien species. By doing that they compiled a first inventory of non-native macrobenthic species comprising marine and brackish-water macroflora and macrofauna of the entire sea (non-native micro- and meiobenthos is not known). They then discuss the integration of non-native species in the ecosystem and options for their management.

From the assessment the authors found that only a few of the non-native species were directly introduced as most had arrived either by natural dispersion from sites of primary introductions, by shellfish translocations, by regional shipping along coasts or through inland canals and rivers. Given that the Wadden Sea is located downstream of coasts prevention will only be effective at larger scale, indicating the need of coordinated strategy for the entire European Atlantic coast.

Given that the non-native species in the Wadden Sea have increased regional species richness and ecological complexity, evolutionary change has been and is inevitable. Such eco-evolutionary dynamics cannot simply be reversed and often invading populations will tend to differ more and more from their source populations and co-evolution will ultimately soften the distinction between non-natives and native in the invaded region. Here the question of whether it is desirable and feasible that environmental management try to eradicate the intentionally or unintentionally introduced species becomes apparent. Some questions coupled to this are: for how long should an invasive species be regarded as an alien? Do "old" non-natives deserve more rights than new ones even though both have now an essential role in the food web? Is it better to have empty niches than filling them with already introduced species?

The authors suggest that in the Wadden Sea the already established species deserve the same treatment as the native species. Otherwise environmental management would need to embark on an endless chain of manipulating species compositions and interactions. Rather, mitigation measures should concentrate on controlling vectors, early detections and attempting eradications before establishment on a scale of the entire European Atlantic coast. When it comes to the problem regarding the fading the degree of uniqueness, which is in conflict with the aim to sustain natural conditions in the Wadden Sea area, management could implement measures which mitigate this development, e.g. reducing eutrophication, covering hard shores with sand and trying to minimize introducing alien substrates.

6   RISK ASSESSMENTS FOR EXEMPTIONS FROM BALLAST WATER MANAGEMENT

Summary of David et al. 2013b

The Ballast Water Management Convention (BWM) of the International Maritime Organization (IMO) introduced two different BWM requirements to be implemented sequentially. First, the *Ballast Water Exchange Standard* (Regulation D-1) requires ships to exchange a minimum of 95% ballast water volume at the open sea, second, the *Ballast Water Performance Standard* (Regulation D-2) requires that discharged ballast water should contain viable organisms below specified limits (IMO, 2004). It is believed that the only way to meet the ballast water performance standard is with the onboard installation of ballast water treatment systems, but in theory the standard may also be met with other BWM measures, e.g., improved ballast water exchange or ballast water discharged to port reception facilities for treatment.

The BWM Convention also provides for cases where vessels do not need to manage their ballast water, i.e., Regulation A-3 Exceptions and Regulation A-4 Exemptions. Exceptions are identified for specific cases when ballast water uptake, or discharge, is necessary in an emergency situation or is resulting from damage to a ship, or in order to avoid a pollution incident, or when uptake and discharge is conducted on the high seas or at the same location (IMO, 2004; Gollasch and David, 2012; David et al., 2013a). Exemptions are permitted when a risk assessment (RA), prepared according to the IMO

Guidelines for Risk Assessment under Regulation A-4 of the BWM Convention (G7 Guidelines), results in an acceptable low risk for a ship, or ships, sailing only between specified ports or locations, and are granted for a period of up to five year. The study by David et al. (2013b) presents the first RA model for BWM exemptions under the provisions of the BWM Convention worldwide. The application of RA methods and approaches in the European seas according to the BWM Convention and the IMO G7 Guidelines are being studied by David and Gollasch within the framework of the EU 7th FP project VECTORS, and these represent the IMO regulations framework of this study.

Basically, the RA could be conducted by a Party, or a Party may ask the applicant to undertake it. In both cases the Party which receives the application needs to have available a common RA model, as well as all necessary data and arrangements to conduct a RA with the aim to grant, or not, an exemption from BWM requirements. The process is globally applicable, however, David et al.'s (2013) paper was written on intra-Baltic shipping routes, also involving one route with a port in the North Sea region, as an example of a RA model application. The RA model presented in the paper was prepared according to BWM Convention and IMO G7 Guidelines requirements, also considering the HECLOM RA Guidance. It was prepared as a decision tree, which allows high transparency in the decision process, and could relatively easy be adapted to new conditions or requirements (see Fig 1).

Reliable data are a crucial component for a RA (Lodge et al., 2006; David, 2007). Given that introductions of non-native species may occur by secondary introductions between ports inside the same bioregion (Olenin et al., 2000; McCollin et al., 2008; Darling et al., 2012) a single port baseline survey is not enough as a long-term basis for RA, but should be followed by a regular (e.g., every 6 or 12 months) monitoring program for harmful species (e.g., Hewitt and Martin, 2001). At the moment there are only very few regular monitoring programs in Europe specifically targeting aquatic non-indigenous and cryptogenic species (e.g., in Estonia and Germany). Reliable data for port baseline surveys and regular monitoring programs can only be obtained by recognized experts and with a harmonized approach for the sampling standards and protocols. In this process the frequency of studies, the habitats to be included, i.e., plankton, benthos, fouling, the number of sampling stations, and the availability of taxonomic expertise would need to be considered.

The IMO G7 Guidelines include three different RA methods, i.e., "environmental matching", 'species' biogeographical" and "species-specific" methods. *Environmental matching*, between the areas of ballast water origin and discharge, takes into account the port environmental parameters as an indication of the species capability of survival in the ballast water recipient environment. *Biogeographical distributions* identifies overlapping species occurring within the ballast water donor and recipient ports and biogeographic regions, and these mean to be direct indications of the similarity of environmental conditions. The *species-specific* method involves an examination of the potential invasiveness of each species and the harm that might take place once transferred to a new environment. In general a RA is meant to operate at different levels: (i) the environmental matching and species' biogeographical methods are used (in a global context) where donor and recipient ports are located in different bioregions. In the case where the donor and recipient ports are within the same bioregion (e.g., in the Baltic Sea context), it is assumed that environmental conditions are similar, hence (ii) a species-specific RA approach is needed.

An issue with the RA based exemptions from BWM requirements is that one focus is (largely) on "target" species, i.e., the presence of already-known impacting non-indigenous species or identified potentially harmful species in the donor region. Challenges with this approach are multiple and fundamental, including that native species in a region can become invasive when transported to a new region, and that an introduced species of no concern (a non-target species) in a donor port may become invasive when transported to a new region (Carlton and Geller, 1993). It is also frequently assumed that strong environmental mismatches indicate a low species introduction risk, e.g., ballast water from the Tropics carried to the Arctic should pose a low species introduction risk in the same way as ballast water from an entirely freshwater port carried to a high salinity marine port (and viceversa). However, exceptions from these assumptions occur. Protists in general, and phytoplankton occurrences in particular, show an overlap between the Tropics and the Arctic (e.g., Tomas, 1997). Further there are many euryhaline species that survive in almost all salinity conditions (see above). If all these variables and parameters are added to the model, a possible conclusion could be that, in theory, there never could (or should) be exemptions, i.e. zero risk level may be unachievable so that a certain risk level always remains.
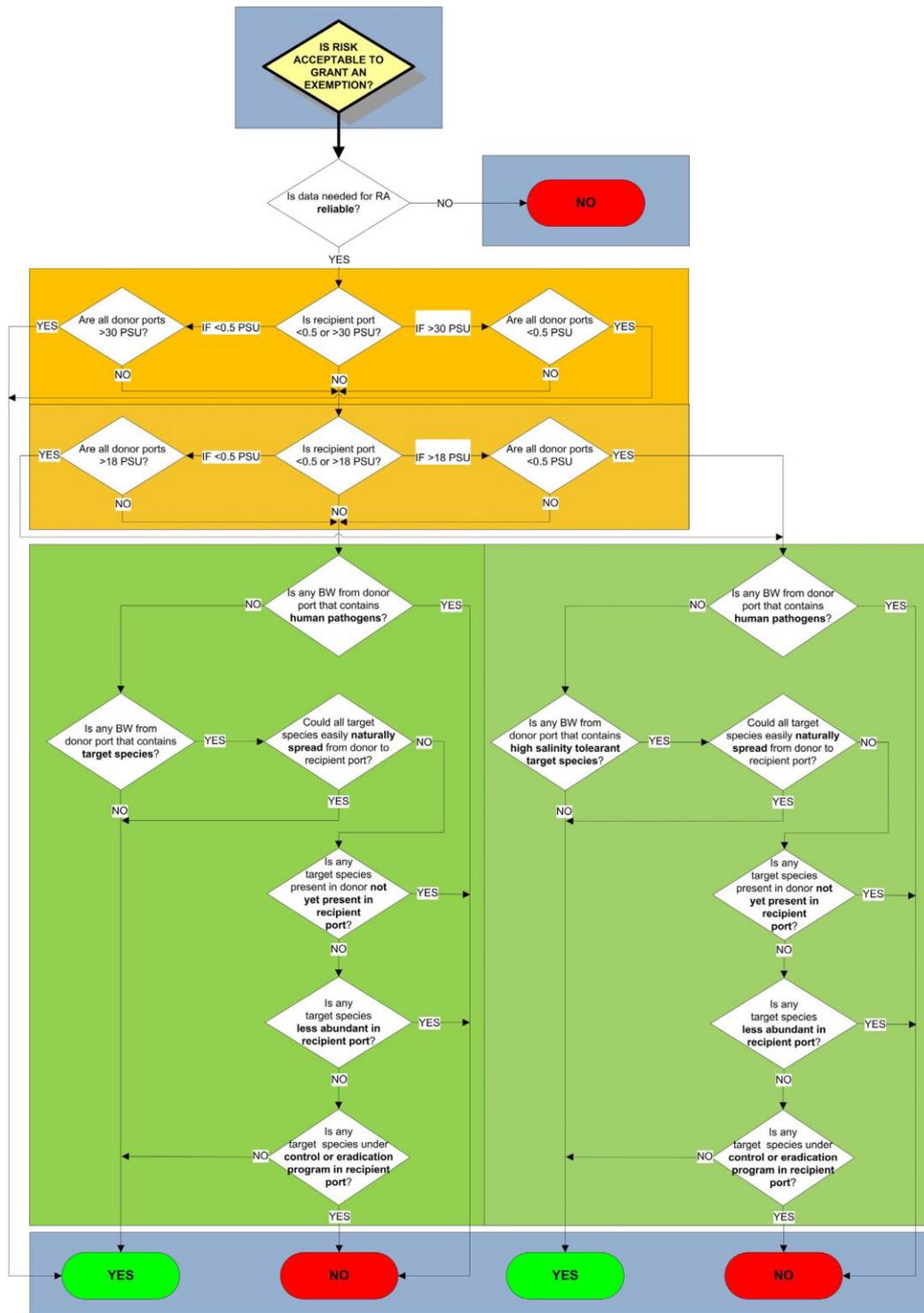
Figure1: Intra-Baltic Sea RA model for granting exemptions from BWM requirements based on the BWM Convention and the IMO G7 Guidelines, considering also HELCOM RA Guidance. The orange box area shows the environmental matching RA process, in the green box area is the species-specific RA process, in the shaded area is the combined RA approach, and in the blue boxes are the decisions. The RA model developed in this study may be of value in other areas worldwide, and if needed, it may be adapted to address different local specifics. From David et al. 2013b.

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