

# **BIO-INVASION AND ONSHORE BALLAST WATER MANAGEMENT: A VIABLE SOLUTION FOR DEVELOPING ECONOMIES**

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## **ABSTRACT**

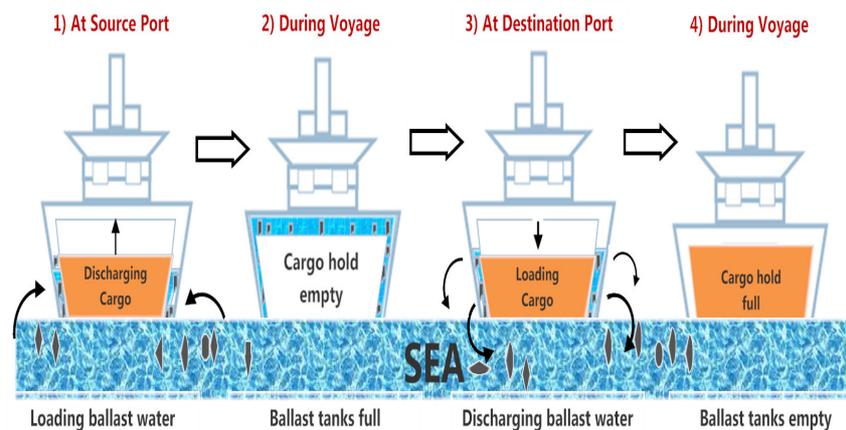
The arrival of aquatic exotic species in a new area increases with proximity to seaports, thereby raising bio-security concerns for our seaports and coastal environments. Protecting our national borders against these possible biological invaders arising from the discharge of planktons found in ships ballast water could be a very difficult undertaking. This is because the environmental and socioeconomic costs associated with these invaders are the unintended and unavoidable side effects or externalities of the shipping trade. There are two motivations for this paper. The first is the concern raised at the Marine Environment Protection Committee (MEPC) 67 and 68 meetings of the International Maritime Organization (IMO) regarding the capacity of some type-approved Ballast Water Management (BWM) Systems to meet the performance standard (D-2) required in the BWM Convention at-all-times and in all conditions. The second is based on the reluctance expressed by some ship-owners to install the BWM System on-board their ships as suggested by a Lloyd's List survey. In an attempt to address the aforementioned concerns, a holistic view of ballast water management encompassing design, regulatory compliance and the associated ergonomics of BWM Systems operation were reviewed with respect to some peer reviewed research work done by the author. The outcome revealed a preference for onshore BWM as against the predominantly globally accepted shipboard management. An exemption concept for ships was subsequently proposed in this paper to optimize onshore application of BWM, especially for developing countries.

## **1. INTRODUCTION**

Shipping as the backbone of the global economy is responsible for moving at least about 90% of the world's commodity (UNCTAD/RMT, 2018). Ballast water is used by these ships to maintain maneuverability, stability and correct immersion for safe navigation especially when cargo is offloaded. This ballast water contains aquatic organisms which when they are transformed into marine pests may have negative impacts with economic and ecological dimensions.

Every species removed from its native range and introduced to a new area has the potential to become invasive (Veldhuis et al., 2010). The potential of species transfer is compounded by the fact that most marine species have planktonic (water-borne) stage (Figure 1) in their life-cycle, which may be small enough to pass through a ship's ballast water intake ports and pumps (sea chests) (Raaymakers, 2002). Under natural conditions, these organisms are restricted to their natural bioregions by layers of obstructing environmental barriers in the form of biotic (presence of predators, the absence of prey) and abiotic (nutrients, salinity, temperature, landmass) conditions (Ekweozor et al, 2016).

These natural barriers between donor and recipient bioregions, however, have become easily surmountable by anthropogenic vector provided by modern international shipping.



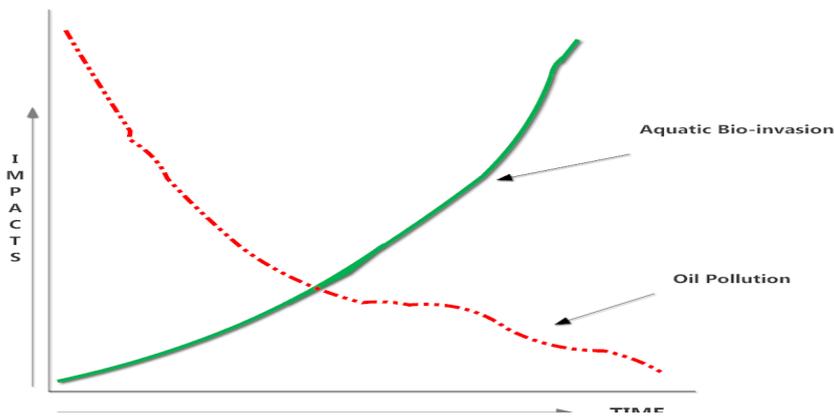
**Figure 1: A typical ballast water cycle procedure (Kuroshi, 2017)**

Ship discharged ballast water has been identified as the greatest means of organisms transfer between geographically separated sea areas (Rigby and Taylor, 1999; Humphrey, 2008; Amoaka-Atta and Hicks, 2002). This was made possible by the introduction of faster and bigger ships, which has led to a reduction in voyage duration and increase in the number of organisms within a much bigger ballast tank. These have consequently resulted in a tremendous increase in the probability of the transfer of these organisms. As a matter of fact, ships on international voyage have been identified as the largest vectors for aquatic species introduction (Molnar et al., 2008). It is estimated that more than 3,000 species of animals and plants are transported daily around the world in ballast water (NRC, 1996) and at least one foreign marine species is introduced into a new environment every nine weeks (Akeh, et al., 2005).

## **2. THE PROBLEM WITH THE DISCHARGE OF UNMANAGED BALLAST WATER**

The introduction of these organisms otherwise referred to as Harmful Aquatic Organisms and Pathogens (HAOP) into new environments via ships' ballast water and other vectors has been identified by the International Maritime Organization (IMO) as one of the 'four greatest threats to the world's oceans' (IMO, 2005). HAOPs, once established in a new environment are always very difficult and cost prohibitive to control and almost impossible to eliminate (Ekweozor, et al., 2016). As a matter of fact, their impact on the environment is irreversible (IMO, 2001; Raaymakers, 2002) and generally increase in severity over time because of their ability to reproduce (Kuroshi, 2012). This is in contrast to oil-spill pollution which decreases with time (Figure 2).

Some of the potential consequences of bio-invasion aside the loss of biodiversity includes public health impacts such as the risk of cholera disease from the discharge of its pathogen, vibrio cholerae contained in untreated ship's ballast water from endemic regions of the world. There are reported cases of deadly paralytic poisoning from human ingestion of fish poisoned by red tide algae; a consequence of untreated ballast water discharge. Bio-invasions have some economic and social impacts on fisheries, aquaculture, and tourism respectively. Disruption of normal port operations may also result from bio-invasion, in cases of severe algal bloom in the port or invasion of seaport channels by water hyacinth.



**Figure 2: Impacts over time of major oil spills versus aquatic bioinvasions adopted from Raaymakers, 2002; Kuroshi, 2017**

In response to the threat posed by these harmful marine species and in order to manage and control the menace thereof, the IMO in 2004 adopted by consensus 'The International Convention for the Control and Management of Ships Ballast Water and Sediments' otherwise referred to as the Ballast Water Management (BWM) Convention (IMO, 2004). The Convention stipulated two goal-based management standards for ship discharged ballast water; a stop-gap measure requiring ships to carry out Ballast Water Exchange (BWE) or mid-ocean exchange known as regulation D-1 and regulation D-2, where a numeric requirement for ship discharged ballast water is stipulated. The BWE process entails replacing biologically rich ship-borne ballast water from the coastal environment with mid-ocean water that is nutrient deficient.

Regulation B-3 of the BWM Convention, however, stipulates that ships on international voyage should treat their ballast water to the regulation D-2 standard. This requirement became globally enforceable on 8 September 2017 on new ships, while compliance deadlines for existing ships or ships constructed prior to 8 September 2017, shall be through a phase-in schedule linked to the ship's International Oil Pollution Prevention (IOPP) certificate renewal survey up to the year 2024 (IMO, 2018). But a study by Lloyd's List (Lloyd's List, 2014) showed a reluctance by ship-owners to install treatment system onboard their fleet. With the current less than encouraging global compliance to the tenets of the treaty, it is only reasonable to seek alternative concepts that will ensure compliance.

The concerns raised and presented by the 'correspondence group' set by the Marine Environment Protection Committee (MEPC) 67 and 68 meetings of the IMO regarding the performance of some type-approved BWM Systems to meet the D-2 standards of the BWM Convention as well as the reluctance of some ship-owners to install the BWM System onboard their ships as revealed by the Lloyds List survey, preferring in some instances to scrap tonnage than install treatment systems onboard their ships are the major motivations of this paper.

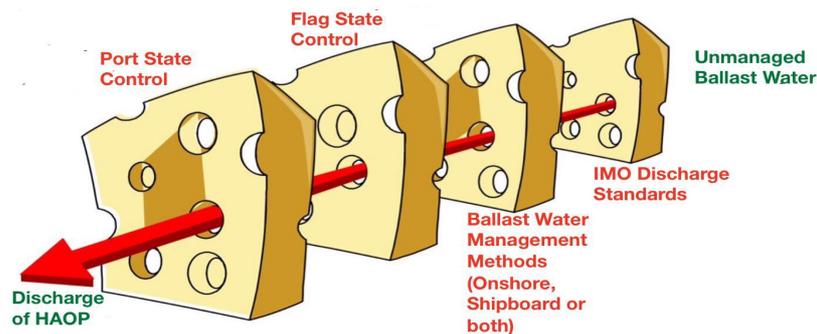
### **3. LITERATURE REVIEW**

Although the aggregate tonnage required for the full ratification of the BWM Convention has already been attained, and the Convention has been in force since September 2017, issues regarding the viability of the type-approved systems (especially the first-generation systems) are still major concerns. To address this challenge, some peer-reviewed publications (by the author) on Ballast Water Management (BWM) were reviewed by the author under the following headings:

### 3.1 Underlying theories in ballast water management

As a consequence of the essential economic activities of shipping, the likely ecological and economic impact that may result from the discharge of planktons found in ships ballast water transported from one port environment to another, informs the necessity by Ekweozor et al. (2016) to study the underlying principles in the control and management of ballast water. The authors were able to show how some theoretical concepts from non-ballast water management domains can help in understanding the dynamics of bio-invasion of coastal seaports. Scientific principles established outside the domain of ballast water management such as the 'Swiss-cheese' model (from the aviation industry), 'tens rule' model (from invasion in terrestrial environment), 'spatial sorting' (from invasion by cane-toad in Australia) were deployed to explain the dynamics of invasion by HAOPs transported via ship's ballast water.

The study explained how with increasing globalization through maritime trade, seaports have become increasingly vulnerable to exotic marine species invasion as corroborated in a study by O'Brien, et al. (2017). This informed the heightened biosecurity concerns related to harmful marine species invasions in Seaports. The study was able to show using these aforementioned theoretical paradigms that the potentials of planktonic species introduction into a harbour via ships' ballast water will be greatly minimised once barriers like management regimes are introduced (Figure 3).



**Figure 3: Metaphorical Swiss-cheese model of a human-induced barrier for ballast water management (modified from Reason et al., 2006; Ekweozor et al., 2016).**

The analytical outcomes from water samples collected from some seaports and ships' ballast tanks in the study revealed that the probability (at a priori  $\alpha$ -level of 0.05) of species found in the sampled ships becoming invasive is not significant at  $p=0.043$ . The resultant propagule pressure of the organisms (with respect to the 'tens rule') would not be sufficient to lead to introduction and consequently invasion once management procedures are deployed.

### 3.2 Selection of appropriate environment for ballast water management

Following the Lloyd's List survey which revealed a reluctance in ship-owners to install onboard BWM Systems for their ships, the acceptability of shipboard management of ballast water was called into question. The potential of non-shipboard alternatives to manage the menace of invasive species transfer via ships' ballast water was, therefore, investigated by Kuroshi and Ölçer (2017). The aim was to compare the viability of both shipboard and onshore-based systems of managing ballast water with respect to the evaluation criteria stipulated in the BWM Convention of the IMO. To achieve that, an appropriate decision-making technique was selected using a robust procedure; this is

critical in the evaluation and ultimate determination of an appropriate BWM method. A multi-criteria decision-making technique known as Intuitionistic Fuzzy Multi-Attribute Axiomatic Design (IFMAD) which is a hybridised extension of fuzzy axiomatic design was selected. The technique was then used to evaluate the BWM options based on the linguistic data collected from an interview with subject matter experts. The novel applications of IFMAD here for technique selection and for BWM methods evaluation exemplify not only the versatility of the technique as a decision-making tool but also showed a strong paradigm shift in experts' opinions about the future of BWM beyond just the traditional shipboard applicability. Onshore management of ballast water was the preference (Table 1).

**Table 1: Value of the score function of BWM concepts from the perspectives of experts (Kuroshi and Ölçer, 2017)**

Alternatives	Score Function	Ranking
A <sub>1</sub> BWE	-0.883	4
A <sub>2</sub> Shipboard	-0.113	2
A <sub>3</sub> Pre-OBWTS (onshore)	-0.278	3
A <sub>4</sub> Post-loading (onshore)	-0.024	1

### 3.3 Convention based-design of ballast water management systems

The design of a conceptual model of BWM System that can satisfy all the requirements of the BWM Convention was achieved using a novel methodology developed in a study by Kuroshi and Ölçer (2018). The novel methodology was used in the design and performance enhancement of a regulation-compliant BWM System. Three methodologies were integrated in the process. The application of the multi-functional framework of classical Axiomatic Design (AD) in developing a design matrix was firstly modified using the influence of the Software–Hardware–Environment–Liveware (SHEL) interaction concept to factor all the system's interacting elements into the solution design.

The BWM Convention was used as a guide to identify the functional requirements for the proposed system design. The eventually identified AD couplings in the design matrix were then analysed using Sufield technique; a concept of Altshuler's Theory of Inventive Problem Solving (TRIZ). The design's most promising performance enhancement pathways were subsequently determined and prioritised.

This particular study is the first-time regulatory stipulations were used in any study for the purpose of design using the principles of axiomatic design. The outcome is a regulation-compliant design of BWM System. The design was achieved by integrating a modified version of the principles of AD with that of TRIZ.

### 3.4 Impact of human factors on BWM system operability

This section presents a new methodology developed by Kuroshi et al. (2019) to quantitatively analyse and prioritise the contributions of Human Factors (HFs) in the human-machine-interaction (HMI) within a complex sociotechnical system such as a BWM System. The methodology is a combination of the Human Factor Analysis Classification System (HFACS), Analytic Hierarchy Process (AHP), and a modified version of the Theory of Inventive Problem Solving (TRIZ) known as the Radial Dynamics Model (RDM). The

tripod methodology (HFACS-AHP-RDM) is based on a five-step algorithm, with which data from experts' judgment was analysed. A human-error and system risk minimisation hierarchy was subsequently proposed to improve human performance and minimize the likelihood of an unwanted event such as the discharge of harmful aquatic organisms and pathogens. The result from the study in order of hierarchy showed fatigue, training and complex automation to be the HFs with the greatest impacts on BWM operations irrespective of the environment of operation (onshore or shipboard) (Table 2). Minimizing their impact, therefore, will have the greatest positive contribution to the performance of the system. This is because over 80% of maritime accidents are attributable to human factors (Decola and Fletcher, 2006; Kuroshi et al., 2019).

**Table 2: Contribution ranking of HFs on BWM system performance (Kuroshi et al., 2019)**

IMPACT RANKING	SHIPBOARD BWM SYSTEM	ONSHORE BWM SYSTEM
1	Fatigue	Fatigue
2	Training	Training
3	Complex Automation	Complex Automation
4	Manning	Manning
5	Communication	Communication
6	Cultural Diversity	Teamwork
7	Teamwork	Cultural Diversity

The relevance of the section's outcome to Industry is thus: The study's outcome shall help decision makers in prioritising limited resources (e.g. time and money) allocation to resolving only issues related to the identified HFs with the greatest impact on BWM System's performance. The new methodology could also be applicable in assessing the relative impacts of subjective criteria like HFs in complex sociotechnical systems other than BWM Systems.

The above studies collectively were able to establish the appropriateness of onshore BWM with respect to safety, environmental acceptability, practicability, biological and cost-effectiveness. These are criteria stipulated in regulation D-5.2 of the BWM Convention as criteria for an appropriate BWM System (IMO, 2004). However, to optimise the onshore systems especially in view of the requirements of regulation B-3 (i.e. shipboard treatment of Ballast Water to D-2 standard), the introduction of an exemption concept similar to the same risk area (SRA) concept proposed by Denmark (IMO, 2016a) and Singapore (IMO, 2016b) at the IMO becomes mandatory.

#### **4. A NEW EXEMPTION CONCEPT: PORTS WITH ACCEPTABLE RISKS (PWAR) CONCEPT**

In regulation A-4 of the BWM Convention, the conditions by which certain ships may be granted exemption from the requirements of regulation B-3 is provided. The regulation B-3 requires all ships to treat their ballast water to D-2 standard of the BWM Convention. By the enforcement deadline of the Convention (September 2017) the majority of the global merchant fleets were yet to comply. The IMO, however, through resolution MEPC 297(72) amended the requirements in regulation B-3 (IMO, 2018). The amendment stipulates that the D-2 Standards are currently mandatory for only new ships constructed/keel-laid on or after 8 September 2017. But for existing ships or ships constructed prior to 8 September

2017, compliance deadlines shall be through a phase-in schedule linked to the ship's IOPP certificate renewal survey up to the year 2024.

Also, regulation B-3.7 permits the use of 'other methods' of ballast water management to achieve at least the same level of protection of the environment, human health, property or resources as described in regulations B-3.1 to B-3.5 of the BWM Convention, and approved in principle by the MEPC. All onshore systems such as Pre-loading Onshore Ballast Water Treatment System (PreOBWTS) proposed in Kuroshi et al., 2013 and Kuroshi and Ölçer, 2018; Port-based contingency measure proposed by the Netherlands (IMO, 2017); and BWTBoat proposed by India (IMO, 2013) at the MEPC meeting of the IMO are categorised as 'other methods' by the BWM Convention.

An area-based exemption solution known as the Same Risk Area (SRA) Concept was proposed by Denmark in submission MEPC 71/4/13 (IMO, 2016a) and Singapore in submission MEPC 70/4/8 (IMO, 2016b). As an exemption concept, the SRA is defined as an area-based approach for the risk assessment of aquatic invasive species that considers the extent of natural dispersal (Lauridsen et al., 2017). It is however regional and subject to an extensive risk assessment process which might be prohibitive from the perspective of developing economies, especially in Africa.

An alternate exemption concept appropriate for developing economies referred to as 'Port with Acceptable Risks' (PWAR) is presented by this paper. The Concept entails granting of an exemption to non-compliant ships visiting strictly ports with type-approved onshore BWM Systems. The PWAR Concept which is proposed by Nigeria at the IMO is an additional approach to exemption from regulation B-3. It is designed to facilitate the granting of an exemption to ships by the Maritime Administrations (MARADs) of member states to the BWM Convention who have ports that are classified as having 'acceptable risks' as a result of the existence or presence of a type-approved Onshore BWM System.

Ports classified as PWAR shall be ports which have installed and functional onshore BWM Systems that meet the requirements of regulation D-2 discharge standard and whose risk level is categorized as 'acceptable' by the national maritime administrations and other trading parties with such ports. The PWAR Ports can be regarded as 'low risk' ports or areas because the approved onshore treatment system shall provide the same level of protection to the environment as an approved shipboard treatment system.

In order for ships to be considered for exemption from the requirements of regulation B-3 under the PWAR Concept, the following Risk Assessment (RA) methodologies or procedures on the prospective ports is proposed:

- Baseline studies of the ports to establish their biological and physicochemical characteristics.
- Establishment of a port specific onshore ballast water management procedure or system for that particular port. The onshore system should satisfy the minimum requirements of the BWM Convention's D-2 standard. Ports with these types of systems shall then be categorized as PWARs.
- Identify ports regionally or globally with such systems as well as the ships whose voyages are restricted to only these ports possessing onshore treatment system.
- Ships whose voyages are restrictive to only these specified ports which are categorized as PWAR shall be granted exemption from the requirements of regulation B-3 of the BWM Convention. The exemption shall be for a period of no more than five years, subject to intermediate review.

## 5. DISCUSSION AND CONCLUSION

From the reviewed literature referenced in this paper, the following outcomes were attained: a successful design of a robust BWM System which is fully compliant with the BWM Convention and onshore environment was discovered to be the most appropriate environment for managing ballast water with respect to safety, environmental acceptability, practicability, biological and cost-effectiveness. Additionally, one of the reviewed works revealed that whilst operating the BWM System, greater attention should be given to the following factors: minimising *fatigue* and *training*. This is in order to reduce operator-error and consequently achieve the non-discharge of non-compliant ship ballast water into the environment. According to the reviewed study, these factors are the most influential human-factors in the operation of BWM Systems.

To optimise the benefits of onshore systems, the PWAR Concept was introduced. The Concept, once deployed in ports with approved onshore BWM Systems, would confer a compliance status on ships (without installed BWM Systems) whose voyages are restrictive to only ports classified as PWAR. This is because sound and practical measures for ships to satisfy the discharge requirements stipulated in the D-2 standard via means of onshore systems has been achieved. This will ensure the following: the protection of the marine environment, ship safety and minimising any impact on the continuity of port and ship operations even without an installed shipboard BWM System or when there is a dysfunctional BWM System onboard. This can potentially increase ship traffic to these ports since ships with dysfunctional or without installed BWM Systems can still visit the ports under the PWAR Concept. Also, the onshore system can generate income for either the port or the approved operator of the system in the port. This is because the visiting ships will pay a premium for BWM services provided in the port.

The PWAR Concept shall ultimately provide a means of compliance with the discharge requirement of the D-2 standard to many global merchant fleets and flags (especially from developing countries) whose ships have either not installed or retrofitted the system or who are bothered by any or a combination of the following: uncertainties surrounding the effectiveness of available type-approved shipboard systems at all times and in all conditions (especially first-generation type-approved systems), a malfunctioning system and the cost of onboard ballast water treatment and system installation.

In conclusion, with over 80% of maritime accidents linked to human factors such as fatigue, the resultant offshoring of most of the BWM operations to onshore systems as a consequence of the application of the PWAR Concept means shipboard related work-load impact on ship crews' performance shall be substantially minimised. The introduction of the Concept shall, therefore, lead to a reduction in the number of fatigue-related maritime accidents. Administrative burdens on both the ship as well as coastal states administrations should be expected to be considerably lessened as a result of the Concept. This is because extensive or detailed area risk assessment (which is required for exemption under SRA) might not be required for exemption under the PWAR Concept.

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