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Aquaculture Biosecurity Challenges in the Light of the Ballast Water Management Convention

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Abstract

Shipping plays a crucial role in supporting global trade, including the transport of products from the aquaculture industry. However, ships may also unintentionally transport invasive species and pathogens in their ballast water which pose biosecurity risks for aquaculture. The Ballast Water Management Convention was developed to manage the biosecurity risks posed by ballast water and has entered into force in September 2017. The management measures and technologies arising from the convention provide some solutions and opportunities for the aquaculture industry. Among these is the potential transfer of treatment technologies between shipping and aquaculture in order to deal with bio-invasion and biosecurity. However, there are residual weaknesses in the regulatory regimes for ballast water management which may reveal a continuous risk from shipping to the aquaculture industry. Gaps include knowledge and management of other aquatic bacteria or viruses that could cause outbreaks in the aquaculture industry and threaten food security and human health. Solutions include focused risk assessments for aquaculture and regional collaboration.

Keywords: compliance, invasive species, pathogens, regulation, shipping, water treatment

Introduction

Shipping is one of the key stakeholders of global trade and plays a crucial role in transporting more than 90 % of all international goods across the globe (Wan et al. 2016). Altogether, there are more than 50 000 merchant ships sailing the world's oceans, and this represents a global tonnage of 600 million tonnes (Globallast 2016).

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Naturally, this global trade also includes the trade of fish meals, animal feeds and aquaculture products. Nearly 40 % of fish output (wild caught and farmed) is traded internationally, making seafood one of the most extensively traded commodities in the world. It is considered that exports of fish products from developing countries represent a larger proportion of total exports compared to that of tropical beverages, nuts, spices, cotton and sugar combined (Asche and Khatun 2006). In this respect, the aquaculture industry is dependent on the capacity of shipping to transport these goods and products, and at reasonable prices. There is however, another linkage between these two industries, and that is the biosecurity risks posed by the global movement of ships which may unintentionally transport pathogens with the potential to affect aquaculture. There is a need to understand and evaluate how these two industries are inherently connected. In this paper, we offer an overview of the existing regulatory regimes developed by the member states participating in the global objectives of the International Maritime Organization (IMO) as well as the United States of America's Coast Guard to decrease the risks of transfer of pathogens. We focus on the management tools and frameworks dealing with the risks associated with the transport of ballast water and eventually reflect on the potential transfer of technologies between shipping and aquaculture in order to deal with bio-invasion and biosecurity.

History of Bio-Invasions Associated with Shipping

Invasive species are viewed as a major threat to aquatic ecosystems and have been reported to affect global economies and societies (Carlton 2002; Occhipinti-Ambrogi and Savini 2003). In the United States of America alone, the impact of aquatic invasive species is estimated to range between millions and billions of dollars annually (Lovell et al. 2006). The shipping industry has been identified as a major source of transport of exogenous species across ecosystems, with about a third of the introductions due to fouling on ships' hulls and another third due to ballast water exchanges (Gollasch 2006, 2007; Galil et al. 2014). Aquaculture as a whole represents the other major source of invasions, and approaches to diminish these risks have been proposed (Leung and Dudgeon 2008). The impacts of shipping on the occurrence of biological invasions was recognized over 100 years ago, when the first suggested introduction of a non-indigenous marine species, the diatom *Odontella sinensis*, known from the tropical and subtropical coasts of the Indo-Pacific, was reported in European waters where it produced dense plankton blooms in the North Sea and more recently in the Baltic Sea (Olenina et al. 2009). Unlikely to have been carried by ocean currents from such distant seas, Ostenfeld (1908) suggested that this species was introduced by shipping as part of the biofouling community on a vessel’s hull or discharged with the water or sediments contained in ships’ ballast tanks. Later, other phytoplankton species such as toxic dinoflagellates were also demonstrated to be transported via ballast water (Hallegraeff and Bolch 1992). This is also the case for species of zooplankton, for which *Acartia tonsa*, for example, was first described in Europe in 1927 and for which haplotypes were found in the Baltic Sea that were 100 % similar to specimens from Rhodes Island, United States of America (Rémy 1927; Drillet et al. 2008).

Fortunately, not all species can survive the transfer through ecosystems in tanks or on ship hulls; and those surviving the transfer may not become invasive. In order to be successful at invading a new area, an exogenous species must first be pumped into ballast water tanks or colonialize the hull of a ship; it must survive transportation to a new location where it would be either discharged or would release offspring; then it must be able to colonize the new ecosystem and establish itself to the point that it becomes considered invasive (Carlton 1985; Smith et al. 1999). There is a broad principle that estimates that only 10 % of all potential invasive species make it to the next step of this succession (Williamson et al. 1986; Williamson and Fitter 1996; Boudouresque and Verlaque 2002; Coutts et al. 2010).

However, aquaculture pathogens are particularly of concern because they usually remain unnoticed until disease outbreaks are recognized, by which point they have already affected a multibillion dollar industry (Minchin 2007; FAO 2016). Furthermore, there is clear evidence of the role of ships in spreading protozoans, bacteria and viruses to different world regions in ballast water and sediments, as well as in biofilms on ballast tank surfaces (Drake et al. 2007) and ship hulls (Sylvester et al. 2011). As most aquaculture activities are usually in the vicinity of ports and quite often create nutrient-rich sediments, there is a possibility of transfer of pathogens from ballast water to aquaculture facilities. For example, the human pathogen *Vibrio cholerae* was released by ships' ballast waters in Mobile Bay, United States of America in 1994 and led to the poisoning of oysters, which were subsequently taken off the market for a period of time, leading to significant economic losses (McCarthy and Khambaty 1994). Other famous cases include the spread of the parasite *Bonamia ostreae* or bonamiosis along the south coast of Britain, potentially via barges fouled with infected native oysters (*Ostrea edulis*) (Howard 1994). Vertical transmission of certain molluscan diseases such as *Perkinsis* spp. have also been observed as a result of the fouling of ships' hulls by contaminated commercial molluscs (Gollasch 2002). Contamination via biofouling communities has also been held responsible for the spread of amoebic gill disease (*Neoparamoeba pemaquidensis*) in cultured Atlantic salmon (Tan et al. 2002).

Ballast Water as a Vector of Concern

As previously mentioned, global trade is heavily dependent on the import or export of raw materials such as wood products, grains, coal, iron and other minerals. These commodities are transported across the oceans in specialized bulk carrier ships in one direction, taking on ballast water for their return voyages when not carrying goods. Although ship owners try to transfer goods during voyages from and to different ports to avoid travelling empty, there is often a need to balance cargoes in weight. Other ship types such as container vessels may adapt their ballasting regime to the amount and type of cargo in each port visited through a route across the globe. Ballast water is used in ships as a means to stabilize the ship when no or limited cargo is present (Fig. 1). It is an important aspect of the routine activities on-board and ensures that the ship and the crew are safe. Because of this vital role, ships will to continue to use ballast water for many more decades, if not forever.

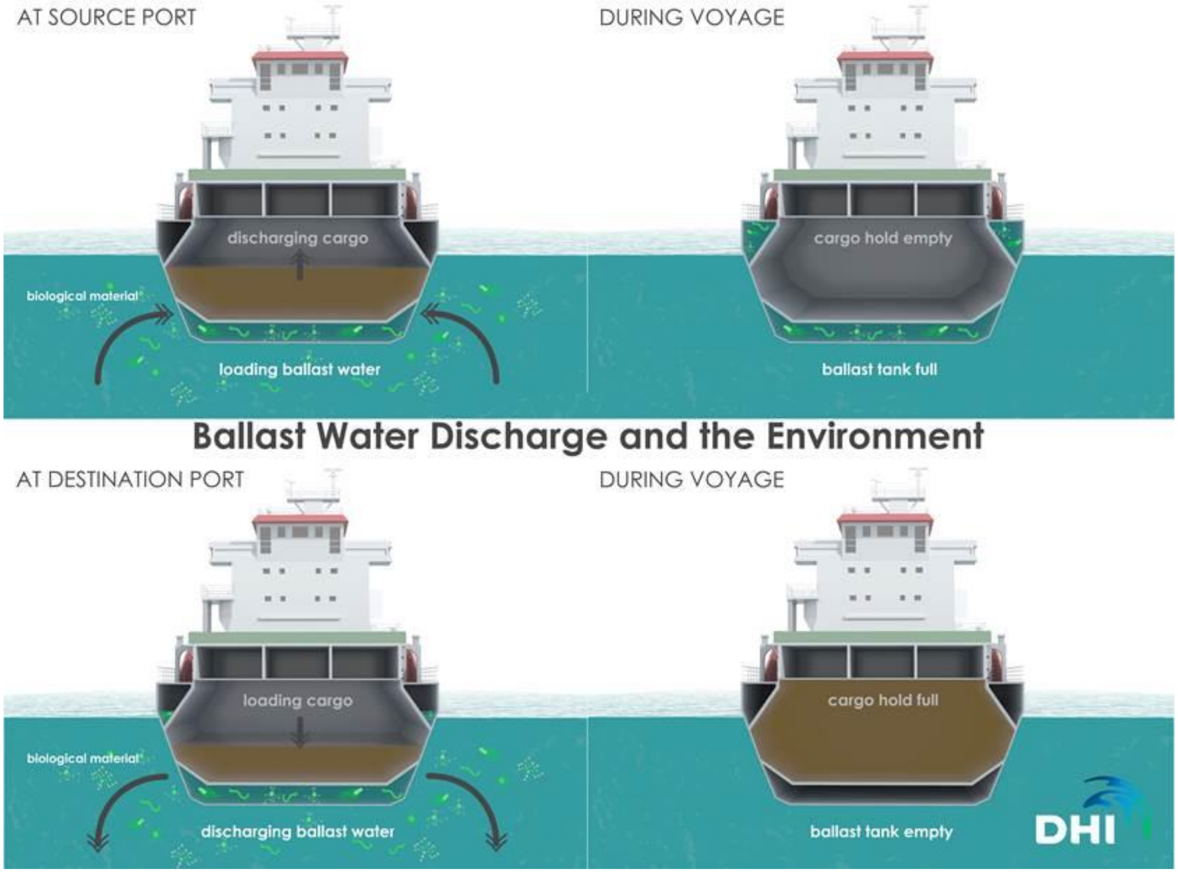

Fig. 1. Cross-section of ships showing ballast tanks and ballast water cycle. (Adapted from GloBallast 2016).

Because of the consequences of bio-invasions generated by the exchange of ballast water across ecosystems, this topic has received quite a bit of attention in the last decades, and much research on organisms transferred through ballast water or its sediments has been carried out (Carlton and Geller 1993; Eno et al. 1997; Ruiz et al. 1997; Briski et al. 2011; Seebens et al. 2013). Ballast water is estimated to be responsible for the transfer of between 7 000 and 10 000 different species of marine microbes, plants and animals globally, each day (Carlton 1999).

The annual amount of ballast water transported is large; estimated to be between 3.5 billion tonnes (Endresen et al. 2004) and 10 billion tonnes (Gollasch 1998). Large ships such as bulk carriers may pump 10 000 to 20 000 m^3 of water per hour (GloBallast 2016). Relating this to a traditional pond size in the Asian shrimp industry, this would equate to 1–3 shrimp ponds per hour. The International Maritime Organization (IMO), with its headquarters in London, has come up with a list of the ten most unwanted marine species carried by ballast water (Table 1).

Table 1. The International Maritime Organization's top-ten most unwanted species. Note that this list still omits viruses and bacteria, which may be more problematic for aquaculture.

Organism(s)	**Species**
Cholera	*Vibrio cholerae* (various strains)
Cladoceran water flea	*Cercopagis pengoi*
Mitten crab	*Eriocheir sinensis*
Toxic algae	Red/brown/green tides of various species
Round goby	*Neogobius melanostomus*
North American comb jelly	*Mnemiopsis leidyi*
North Pacific seastar	*Asterias amurensis*
Zebra mussel	*Dreissena polymorpha*
Asian kelp	*Undaria pinnatifida*
European green crab	*Carcinus maenas*

Ballast Water Management

To address the issue of biological invasions through shipping, the IMO has worked towards the development of a regulatory regime which provides measures to protect the environment from bio-invasions. This includes the *Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species* (Biofouling Guidelines, resolution MEPC.207 (62)), which are intended to provide a globally consistent approach to the management of biofouling.

In 1991, the Marine Environment Protection Committee (MEPC) of the IMO adopted the *International guidelines for preventing the introduction of unwanted aquatic organisms and pathogens from ships' ballast water and sediment discharges* through the resolution MEPC.50 (31). A few years later in 1997, the developments and discussion generated from these first guidelines supported the IMO-MEPC in adopting the *Guidelines for the control and management of ships' ballast water to minimize the transfer of harmful aquatic organisms and pathogen* through the resolution A 868(20). Eventually, the International Convention for the Control and Management of Ships' Ballast Water and Sediments was adopted in 2004 through the resolution MEPC.253 (67). This last resolution is also referred to as the Ballast Water Management Convention, or BWMC. As a convention and not a guideline, this last is legally binding. The convention was to enter into force exactly one year after at least 30 countries representing 35 % of the world merchant shipping tonnage have ratified it (Article 18). In order to prepare for the convention to enter into force, there has been a large amount of work carried out by IMO (Fig. 2). To support the preparation of stakeholders to the entry into force of the convention, the GEF-UNDP-IMO GloBallast Partnerships Programme was developed (Globallast 2016). This programme was initiated in late 2007 and was intended to be finished in 2012, but has been extended until the spring of 2017.

Following the ratification of the convention by Finland in September 2016, the BWMC has entered into force in September 2017. The world merchant fleet is now bonded to the convention. This entry into force will ensure that a good part of the bio-invasion risks associated with ballast water exchanges will be managed and reduced.

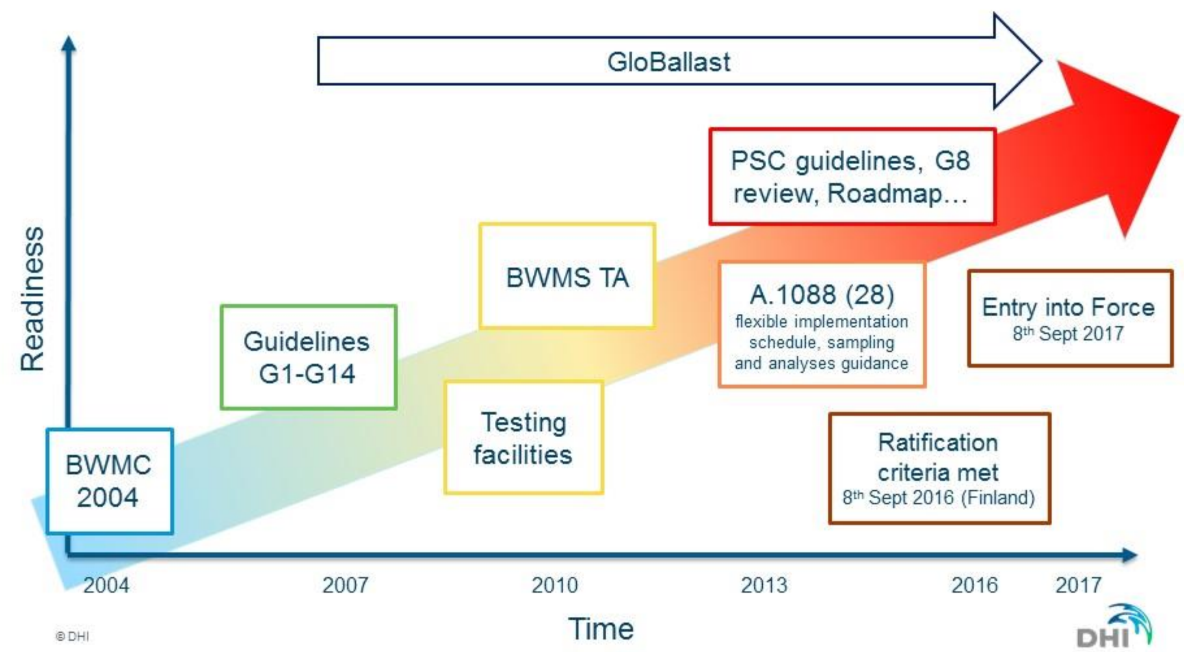

Fig. 2. Developments associated with the preparation of the entry into force of the Ballast Water Management Convention. (Adapted from Drillet (2016)). BWMC = Ballast Water Management Convention, BWMS TA = Ballast Water Management System Type Approval, PSC = Port State Control.

In short, from September 2017 to 2024, more and more ships will have to comply with the convention in that they will have to ensure that every single ship will have a ship-specific Ballast Water Management Plan (BWMP) describing how the ship is managing its ballast water and its sediments, an International Ballast Water Management Certificate (delivered by a flag state, eventually through a recognized organization), and a Ballast Water Record Book, where every single ballasting or de-ballasting event will have to be reported. The BWMP will in most cases include the treatment of ballast water using a Ballast Water Management System (BWMS) which must receive a Type Approval by an administration (see following paragraphs). However, ship(s) on short-sea voyage(s) between specified ports or locations across international borders may be granted an exemption from applying ballast water management systems under the convention (regulation A-4), if it is decided that the risk of transfer of invasive species is acceptable. A risk assessment should be carried out and Guideline G7 details the recommended process for this. The regulations allow an exemption to be granted for multiple ships and voyages between specified ports and locations, thereby supporting a regional approach to exemption through the identification of a “Same Risk Area” or SRA (Stuer-Lauridsen et al 2018).

Draft guidelines for the risk assessment of a SRA were proposed (Saunders et al. 2016 and references therein) and were accepted by the MEPC in 2017. Nevertheless, while short-sea shipping may have a possibility to be exempted of using BWMS, it is expected that most ships will have to fit or retro-fit a system type approved to treat water.

The Type Approval of Ballast Water Management Systems

In line with the convention, all equipment on-board a ship is type-approved and proven to work according to a strict set of specifications; BWMS therefore have also to be tested. There are to date 59 type-approved systems under the IMO umbrella, and the guidelines used for carrying out these evaluations are referred to as the G8 and G9 guidelines. Globally, there are at least 19 organizations involved in testing BWMS, and these are represented by the NGO Global TestNet (Global TestNet, 2018).

This network was initially supported through the work of The GEF-UNDP-IMO GloBallast Partnerships Programme and became independent from this support when signing the Busan Memorandum of Understanding (MoU) in 2013. The Global TestNet aims to increase levels of standardization, transparency and openness in testing BWMS. Typically, the BWMS are tested using volumes of 250 m^3 of water through the use of pumps; the water is stored in tanks before testing the capacity of the BWMS to ensure a valid discharge through a stringent biological evaluation by an independent laboratory (Fig. 3).

Fig. 3. Top left: the DHI ballast water technology and innovation centre in Singapore, bottom left: cultures of standard test organisms (*Tetraselmis* sp.); right: inside a 250 m^3 retention tank used for mimicking ballast water transported during a ship's voyage.

Similar to the BWMC of the IMO, the United States of America has implemented its own regulation to deal with the risk management of biological invasions through ballast water. This is commonly referred as the United States Coast Guard (USCG) regulations, and they became effective in June 2012 (U.S. Coast Guard. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. 33 CFR Part 151 and 46 CFR Part 162). Being a national regulation, this applies only to ships discharging ballast water in United States waters. The discharge standard of both the USCG and the IMO regulations is similar, and a ship may discharge water containing less than the following number of organisms:

a) 10 viable organisms per m^3 >50 μm;
b) 10 viable organisms per mL between 10 and 50 μm
c) one cfu of *Vibrio cholerae* per 100 mL or one cfu per 1 g (wet weight) zooplankton;
d) 250 cfu of *Escherichia coli* per 100 mL; and
e) 100 cfu of intestinal enterococci per 100 mL.

There are some differences between the two regulations, for example, in terms of the definition of "viability": the USCG regulation considers that an organism discharged in its territorial waters should be dead, whereas the IMO considers that non-viable organisms should not be taken into account in the discharge assessment, because of their incapacity to reproduce. Other differences between the IMO and USCG regulations exist in the guidelines and protocols describing the testing procedures for granting a type-approval to a BWMS. To date, the USCG has only approved six systems and more applications are being processed. Yet, this this is seen as a bottleneck by the shipping industry, who must fit systems onboard ships as soon as possible. The G8 guidelines which are used as a basis for the testing of BWMS under the IMO umbrella initially presented limitations because they were developed before any BWMS was ever tested. Some of these limitations have been raised to the IMO-MEPC, as well as in peer-reviewed papers (Miller et al. 2011; Drillet et al. 2013). In light of these issues, the MEPC has re-opened the G8 guidelines for review and a new version with a set of more stringent testing obligations was submitted to MEPC, and approved in October 2016. The revised testing Guidelines G8 are now mandatory (as a code) and this ensures that no new type-approval will be given to systems tested under the old G8 guidelines after 2018; and all systems installed on ships after 2020 will be required to be tested under the revised G8 guidelines (the Code). This revision by IMO ensures that the convention will become better at reaching its objectives of decreasing the rates of bio-invasions.

Remaining Weaknesses, Biosecurity Challenges and Gaps

Although the BWMC provides an important tool for managing the environmental risks from ships' ballast water, some stakeholders still consider that the 27 years taken to achieve this has been too long, that too few states representing the highest tonnage have signed up to the Convention (Wan et al. 2016) and that gaps remain in the protection measures (Drillet et al. 2016).

The BWMC is an international agreement and therefore only regulates ships exchanging ballast water across international borders, not wholly within domestic waters. The regulation applying to ships travelling solely in a single country's water are specific to that particular country. The convention therefore creates a scenario where exchange of ballast water between distant ports of a single country may be unregulated (if not regulated at the national level), while the discharge of ballast water between ports in neighbouring countries (for example across a strait) is subject to the regulations set out by the BWMC despite the expected higher ecosystem similarity at the local scale.

For example, in the Southeast Asian context, a ship ballasting on the west coast of Thailand in the Andaman Sea and travelling to and deballasting in a Thai port in the Gulf of Thailand (ca. 1 500 nautical miles away) would not require an application under the BWMC, while a ship sailing from Singapore to the island of Pulau Batam (Indonesia), less than 10 nautical miles away, would have to comply with the convention. This is both biologically and administratively unsound (Stuer-Lauridsen and Overgaard 2014; Saunders et al. 2016). Currently the only way to resolve such issues is voluntarily through regional sea approaches and working groups such as the Helsinki Commission (HELCOM) for the Baltic Sea, OSPAR Commission for the North-East Atlantic sea region and the Regional Marine Pollution Emergency Response Centre (REMPEC) for the Mediterranean Sea.

Furthermore, while the BWMC will reduce the risks of transfer of organisms larger than 10 μm and of bacteria that are harmful to humans, including *Vibrio cholerae*, *Escherichia coli* and *Enterococcus* spp., the convention does not mention any other aquatic bacteria or viruses that could cause epizootics in the US$ 160 billion aquaculture industry and threaten food security and human health (Drillet et al. 2016). Therefore, it has been proposed that risk assessments should be carried out and eventually flagged to United Nations (UN) interagencies such as UN-Oceans or GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) to circumvent the potential residual risks which may have been omitted in the BWMC (Drillet et al. 2016).

Opportunities: Common Treatment Methodologies

While the gaps outlined above are being addressed, there is also an opportunity for the aquaculture industry, partly due to the efforts of the shipping industry, to advance the technologies available for water treatment. The BWMC has permitted the development of a range of technologies which have been tested in independent test facilities in a robust and controlled manner (see above-mentioned regulations and guidelines). Some of the technologies developed for the shipping industry are therefore applicable to aquaculture as well. For a ships' ballast water, the technologies can be either port-based or ship-based, with the latter being easier to implement because it is more flexible and ensures that systems are able to function during worldwide operations and capable of treating very dirty/murky waters (Tsolaki and Diamadopoulos 2010). Ballast water treatment methods can be categorized as physical separation, mechanical or chemical methods (Tsolaki and Diamadopoulos 2010).

Filtration, either by screen or hydro-cyclone filters, is effective against sediment particles and a wide range of organisms. Hydro-cyclones require less pump pressure than screen filters and allow separation of sediments and other suspended solids to approximately 20 µm. Particles or organisms smaller than this require additional treatment methods.

Thus, filtration or separation treatment is generally run in combination with additional treatment methodologies such as ultraviolet radiation, heat treatment, electromagnetic pulse applications, oxidizing and non-oxidizing biocides, and deoxygenation (see review by Tsolaki and Diamandopoulos 2010). These treatment approaches have also been tested and used in aquaculture (Otte and Rosenthal 1979; Summerfelt 2003). Therefore, lessons learned in the development of systems for the shipping industry could be readily transferred to the aquaculture sector in order to maintain the required high levels of biosecurity in farms (FAO 2010).

Conclusion

Ballast water is a vital aspect of maritime safety, as it ensures the stability and safety of the ship and therefore protects its crew. The USCG and IMO regulations stand as a cornerstone of the upcoming achievements from the shipping industry. These regulatory regimes, developed to support the management of the risks inherently associated with the use of ballast water, will help to reduce the rate and number of exogenous species transferred across ecosystems. Nevertheless, the understanding of the risks generated by the exchange of ballast water for the aquaculture industry is generally low. Limitations in the testing of BWMS have been identified and reveal potential impacts on human health risk management (Cohen and Dobbs 2015). This may also be true for understudied pathogens in ballast water tanks and their potential impacts on aquaculture, even after the installation of BWMS in all ships worldwide (see recent work by Ng et al. 2015; Kim et al. 2015; and Kim et al. 2016).

There is a gap in our knowledge and a residual weakness in the regulatory regimes for ballast water management which may reveal a continuous risk from shipping to the aquaculture industry (Drillet et al. 2016). Until this is evaluated, there are dispositions in the BWMC about the measures which port states are to take in the event of a bloom of potentially harmful organisms occurring in their waters and where a ship may ballast water from (regulation C-2). In such cases, port states are required to inform the ships and eventually propose measures to decrease the risk of ballasting water containing such organisms in ballast water tanks.

The aquaculture stakeholders may benefit from this disposition by ensuring that countries monitoring the water quality in their port test for pathogens potentially affecting aquaculture, such as those reported by the World Organisation for Animal Health (OIE, 2017). Impact assessments of the risk for aquaculture and marine spatial planning may be used as proper tools to ensure improved biosecurity (Drillet et al. 2014).

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