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COMMUNICATION

Challenges in Managing Marine Bio-invasions via Shipping in Singapore

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ABSTRACT The economic, social and environmental impacts arising from the transfer and establishment of non-indigenous marine species (NIMS) mediated through ship hull biofouling and ballast water discharges in the coastal marine environment require a regional approach to manage bio-invasions. As the coordinating body for maritime shipping affairs and protection of the marine environment, the International Maritime Organization (IMO) has been working with member states to adopt and ratify global conventions aimed at preventing invasive species transfer through shipping. As a major shipping hub and port-of-call in Southeast Asia, Singapore faces multiple challenges in managing marine bio-invasions including managing the transit of high risk vessels to environmentally sensitive areas beyond national borders. In this article, global frameworks for managing bio-invasions and its challenges for marine invasive pest management are discussed.

1. INTRODUCTION

Biological invasions or bio-invasions refer to the phenomenon and suite of processes that cause the *transport, survival, establishment, reproduction and spread* of organisms through human activity (either intentional or accidental) to areas outside the potential range of those organisms as defined by their natural dispersal mechanisms, biogeographical barriers and their interaction and influence on the native ecosystem (Richardson et al. 2011). The transfer of non-indigenous marine species (NIMS) to the recipient marine environment causing significant economic, ecological and environmental impact may therefore be categorized as marine bio-invasions and the organisms as marine *invasive* species. Well documented cases of the establishment and proliferation of the zebra mussel (*Dreissena polymorpha*) from the Mediterranean to the Great Lakes (Carlton and Geller 1993) and the spread of the comb jellies (*Mnemiopsis leidyi*) from North America to the Black Sea (Shiganova 1998) leading to the crash of local fisheries serve reminder of the significant impact of invasive species on the marine environment and drew attention to the significance of the introduction pathways of these species via ballast water transfer across continents. Such concerns led to the drafting and adoption of the 2004 International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention, IMO) with the aim of establishing a universal set of guidance documents and setting performance standards for ballast water treatment and management. The BWM Convention entered into force on 8 September 2017 after a minimum of 30 contracting parties representing 35% of the world's gross shipping tonnage ratified the BWM Convention. However technical issues regarding implementation of the BWM Convention remain unresolved.

Biofouling on vessels affects operational efficiency by increasing fuel consumption due to increased drag forces during vessel motion (Schultz and Swain 2000). In addition, biofouling on vessels and its niche areas increase the risk of transfer of NIMS to recipient environment (Bax et al. 2003; Hewitt and Campbell 2007). In growing recognition of the impact of NIMS transfer, IMO published the 2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Pests (Biofouling Guidelines, MEPC 62). In this document, a holistic approach to ship biofouling management was proposed and a series of guidelines through the adoption of appropriate antifouling systems and operational practices were proposed. IMO encouraged member states to adopt relevant guidelines and incorporate them into port state controls. This set of guidelines is important because it converses the responsibilities of the ship owners and operators to manage biofouling on their vessels and also highlight port state controls to manage bio-invasions through identification, monitoring and communication of invasive pest information that are present in local port waters to vessels in their port waters. This suggests a fostering of cooperation between industry partners and port authorities to manage NIMS.

In this article, some of the challenges in managing marine bio-invasions from ballast water management and ship biofouling are discussed with reference to existing global environmental instruments. The role of the shipping industry in managing and reconciling the issue of bio-invasion is also discussed.

2. SHIPPING AND ITS ROLE IN FACILITATING MARINE BIO-INVASIONS

Natural causes for marine bio-invasion are often a result of oceanic currents ferrying species in ocean currents to a non-native area of similar environmental conditions (Mack et al. 2000). While rising ocean temperature as a consequence of climate change is expected to increase some of these cases for NIMS (Occhipinti-Ambrogi 2007), these cases often take place over a wider temporal scale. The introduction of shipping over 200 years ago has played a role in facilitating the transfer of NIMS. With the advent of steam powered engine vessels at the turn of the last millennium, shipping has accelerated the frequency of marine species larvae or their propagule transfer. With shorter travelling times, marine species hitch-hiking on the hulls of vessels and as stowaways in water-filled ship ballast tanks experience less environmental stress and a greater chance of survivorship upon arrival at the destination. Today more than 80% of the world's global trade is carried around by shipping and close to 12 billion tons of ballast water are carried around each year (Bax et al. 2003).

Not all introductions (intentional or accidental) of NIMS may present a significant long-term impact to the environment. In cases where the native ecosystem may provide biological resistance to NIMS incursions, the *alien* population may fail to establish or perish after a few cycles of reproduction. Predicting the success of an incursion is however usually complicated and inconclusive without an understanding of the wide array of factors in the environment (Shrader-Frechette 2001). The dominant factors often associated with successful bio-invasions arise from *high propagule pressure*, *lack of native ecosystem resistance*, *environmental similarity*, *biogeographic dissimilarity and presence of anthropogenic disturbances*. When a combination of these factors is coupled with higher influx of NIMS as a result of ballast water discharges and hull fouling, the result may be an increased rate of incursions. Given the right physical, biochemical and ecological conditions, the NIMS population may then be able to establish themselves in the new environment and propagate sustainably. When this occurs, the new population may cause significant impacts by interfering with native species interaction causing displacement of native species and ecosystem modification. Remediation and eradication is often costly and impossible; one notable example of a successful eradication was the elimination of the black striped mussel (*Mytilopsis sallei*) from three sites in a Darwin marina using copper sulphate in March 1999 (Department of the Environment and Heritage, Environment Australia). Impacts may include damage to infrastructure such as clogging of canals and pipes, loss of native biodiversity, permanent modification or devastation of ecosystem, changes to nutrient fluxes in the environment, and transfer of harmful pathogens and toxins to humans (Crowl et al. 2008). There is also a need to address not only the direct impact of bio-invasion on native species (e.g., predation and competition for food), but from a larger ecological perspective and indirect impacts.

The unintentional introduction and establishment of NIMS via shipping are now well-known. The transfer of NIMS via shipping is attributed to two major factors: the discharge of untreated ballast water, and ship hull fouling transported into port and coastal areas (Mack et al. 2000; Bax et al. 2003; Lewis et al. 2003). Such studies were mainly documented in temperate regions such as North America, New Zealand, Australia and Japan (Fofonoff et al. 2003; Kospartov et al. 2008; Hewitt et al. 2004; Otani 2006) where the effects of NIMS have been felt. In contrast, fewer studies have been conducted in the tropics (e.g., Hawaii; Eldredge and Carlton 2002) where in general, the impacts of NIMS have so far been localized and of limited impact. This has led to a belief that bio-diverse tropical areas are less susceptible to the establishment and proliferation of NIMS, hence a lower risk of bio-invasion. However, Hewitt (2002), in a survey of the spatial distributions of NIMS in Australia's tropical marine environment suggested that the rich biodiversity in the tropical region does not support evidence of lower invasion risk or environmental resistance. The recent discovery of the American mussel *Mytella strigata* in Singapore (Lim et al. 2018) showed that the tropical marine environment is not immune to invasions. Further, correct identification and management of NIMS in the tropics are often limited due to a lack of marine taxonomic knowledge. This is due in part to higher species diversity in the tropics and inadequate taxonomic research. Limited identification and understanding of NIMS, its life cycle traits and its response and adaptation to a host environment in local waters often hinder adequate management of marine invasive species and policy development in national biodiversity plans.

The confluence of increasing shipping volume with the capability of major ports to handle efficiently larger transshipment vessels has led to the development of a global shipping network into a hub and spoke model (Wang and Wang 2011). In this study, which modeled the spatial pattern of shipping network through international carrier movement, South East Asia (SEA) was pointed out as one of the concentration regions of worldwide shipping lines, and Singapore was identified as one of the SEA region shipping hub in the model. This suggests a possible risk of higher potential propagule pressure (PPP) in the SEA region as transshipment vessels connects regional ports via shipping hubs. A study by Seebens et al. (2013) that focused on vector-based modeling using vessel trading patterns environmental heterogeneity (i.e., temperature and salinity) and biogeographic distribution to model bio-invasion probability also indicated Singapore and the SEA region as a bio-invasion hotspot. Earlier studies by Kaluza et al. (2010) and Keller et al. (2011) highlighted global shipping movement patterns as a key factor in determining the risk of bio-invasion in risk assessment models. An increase in anthropogenic influences in the SEA region especially in modified coastlines, habitat degradation, deforestation and loss of native species may further weaken biological resistance to bio-invasions (Peh 2010), in the light of these emerging researches on the global shipping patterns against bio-invasions risk management. The lack of an appropriate and timely management plan against marine invasive pest incursions may exacerbate the risk of bio-invasion in the region.

3. MANAGING MARINE BIO-INVASION WITH A FORWARD-LOOKING PLAN

In Southeast Asia (SEA), the continued safeguard of the coastal marine environment and resources is important for fisheries, aquaculture and tourism while many traditional forms of livelihoods are still closely dependent on these resources. In the case of marine environmental protection and conservation in SEA, the closeness of our waterways, marine habitats and proximity of these waterways to the pressures of international shipping traffic challenges national interests in increasing economic trade while preserving the marine environment. In particular, the threat of marine pollution in the Straits of Malacca (Rusli 2012), an important gateway to the South China Sea and the emerging economies of China, South Korea and Japan prompted a call for the designation of the Straits as a Particularly Sensitive Sea Area (PSSA) which accords additional environment protection through IMO.

Singapore's terrestrial environment and coastal boundaries have also evolved rapidly since achieving independence in 1965 (see review by Tan et al. [2016] and references therein). Most strikingly so is its heavily modified and 'straightened' coastlines and conglomeration of islands through reclamation (e.g., Jurong Island, which houses Singapore's petrochemical industry). Not all reclamation works were for commercial purposes. Pulau Hantu Besar and Pulau Hantu Kecil islands off the south coast of Singapore were combined and expanded in 1975 for recreational purposes. The Marina Bay Cruise Centre located in the Marina Bay area aims to bring recreational cruise vessels to the region. Singapore has also invested on upgrading of port infrastructure to expand port handling capabilities. Besides expanding existing port areas, the use of information technology to boost port handling efficiency is expected to increase total port handling capability to 50 million twenty-foot-equivalent (TEUs) by the year 2020. By 2030 consolidation of port activities at the newly reclaimed Tuas Port is expected to handle 65 million TEUs per year. These interests present a challenge for preserving native marine habitats and biodiversity.

These impending changes may present two distinct challenges for Singapore and government policies. On the economic front, Singapore strives to maintain a leading international trading port status. At the same time, there is already a growing awareness of the need to incorporate environmental conservation issues into the marine environment. These are reflected in the Singapore National Parks Board initiative on the conduct of a comprehensive marine biodiversity survey of marine habitats in Singapore. The results of these surveys will aid the understanding of native marine biodiversity. There is an increasing recognition among the international community of the need to preserve the richness, unique biodiversity and ecological wealth of marine and terrestrial resources for the benefit of future generations. Bio-invasion is now recognized to be one of the major challenges and goal in biodiversity conservation. These policies may be reflected in individual countries environmental management agencies that may deal directly or indirectly with biodiversity conservation through for example, anti-pollution or anti-encroachment laws. In Singapore, the management of non-native species of animals and plants are governed by several legislative Acts administered by a few agencies (Animals and Birds Act; Control of Plants Act (Agri-Food and Veterinary Authority (AVA)); Parks and Trees Act (National Parks Board (NParks)); Prevention of Pollution of the Sea (MPA)). AVA is also the national body tasked for managing the Convention for Illegal Trade and Endangered Species (CITES) while NParks actively discouraged dumping of unwanted animals into local reservoir waters. There is currently no agency that is tasked specifically with managing NIMS and bio-invasion issues. Nonetheless some countries including Australia, New Zealand and in some US states (e.g., California) are leading the way in pushing for coordinated effort in managing the impact of shipping and other vectors (e.g. aquaculture intentional release) for NIMS transfer through active engagement with the stakeholders (e.g. ship operators and owners of recreational vessels). Marine and terrestrial conservation however require different management approaches (Kearney et al. 2013). The factors that cause bio-invasions are usually complex. While national laws and institutional framework that tackle bio-invasion management are necessary, regional cooperation in managing a trans-boundary problem is necessary for effectiveness. Furthermore, the challenge of managing bio-invasion is a complex issue within the socio-economic boundaries of global shipping trade and national political interests. The challenge ahead lies in balancing the need for economic trade, environmental awareness and protection. These challenges are not unique to Singapore.

While a complete understanding of the marine biodiversity of the region and the life cycle traits of invasive pest species is time consuming, laborious and costly, placing limitation on available resources, these efforts must continue if we are to address marine bio-invasion issues.

4. THE 2004 BALLAST WATER CONVENTION

The intake of ballast water is necessary for the safe operations in large vessels for stability and maneuverability when vessels ride on an empty load, but this is also responsible for carrying large numbers of marine organisms around the world in global cargo trade. Marine species carried around in ballast water and sediments in the ballast tanks can consist of biofilms, bacteria, microalgae, macro-invertebrates and their propagules. Microbial (i.e., bacteria and viruses) (Drake et al. 2007) toxic microalgae responsible for harmful algal blooms (HAB) (Hallegraeff and Bolch 1991; van den Bergh et al. 2002) and macro-invertebrates (Mack et al. 2000) have been implicated in the risk of bio-invasion through exchange of ballast water as ships transit between ports. However, the risk varies depending on the type of species in the ballast tank, the transit time and the physical and biogeographic conditions of the recipient port. According to Gollasch et al. (2000) the number of viable organisms remaining in a ballast tank declines significantly after 3 days and few living organisms remain after 10 days. This may put regional operating vessels at a greater margin of risk than long-haul trips. To mitigate the risks involved in ferrying ballast water containing large amounts of viable organisms, ballast water exchange or flushing (BWE) was introduced to replace ballast water with mid-ocean water. However, the efficacy of BWE in controlling viable organism population remains in doubt (McCollin et al. 2008; Briski et al. 2012). To overcome this problem, ballast water treatment systems installed onboard existing vessels aim to treat ballast water before discharge. This forms part of the ballast water management system (BWMS) which also include maintenance and records of the ballast water record book.

There are still caveats regarding the effectiveness of the ballast water discharge limits (D2 standards) to accomplish an acceptable risk of viable organism population (Albert et al. 2013) and lack of standardization over the sampling and analysis protocols (Carney et al. 2013; Frazier et al. 2013). Exceptions to the requirements of the BWM Convention could be granted based on the IMO guidelines (Regulation A3) for vessels under endangerment, poor weather conditions or in the *same location* where the water is taken up and discharged. The *same location* concept however, is challenged by Gollasch and David (2012) because the *same location* definition was not defined in the BWM Convention and may be open to interpretation to different parties without a meaningful criterion such as one based on biodiversity from port baseline surveys. Vessel exemptions based on Risk Assessment of port location (G7 guidelines) and vessels operating only between specified ports and fixed routes could further be granted.

While several provisions in the Convention continue to be reviewed and modified, a number of nations and states including Australia, New Zealand, Canada and the state of California have adopted ballast water regulations on vessels that primarily deal with BWE of vessels before arrival (Albert et al. 2013). A standardized numeric discharge concentration for ballast water treatment does not exist in these legislations although most standards are generally based on the Regulation D-2 standards of the BWM Convention (Dahlstrom et al. 2011; Albert et al. 2013). While there are currently no established standards for water sampling and analysis techniques for D-1 (BWE standards) and D-2 (discharge standards), general laboratory test methods as well as ISO standards are listed as references (BLG Session 17/Agenda 18 (Feb 2013)). Indicative analysis (as opposed to compliance testing) was highlighted as a possible form of rapid assessment for estimating whether gross non-compliance was present as opposed to detailed analysis for compliance with the D-1 and D-2 standards. Failure to conform to indicative analysis may be regarded as a form of non-compliance and a detailed test could be carried out subsequently. The limitations of using specific laboratory test methods for compliance testing were also highlighted such as in the use of biological indicators (e.g. nucleic acid adenosine triphosphate or chlorophyll a) to detect the presence of viable organisms (phytoplankton or zooplankton) in the water sample to distinguish against organism concentration, specific size class and cell viability. The practicality and detection limit of using specialized instruments e.g. flow cytometer or commercial enzymatic diagnostic kits to detect viable cells and bacteria also places limitations of its use in a ship environment.

5. 2011 BIOFOULING GUIDELINES

The introduction of NIMS into new marine environment via ship biofouling was recognized in several studies (Eldredge and Carlton 2002; Hewitt 2002; Lewis et al. 2003) and is now established as one of the most important shipping related transfer mechanism along with ballast water discharges (Hewitt 2002). The presence of vessel niche areas (i.e., areas on a ship that may be more susceptible to biofouling due to different hydrodynamic forces, absence of coating system and coating wear and damage) was highlighted as a potential risk from fouling-attributed introductions due to preferential settlement and growth of certain marine organisms in a sheltered environment (Coutts et al. 2003; Coutts and Dodgshun 2007). Several studies also highlighted the risks of vessel in-water biofouling cleaning or *defouling* (Hopkins and Forrest 2008; Woods et al. 2012) by inducing larval propagule release and aggravating release of antifouling coating systems.

An effective antifouling (AF) coating system is necessary to control biofouling accumulation on a ship vessel which affects operating efficiency by increasing vessel drag forces. A conventional commercial AF coating system used in the shipping industry employs the use of a biocide-based coating that prevents marine settlement by contact with a toxic leachate from the coating surface thereby disrupting essential life processes. Controlled depletion polymers (CDP) and self-polishing co-polymers (SPC) are two common AF coating systems that achieve this function (Lejars et al. 2012). The difference is in the mechanism by which the chemical compounds are released into the seawater. Environmentally benign or non-toxic systems such as the silicon or fluoropolymer-based foul-release systems do not prevent settlement but instead reduce settlement by interfering with the adhesion processes of organisms on these surfaces so that attached organisms may be removed more easily from the surfaces under vessel cruising or periodic cleaning. However, a minimum flow speed is required over the protected surface for the coating to work effectively. In elucidating the most effective coating system to be used on a ship surface the operating profile and design aspects of the ship has to be made available. Other concerns may include the coating cost, lifespan of the coating and trained manpower to do the application.

Existing understanding of the ship biofouling risk to NIMS transfer and available AF technologies have guided the development of the Biofouling Guidelines. The Biofouling Guidelines aim to adopt a comprehensive biofouling management plan through the use of existing antifouling technologies and a series of operational practices to manage biofouling on a ship vessel. These measures are laid out in several sections of the document.

The ***Biofouling management plan and record book*** is specific to a ship vessel that includes details of identification of niche areas in the vessel as well as details of in-water inspection and remediation measures to remove biofouling on the vessel. An ***Antifouling installation and maintenance plan*** should be in place to record details of the AF coating system application and maintenance on the vessel. This plan highlights the need for differential application of AF system that meets the ship operating profile e.g. operating speed and the region it is operating in. This is because different AF systems (or technologies) are usually designed to perform optimally under a set of operating conditions. Foul-release coatings (e.g. Intersleek series, International Paint) for example require optimum vessel speeds to maintain a foul-free surface as the surface 'cleans' itself under hydrodynamic flow. Under stagnant conditions e.g. long residence time in port, the vessel surface may foul quickly. SPC coatings tend to slow-release additives at a fixed rate. As different areas on a ship vessel are subjected to different flow regiment during operation, the knowledge and application of suitable AF coating control on a vessel (e.g. hull surfaces versus sea chests and gratings) is important to reduce ship biofouling. These guidelines are intended to work with other existing IMO conventions such as the 2001 International Convention on the Control of Harmful Antifouling Systems on Ships (AFS Convention). The AFS Convention restricts the use and presence of harmful AF systems on existing and future vessels.

In-water inspection and cleaning forms an integral part of a vessel's biofouling surveillance and maintenance regime in between vessel dry dock or inactivity. Timely inspection can determine the presence of suspected invasive species and any damages to AF coating systems which can otherwise create opportunities for fouling to occur. Regular effective cleaning may reduce the frequency of dry-docking and increase vessel operating efficiency but should not impair the coating unnecessarily. In-water cleaning may however cause a sudden release of viable fouling macro-organisms and increase the risks of paint debris release into the environment (Hopkins and Forrest 2008; Woods et al. 2012). The conduct of in-water cleaning should be done in accordance with local port regulations to minimize the associated risks including the use of proper reception facilities for retention of fouling and paint debris into the water. Trained personnel who are able to assess the damage and risk of cleaning should do in-water cleaning. Adequate knowledge of AF coating systems and how they function is essential to prevent pre-mature failure or exhaustion of the coat due to excessive cleaning. Hence in-water inspection should be done not only to assess the state of vessel fouling but to identify early signs of coating failure. Early identification of coating failure may then necessitate early re-mediation or risk identification of fouling on a vessel.

The Biofouling Guidelines also highlighted the importance of niche areas minimization on a vessel design and construction. These areas including seawater pipelines have a high risk of fouling due to the susceptibility of these areas to attract fouling organisms because of low flow and creation of stagnant point for larvae to settle. The sea chest is particularly susceptible to accumulation of fouling and adult motile organisms and may provide refuge for NIMS (Coutts and Dodgshun 2007). *Design and Construction* gives particular reference to this aspect to minimize ship requirements in niche areas, e.g., reduction of sea chest areas and where not possible, to design areas so that they may be accessible for inspection and maintenance.

Dissemination of Information highlights the shared role that port state authorities have in disseminating any information on baseline studies, invasive pest species or other high-risk organisms in local port waters that may be a threat to uptake by arriving vessels as well as communicating efforts and local regulations (i.e. standards and guidelines) in biofouling management. Such information may facilitate conduct of in-water inspection and cleaning prior to leaving the port and aid identification of possible high-risk infestations. Appropriate ***Training and Education*** is relevant in communicating the goals and plans of the biofouling management plan to relevant stakeholders (e.g. ship's master and crew, in-water cleaning and maintenance facility operators and inspectors) to maximize the effectiveness of the Biofouling Guidelines. It is important that different stakeholders are made aware of the risks involved in transfer of invasive pest species and to create synergy among different parties to manage biofouling effectively. It is unlikely vessel owners and operators can be expected to manage the biofouling problem alone without commitment and support from local authorities to support vessel operation. As biofouling and bio-invasion straddles between biology and economics of shipping, port state controls will do well to engage the shipping industry to create synergy in managing the risks.

Under ***Other measures and Future work***, the possibility of *just-in-time* operation (i.e., to minimize residence time for vessels in port waters) aims to reduce vessel biofouling while continued efforts on the research of AF technologies to target niche areas, effective management of in-water cleaning, biofouling detection and quantification technologies on ships, geographic distribution of invasive pest species and establishing emergency response plan to bio-incursion are advocated.

6. DISCUSSION

6.1 The role of shipping in managing transfer of non-indigenous marine species

Shipping has facilitated the transfer of NIMS across the globe allowing non-native species to cross water bodies that were once physically isolated by continental landmasses and sheer distances. Modern shipping has overcome this barrier to introductions through shortened transit time and the creation of 'refuge spots' in vessel niche areas for these marine hitchhikers. While some deliberate introductions of non-native species of plants and animals have broadened geographical advantages in crop cultivation and animal rearing, humans are now aware of the negative impacts of deliberate introductions. The risks and associated impacts of NIMS are more poorly understood compared to terrestrial plant and animal species but there is now a heightened urgency in dealing with accidental introductions of NIMS via shipping, notably through the IMO resolution on BWM Convention in 2004 and more recently through the 2011 Biofouling Guidelines. These developments signify a closer attention towards the risk and impact of shipping as a vector mechanism for NIMS transfer. Hence the shipping industry stands out as a key driver for environmentally responsible operations. It is timely to re-examine how the shipping industry and its global network operation may be part of a larger framework to improve marine environmental issues. In particular, the network operations of global shipping may be a key to identifying marine bio-invasion hotspots. The shipping association is often represented internationally and guided by performance and operational standards to meet efficiency. This has significance because the likelihood of any resolution that is passed and recognized by an association may have a greater chance of implementation amongst its members. With common goals and standards, industry representatives may be more likely to effect for policies change and implementation. There is no discourse between pursuing environmental causes while fulfilling economic goals. In particular the effective management of vessel biofouling stands out because it fulfills two separate goals. Firstly, maintaining a clean and smooth ship hull through the application of antifouling coating systems, in-water cleaning or a combination of the two methods effectively reduces drag forces over the ship vessel in transit and improves fuel consumption thereby constituting an economic saving. Secondly, maintaining a clean ship body means that biofouling on a ship vessel is reduced and hence the risk of a vessel harboring NIMS. This shows that management options that cater to economic desires can also have a positive effect on the environment assuming in this case that the AF systems applied do not cause more harm in the marine environment than it is intended to (e.g. in-water cleaning).

While designed for maintaining smooth clean hulls, AF coating systems are not without its hazards and limitations. The safe application, removal and disposal of these coatings are carefully administrated and must be performed by trained personnel in a proper facility with safety measures. Likewise, the use of the right AF coating system on a ship hull under the right operating environment is crucial to control biofouling. Most AF coatings also require re-application after the intended lifespan is achieved. Presently, most of these coatings are broad-spectrum biocidal paints and therefore designed to work for a diversity of marine organisms, hence achieving effective biofouling control on vessels. The use of properly maintained AF systems on ship hulls can therefore manage biofouling and arrest the transit of NIMS.

The transfer of NIMS through accidental introduction by ship biofouling could arguably be controlled by existing technologies. AF solutions serve not only an economic incentive to ship owners by keeping ship hulls foul-free and reduce fuel consumption, but also control biofouling on ship surfaces. However, the control of NIMS transfer through the discharge of untreated ballast water has yet to reach the same level of control as compared to AF systems. The costs of installation and retrofitting Ballast Water Treatment Systems (BWTS) on vessels and the uncertainty over existing guidelines and standards on compliance testing may provide a conundrum when the BWM Convention is enforced. According to Albert et al. (2013), the varying ballast water treatment (i.e. discharge concentration) standards hinder development of treatment technologies due to uncertainty in the efficacy of the treatment standards to reduce the viable organism population to an acceptable risk. The existing option to perform BWE in mid-ocean is perceived to be an interim measure to reduce transfer of viable organisms in ballast water while treatment technologies are built up. Administering the discharge of untreated ballast water as a form of ship-based pollution may be one way of integrating the management plan into proper administration.

6.2 Future possibilities

Risk assessment of the transfer of NIMS via ballast water discharges is increasingly supported by the sophisticated use of predictive models and analysis of shipping related data, i.e., ballast water discharge volume, shipping routes and patterns (Niimi 2000; Liu and Tsai 2011; Lo et al. 2012) to establish propagule pressure. These are also aided by the attention to environmental and biogeographical identity of bioregions in the source and recipient ports to identify probability of species survival and successful establishment (Inglis et al. 2006; Keller et al. 2011; Seebens et al. 2013). As the 2004 BWM Convention is now in force, it is expected that applications to risk exemptions to the provisions of the BWM Convention will increase by state and national administrations. To this end, risk assessment models based on species-specific risk (e.g. life cycle traits and environmental tolerance) and environmental similarity (e.g. temperature and salinity) has been discussed (Barry et al. 2008; Chan et al. 2013; David et al. 2013). It is possible that similar risk assessments (though not necessarily amounting to an equivalent risk exemption criterion) can be adopted for biofouling species under the Biofouling Guidelines especially when targeted and high-risk species are identified by port state controls and communicated to arriving or transiting vessels. It is also possible that future studies of the shipping network (Notteboom and Rodrigue 2005; Low et al. 2009; Wang and Wang 2011) and its relevance to port regionalization can play a role in refining the understanding of the bio-invasion risk perpetuated by the development and expansion of ports. This may have significance to (South) East Asia ports development. Another option to manage the risk of NIMS is to evaluate the closeness of ecologically sensitive areas to recipient ports, for instance the presence of an ecologically sensitive wetland or offshore aquaculture farming (e.g., Masson et al. 2013) facilities operating in the vicinity of the port.

Successful long-term management of transfer of NIMS requires support and awareness from the stakeholders (i.e. port state controls, local authorities and public) to complement available technologies i.e. the implementation of antifouling controls and ballast water treatment technologies on sea-faring vessels. A holistic bio-invasion management plan that includes vessel and port monitoring, identification and reporting and emergency response plan should be in place. As an important regional trade hub linking diverse shipping trade route links in the region, Singapore has added responsibilities in managing environmental issues that affect the region beyond her national borders. The identification and recording of high risk invasive pest species and their habitat range in Singapore national waters should serve as a good first step towards building resilience towards bio-invasion incursion in the region.

7. CONCLUSIONS

Ship biofouling and untreated ballast water discharges have the potential to cause irreversible disruption to the marine and coastal environment and therefore affects our continued reliance on its resources. Responsible shipping practices through the implementation of ballast water and biofouling management systems will go a long way to manage the transfer and bio-invasion risks posed by NIMS. However, industry and national/state administration face challenges in effective management, given that there is still a need to harmonize the goals between the Convention/Guidelines and practicable solutions. The shipping industry can play an influential role in managing the transfer of NIMS. Given the availability of current technologies for biofouling control and ballast water treatment, bio-invasion management strategies can be achieved if local authorities and port state controls incorporate operational and knowledge-based practices. The shipping industry can be a large lobbying force given the need to operate and comply with good operating practices at all major ports. Port state authorities can also play an important role in sharing information on targeted high-risk pest species. Future port management practices can include the availability of port reception facilities, in-water inspection and cleaning to minimize the risk of targeted species.

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