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Onshore ballast water treatment stations : a harbour specific vector management proposition

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ONSHORE BALLAST WATER TREATMENT STATIONS: A HARBOUR SPECIFIC VECTOR MANAGEMENT PROPOSITION

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

The discharge of Harmful Aquatic Organisms and Pathogens (HAOP) found in ships ballast water from one port environment to another can have severe ecological, environmental and economic consequences, especially when they transform into marine pests. This informs the necessity to investigate treatment options that could curtail the transfer of these organisms from a source harbour. An alternative to the conventional Ballast Water Treatment Systems is investigated and proposed in this study- it entails the onshore treatment of host port water before it is loaded as ballast water into ships. The study covered sampling of Port Harcourt Harbour water in Nigeria. The field samples were subjected to laboratory analysis. Inferential statistics was employed to determine the relationships between the physicochemical properties of sampling stations and organisms' density.

Literature on ballast water treatment research were reviewed, and the most viable treatment options for Port Harcourt Harbour based on the field results obtained were discovered to be treatment combinations that could remove most of the species found in the study area, especially; *Alexandrium minutum*, *Acartia clausi*, *Pseudocalanus elongatus*, *Tortanus sp*., and *Oncaea sp*., which are non-indigenous to North America; one of the Harbour's leading trading regions in the world.

A three stage shore treatment combination process was therefore, proposed by the study for employment in the Harbour. The first stage involves filtration of the harbour's sea water to remove the larger organisms, mainly zooplankton. It is followed by a stage of heating of the harbour's water (>38^{o}C) to remove larger zooplanktons that have escaped the filtration process. The third stage shall involve the use of biocides-this entails the application of chemicals like ozone (which has a strong lethal effect on a lot of phytoplankton and bacteria). And finally, the treated sea water is pumped into the visiting ship as treated ballast water.

Key words: *Ballast Water Treatment, Harmful Aquatic Organisms and Pathogens (HAOP), Planktons, Ballast Water Exchange (BWE), Ballast Water Performance Standard, Propagule Pressure (PP).*

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ANOVA Analysis Of Variance

BWE Ballast Water Exchange

BWM Ballast Water Management

BWMC Ballast Water Management Convention

BWMS Ballast Water Management System

BWT Ballast Water Treatment

CBD Convention on Biological Diversity

GI Gastro intestinal

HAOP Harmful Aquatic Organisms and Pathogens

IMF International Monetary Fund

IMO International Maritime Organization

ISAC Invasive Species Advisory Committee

LPOC Last Port of Call

MARPOL International Convention for the Prevention of Pollution from Ships

MEPC Marine Environment Protection Committee

MDF Maritime Dependence Factor

MSC Maritime Safety Committee

NOBOB No Ballast On Board

NPOC Next Port of Call

NRC National Research Council

UN United Nations

UNCED United Nations Conference on Environment and Development

UNCLOS United Nations Convention on the Law of the Sea

UNEP United Nations Environment Programme

WTO World Trade Organization

CHAPTER ONE
INTRODUCTION

1.1 STUDY AIM AND OBJECTIVE

The aim and objective of this research is to propose a unique ballast water treatment procedure that best suits the established characteristics of the study area which is Port Harcourt Harbour in Nigeria and any port with similar environmental characteristics and also recommend to the International Maritime Organization (IMO) and member states how the vector management procedure could be employed to curtail the menace of Harmful Aquatic Organisms and Pathogens (HAOP) on an international level. These objectives can be achieved by firstly; identifying qualitatively the most common planktons (non-indigenous and indigenous) and the physicochemical characteristics of the harbour from the collected sample of port water to establish a hypothetical baseline for the harbour (i.e. Port Harcourt Harbour, Nigeria). Secondly, it will be essential to determine the best mix of shore treatment procedures/systems for the harbour from the port-specific baseline information of the collected port ambient water samples and from literature reviewed on ballast water treatment research. This is because of the expected diversity of aquatic organisms and differences in physicochemical characteristics of harbours and also the expected variance in organism's response to different treatment methods (as established by research literature). Thirdly, it will be necessary to determine the best sequence to administer the vector management procedure for the harbour before the transport vector (i.e. port water) is uploaded as ballast water into the ship.

It is hoped that the achievement of these objectives will significantly minimize the role of ships and ballast water as vectors of Harmful Aquatic Organisms and Pathogens (HAOP) without compromising ship safety. It is also envisaged that this will satisfy the five IMO Regulation D-5.2 requirements of *safety, environmental* *acceptability, technical feasibility, practicability,* and *biological and cost effectiveness* for all treatment systems or technologies (IMO, 2005).

1.2 THE LIMITATION OF THE STUDY

The following limitations were encountered during this study:

1) There is the absence of literature on harbour water baseline for Port Harcourt Harbour which is located on the Bonny estuary of Nigeria, hence it is difficult to compare the present results with those from previous investigations.
2) There is a lack of established sampling protocols and methodology on ballast water research.
3) The absence of a competent scientific laboratory for analysis and tests to quantify and verify anticipated results is a limitation to the attainment of the objectives of the study.
4) There is a very limited time frame to conduct more thorough research to establish the harbour's baseline, especially for the two prevalent seasons in the study area, i.e. dry and wet season.
5) There are inherent difficulties in indicator microbes identification and enumeration as appropriate test equipment were not readily available. Also, traditional pathogen indicator tests (coliform and E. coli tests) were discovered by Miskowski, Charlie & Dobranic (2012) not to be effective pathogen indicators because they were not consistently accurate due to the die-off of the organisms outside the gastrointestinal (GI) system.
6) The sample site (Port Harcourt Harbour, Nigeria) is remotely located from the World Maritime University and thus difficult to access.

1.3 BACKGROUND

Shipping is the heart of international trade as most of the world's trade depends on shipping. Today more than 90% of all worldwide trade goods are transported on the ocean and via shipping (IMO, 2009). The Maritime Dependence Factor (MDF) of Nigeria, for example, is 19% based on 2004 IMF and WTO data (Shuo, 2011) making the country a relatively high shipping dependent country with ship borne-trade constituting over 80% of the country's trade.

In the bid to move cargo, ships tend to transfer around the world's ocean approximately 3 to 5 billion tons of water known as *Ballast Water* each year (IMO, 2001). For ships to travel safely, they must maintain a correct immersion level by either carrying cargo, ballast or both (Minchin, 1997). *Ballast* is any material used by ships or floating objects to maintain balance (GLOBALLAST, 2012). Prior to the advent of ships that used water to maintain balance, ships/vessels carried solid ballast that ranged from sand, rocks or even metal for many years. In modern times, ships use water as ballast because it is much easier to load on and off a ship, and is, therefore, more efficient and economical than solid ballast (GLOBALLAST, 2012).

1.3.1 What is Ballast Water?

Ballast water is the water used by ships to achieve a correct immersion level and to maintain balance. Ships use ballast water to provide stability, bouyancy and manoeuvrability during a voyage and the water is drawn into the vessel by intake pumps located in the hull, below the waterline. In rough conditions, and when the ship ballast water is at less than maximum cargo load, either during a transit to pick up a product, or after dropping off a portion of the cargo before continuing on to the next port, ballast water is taken on to provide stability and maneuverability for the ship (Deacutis & Ribb, 2002). The water is taken on at one port when cargo is unloaded and usually discharged at another port when the ship receives cargo as illustrated in Figure 1.1.

The propellers of ships carrying little or no cargo could be exposed above water because the vessel will tend to ride high in the water, making her vulnerable to being knocked about by heavy weather conditions and increasing the potential for slamming the bow or stern over high waves and making manoeuvrability impossible. Therefore, this gives rise to the need to lower the ship to a safer and efficient immersion level to remedy the potential risk factor.

A typical ballast water tank in a ship could take water that can be between 30 to 50% of the overall weight of the ship and that represents between 13 to 32 thousand metric tons of water, depending on the size of the ship (GLOBALLAST, 2012).

1.3.2 Why is Ballast Water a Problem?

The IMO regards the introduction of Harmful Aquatic Organisms and Pathogens (HAOP) to new environments via ballast water, as one of the four greatest threats to the world's oceans (Xie & Chen, 2004). Harmful Aquatic Organisms and Pathogens (HAOP) are species that are not native to an ecosystem and cause or are likely to cause economic or environmental harm or harm to human, animal, or plant health (Invasive Species Advisory Committee (ISAC), 2006).

Any species removed from its native range and introduced to a new area has the potential to become an harmful aquatic organism (Veldhuis, Hallers, Riviere, Fuhr, Finke, Steehouwer, Star & Sloote, 2010).

The problem of HAOP was ranked second only to habitat loss as the major threat to marine biodiversity by the 2007 Report of the UN Secretary General on Oceans and the Law of the Sea (Scott, 2008) and their impacts are often irreversible (California Environmental Protection Agency, 2002). Although other methods have been identified by which organisms are transferred between geographically separated sea areas, ballast water discharge from ships appears to have been prominent among those identified (Rigby & Taylor, 1999; Humphrey, 2008). Ballast water discharges are known to be the single largest source of introduction of HAOP into new environments (Amoaka-Atta & Hicks, 2002). It is estimated that more than 3,000 species of animals and plants are transported daily around the world in ballast water (NRC, 1996). At least one foreign marine species is introduced into a new environment every nine weeks (Akeh, Udoeka, Ediang & Ediang, 2005).

Ruiz & Carlton (2003) argue that these biological invasions are 'a potent force of change' that is changing Earth's ecosystems structure and functions. This has created substantial environmental, health and economic impacts on ports and other water resources.

The amount of ballast water held on a ship is dependent on the amount of cargo it is carrying. Figure 1.1 shows a typical ballast water cycle of a ship where the ship loads ballast water after discharging cargo at the source port or last port of call (LPOC) in a process known as ballasting and discharges same at the destination port or next port of call (NPOC) in a procedure known as deballasting. The end result of these ship-safety procedures (ballasting, reballasting and deballasting) is that when this ballast water is pumped into the ship it also loads on-board many of the organisms living in that port.

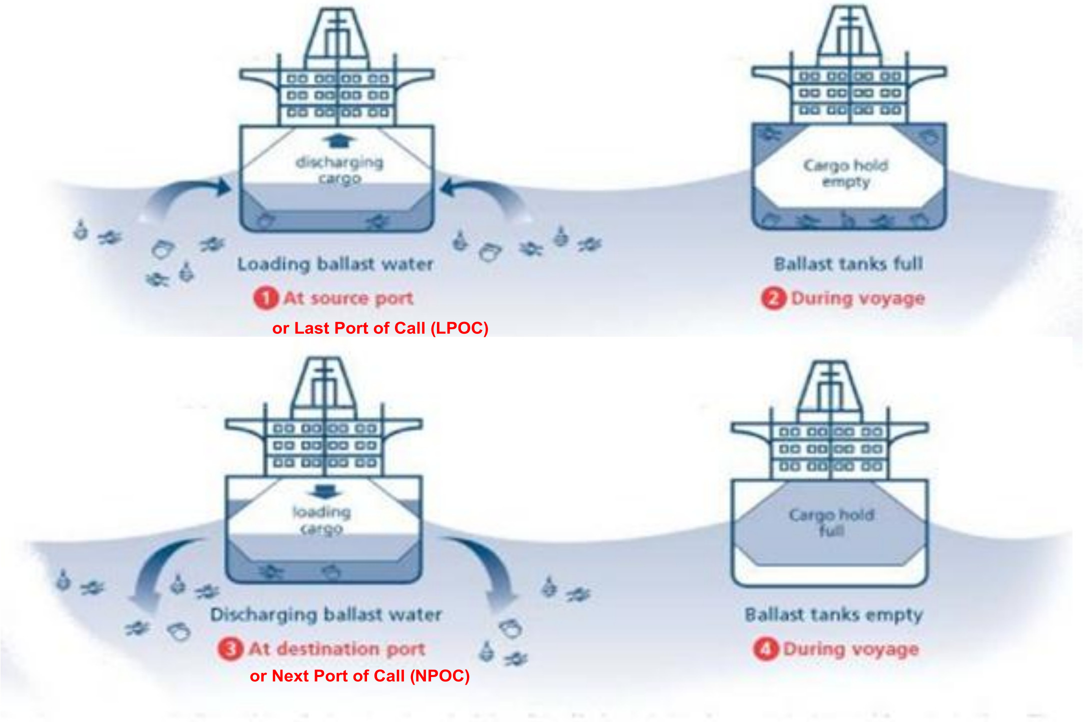

Figure 1.1: Cross Section of Ships Ballast Tanks and Ballast Water Cycle (Source: Globallast, 2004).

Microscopic organisms such as fish larvae or eggs are the ideal size to be sucked into a ballast tank and transported to the next port of call (NPOC) as illustrated in Figure 1.1. Depending on where the ship takes on ballast water, virtually all organisms in the water column, either swimming or stirred up from bottom sediments, can be taken into the ships' ballast tanks (California Environmental Protection Agency, 2002). Often this process will include a wide variety of animals and plants such as molluscs, shrimp, fish larvae, sea grasses, phytoplankton, zooplankton, viruses, bacteria, fungi, protozoans, many types of parasites, pathogenic organisms, egg, cysts, and larvae of various species (California Environmental Protection Agency, 2002).

These introduced aquatic species are non-indigenous species that are transported and released during deballasting operations outside of their traditional range (Figure 1.1). Non-native species in the absence of predators can increase and displace native species, and ultimately alter the natural ecosystem. Non-indigenous species that degrade ecosystem function and benefits are referred to as ***Harmful Aquatic Organisms and Pathogens (HAOP)***. HAOP can completely alter aquatic systems by displacing native species, degrading water quality, altering trophic dynamics, and restricting beneficial uses (Kazumi, 2007).

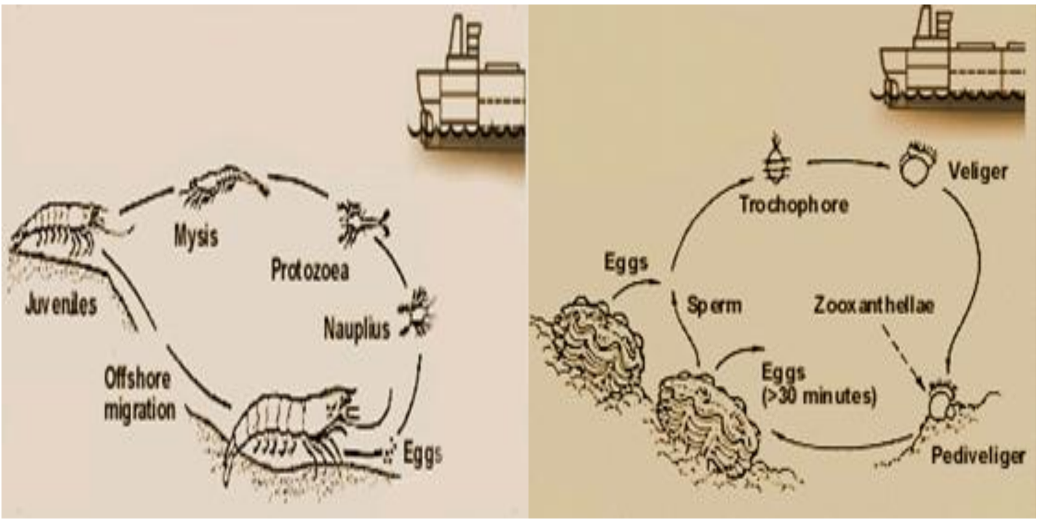

Figure 1.2: Prawn & Clam life-cycles showing Planktonic Stages (Source: California, 2002).

The potential of species transfer is compounded by the fact that all marine species have planktonic stages 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). This can be seen from the life cycles of both a prawn and a clam as illustrated in Figure 1.2.

1.3.3 Invasion Pathway

Humphrey (2008) identified the invasion pathway for HAOP as a multi-step process in which an organism must pass through a series of phases in order to establish itself in a new environment as illustrated in Figure 1.3.

The first phase, *initial dispersal*, requires that an organism utilizes some form of natural (i.e. currents, winds and animals) or human-mediated (i.e. shipping and aquaculture) transfer mechanism to move to a habitat outside its native range (Humphrey, 2008). An organism will move to the second phase of *establishment* if it can survive the voyage in the ship's ballast water tank.

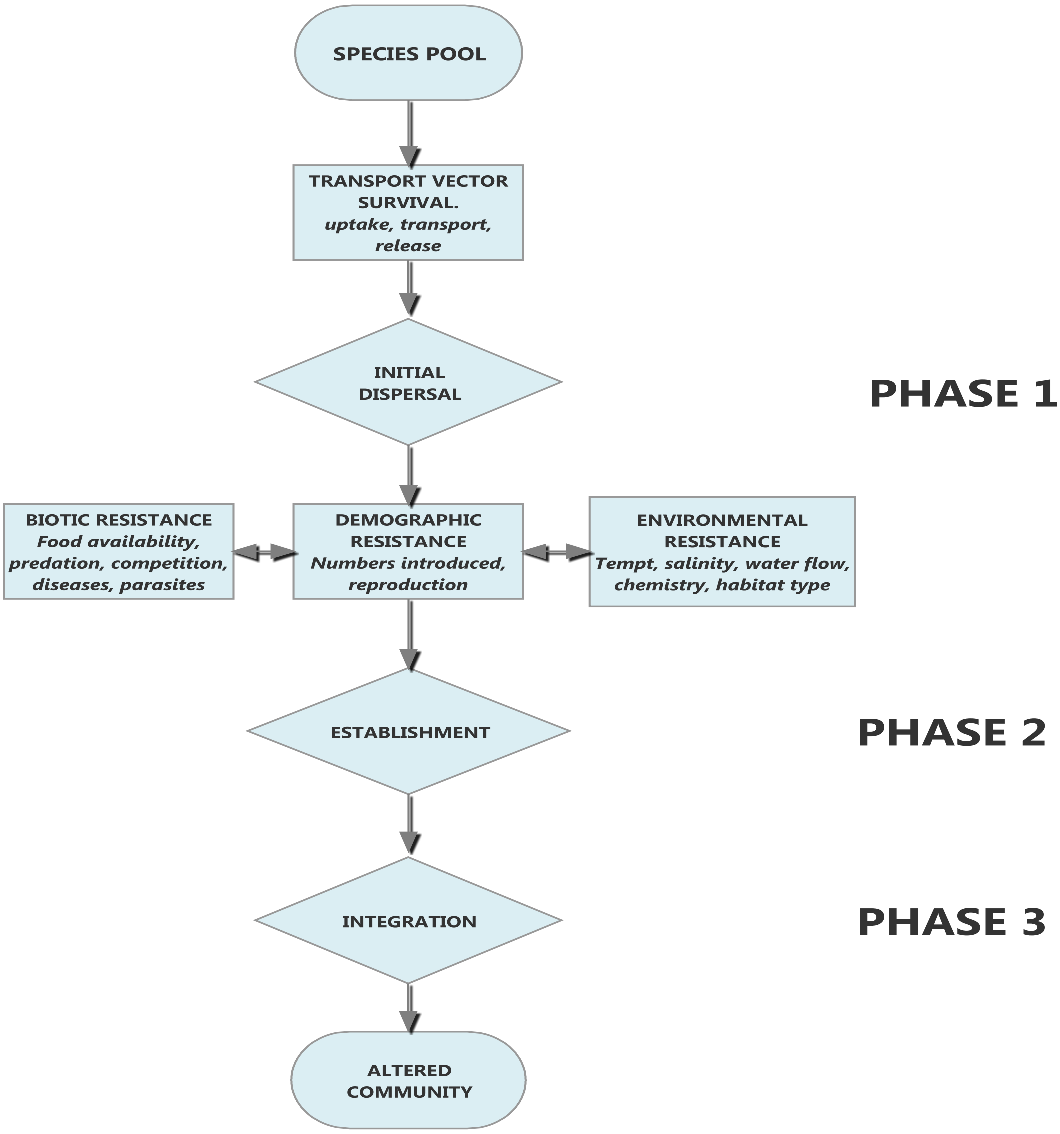

Figure 1.3: Conceptual Model of HAOP Invasion Pathway adopted by Humphrey (2008) from source: Moyle and Light (1996).

The second phase (*establishment phase*) requires that an organism establishes itself in its new environment and is able to persist through local reproduction and recruitment (Humphrey, 2008). Whether an organism is able to establish itself, according to the author will depend on the *ecological resistance* of the new environment and this includes: environmental suitability such as temperature or salinity; biotic resistance such as prey availability, predation, competition, disease and parasites; and demographic resistance such as numbers or organisms introduced and reproduction otherwise referred to as propagule pressure.

Propagule pressure (PP) according to Ricciardi, Jones, Kestrup and Ward (2011) is the most important determinant of establishment success, which means that establishment is a game of numbers. The propagule pressure theory asserts that the potential of invasion of species is contingent on the individual number introduced and the frequency of such introductions into a new environment. This assertion is supported statistically by the concept of the 'tens' rule; this shall be discussed in the next section, *integration*.

Integration is the final phase of the invasion pathway; it requires that the newly introduced species be able to either be self-propelled, or utilize transport vectors to spread within its new habitat (Humphrey, 2008). The release of non-indigenous species into a novel environment constitutes their inoculation but not necessarily their introduction (NRC, 1996) since not all become, 'invasive'. Some fail to thrive in their new environment and die off naturally, others survive, but without destroying or replacing native species (Lovell & Stone, 2005). This phenomenon was explained succinctly by the 'tens rule'.

The 'tens rule' is a generalization about invaders by Williamson and Fitter (1996) where they propounded a statistical approach to study the proportion in which organisms achieve success in new environments. The rule suggests that of the initial pool of species transported to a new environment, only 10% of these species become *introduced*, only 10% of those introduced become *established* and only 10% of those established become *invasive*. Since the 'tens rule' have been used in the past to successfully predict the fate of introduced birds, terrestrial plants and insects, using the principle of substantial equivalence, the same rule can also be applied in the prediction of the fate of introduced aquatic species in a new environment.

1.3.4 Ballast Water Hazard

The introduction of HAOP into a new port environment could constitute a ballast water hazard. *Hazard* is the potential of a substance, person, activity or process to cause harm. According to Jalonen and Salmi (2009), *hazard* is a condition or physical situation with a potential for an undesirable consequence, such as harm to life, environment or property.

The substance here with the potential to cause harm to our coastal environments is ballast water and the activity is shipping. Hayes (1998) identified two hazard components of the introduction cycle of HAOP into a port:

a) *The taxonomic hazard component*-is that set of organisms which is available to vessels ballasting in a particular port, and are capable of surviving the ballasting procedure and the vessel's journey. In this example, the universal set is defined as the complete floral and faunal assemblage in the donor port.

b) *Vector hazard component*- consists of those vessels which harbour viable non-native species. The universal set in this instance consists of all vessels on a given route.

Hayes (1998) here identified aquatic species and ships as hazards or substances that have the potential to cause harm to a receiver port and environs. Ballast water treatment or management can, therefore, be said to be a hazard management process.

1.3.5 Risk Assessment of HAOP Invasion

The Risk of an HAOP invasion can be defined as the product of the consequences or impacts resulting from the invasion of an environment by the HAOP transported in the ballast water tank of a ship and the probability (i.e. the likelihood) of such an invasion occurring. The two components in assessing risk, therefore, are consequences (impacts) and probability (likelihood).

Risk= Probability x Consequence

1.3.5.1 Probability of HAOP Establishment

The probability elements of HAOP establishment in a new environment according to Orr (2003) are: entrainment potential (i.e. probability of organism being in the ballast water), entry potential (i.e. probability of organism surviving the voyage), colonization potential (i.e. probability of colonizing and maintaining a population) and spread potential (i.e. probability for natural dispersal).

Some examples of the consequences or impacts of HAOP (economic, environmental and health), which are necessary components in risk assessment, shall be discussed in the next section.

1.3.5.2 Consequences or Impacts of HAOP Invasion

The *introduction of marine species into new environments by ship's ballast water* attached to ship's hulls and via other vectors has been identified as one of the 'four greatest threats to the world's oceans' by the IMO (GLOBALLAST, 2004; IMO, 2005). The other three are *land based sources of marine pollution*, *overexploitation of living marine resources* and *physical alteration/ destruction of marine habitat* (United Nations, 2002; Hillman, Hoedt & Schneide, 2004).

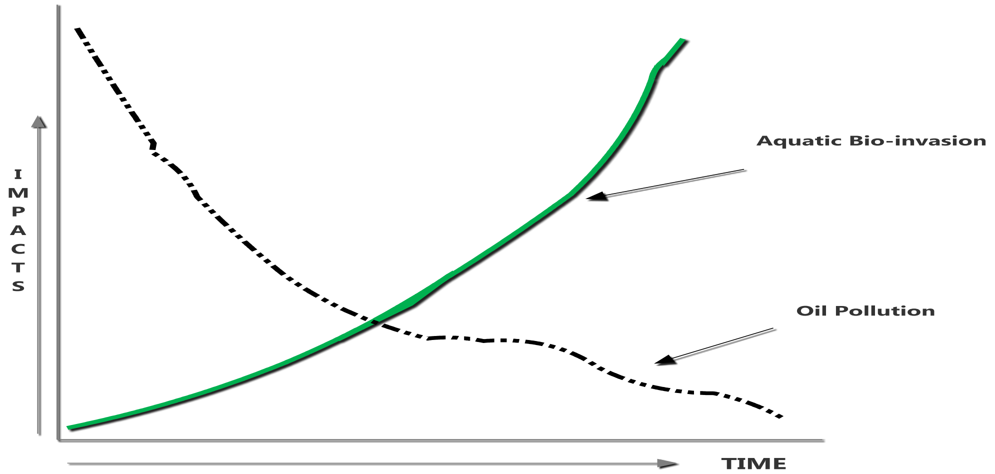

Figure 1.4: Impacts over time of major Oil Spills versus Aquatic Bio-invasions adopted from Source: Raaymakers (2002).

Unlike other forms of marine pollution, such as oil spills, where ameliorative action can be taken and from which the environment will eventually recover as illustrated in Figure 1.4, the impacts of HAOP are most often irreversible (IMO, 2001; Raaymakers, 2002) and generally increase in severity over time because of their ability to reproduce.

Much of this translocation takes place via ships' ballast water and can lead to very high economic and environmental costs (Hillman et al., 2004). HAOP, once established in a new environment, are always very difficult and cost prohibitive to control and almost impossible to eliminate. There is, therefore, a need for ballast water management programmes to be established in every port (host port).

Ecological Impacts

Some examples of ecological impacts are: predation (preying on native species), parasitism, competition (competing with native species for space and food), altering the food web and the overall ecosystem, introduction of new pathogens, species shifts/loss of biodiversity-displacing native species, reducing native biodiversity and even causing local extinction (Deacutis & Ribb, 2002; Raaymakers, 2002).

Economic Impacts:

HAOP invasion could impact negatively on commercial and recreational fishing through a reduction in fisheries production. This according to Raaymakers (2002) could be due to competition, predation, or displacement of the native fishery species by the invading species, or through habitat environmental changes caused by the invading species. Fouling of ship's hull by HAOP could lead to a reduction in the operational efficiency of ships. Fouling of beaches by HAOP such as algae could result in foul odour from algae bloom which could lead to the closure of recreational sites such as beaches, damaging the local economy of developing nations.

There are secondary economic impacts from human health impacts of introduced pathogens and toxic species, including increased monitoring, testing, diagnostic and treatment costs, and loss of social productivity due to illness or even death in persons affected (Raaymakers, 2002). Filter feeders like the zebra mussel and the red king crab, *Paralithodes camtschaticus* can increase water clarity, thereby increasing the economic utility of water bodies around recreational sites such as beaches.

Public Health Concerns:

Ballast water has been recognized by the World Health Organization (WHO) as a vector for disease causing pathogens as well as food poisoning from one region of the world to the other. Some examples of the public health concerns from ballast water are:

1) Risk of Cholera disease: ship ballast can carry the *Vibrio cholerae* (the bacteria that causes cholera disease), concealed in plankton, to estuaries around the world from polluted harbours and bays. Ballast water was perhaps the vector responsible for the transfer of the cholera strain from Asia to Latin America in 1991, which was then spread to Mobile Bay, Alabama, USA where it was found in oysters in closed shellfish bed.
2) Harmful Algal Bloom (HAB)- algal blooms may result due to the transoceanic introduction of harmful algae through ships' ballast discharge and this may be responsible for producing the toxin known as Paralytic Shell Fish Poisoning (PSP) which causes illness in humans and even death (Deacutis & Ribb, 2002).

Global Impacts of Harmful Aquatic Organisms Pathogens;

Between US$ 750 million and US$ 1 billion was expended between 1989 and 2000 to control the infestation by the European Zebra Mussel *Dreissena polymorpha* of over 40% of the internal waterways in the USA (GLOBALLAST, 2004). Between 2000 and 2006, over $7 million was spent to eradicate the Mediterranean green seaweed (*Caulerpa taxifolia*) from two embayments in southern California (Dobroski, Scianni, Gehringer & Falkner, 2009) and approximately $10 million is spent annually to control the Sea Lamprey (*Petromyzon marinus*) in the Great Lakes (Dobroski, et al., 2009). By 2010, over $12 million had been spent in San Francisco Bay to control the Atlantic cordgrass (*Spartina alterniflora*) (Dobroski, et al., 2009).

In the Black Sea, the filter-feeding North American jellyfish *Mnemiopsis leidyi* has depleted native plankton stocks to such an extent that it has contributed to the collapse of entire Black Sea commercial fisheries (IMO, 2001; GLOBALLAST, 2004).

In several countries, introduced, microscopic, ‘red-tide’ algae (toxic dinoflagellates) have been absorbed by filter-feeding shellfish, such as oysters. There were cases of death that followed the consumption of bivalve molluscs that have filter-fed on toxic marine microalgae (phytoplankton). The toxic microalgae were recorded in Alaska in

2010 and major toxic blooms have occurred in Tasmania, Victoria and South Australia (IMO, 2001).

Over 200 indigenous fishes were extinct in Lake Victoria as a consequence of invasion by the Nile Perch (*Lates niloticus*) since it was introduced in the 1950's (Humphrey, 2008).

The financial implication of the menace of HAOP is monumental across the globe. In the United States of America, for example, the annual cost associated with all identified HAOP is estimated at over $138 billion (Kazumi, 2007; Dobroski et al., 2009). This estimate does not include the effects of species' extinction, losses in biodiversity, ecosystem functions, and aesthetics, which are difficult to measure monetarily (Kazumi, 2007).

Nigeria is not exempted from this international problem as the country has had her fair share of HAOP occurrences. An example is the yearly invasion of the coastal and navigational water ways by a harmful aquatic organism known as Water Hyacinth (*Eichhornia crassipes*), which has, according to Fournier (2004), an 'aesthetic cost' because it makes our beaches unattractive to tourists. It also blocks the water ways for fishing activities and for incoming and outgoing ships resulting in delay to ships and thereby raising freight costs.

The HAOP list of impacts continues to grow with several examples of major ecological, economic and human health impacts across the globe (see Appendix D for list of some impacts).

1.3.6 International Efforts

In response to the threat posed by invasive marine species, the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992, in its Agenda 21 called on the IMO and other international bodies to take action to address the transfer of harmful organisms by ships.

Furthermore, on Friday 13 February 2004 at a diplomatic conference in London, the IMO adopted by consensus '*The International Convention for the Control and Management of Ships Ballast Water and Sediments'*. In 2005, the Maldives, Nigeria, St Kitts and Nevis, Spain and Syrian Arab Republic were the first countries to ratify the convention (GLOBALLAST, 2004; Hillman et al., 2004; Kazumi, 2007). By August 2007, the convention had only been ratified by 10 countries that represent 3.4% of the world shipping tonnage (McMullin, 2007). As at the time for the sixty-fourth session of the MEPC in October, 2012, 36 States, with an aggregate merchant shipping tonnage of 29.07 per cent of the world total, have ratified the Convention. 35% of world tonnage and 30 national ratifications are required for the convention to come into force.

This convention requires two management procedures to be employed by ships in managing and controlling the menace of ballast water discharge around the world; *Ballast Water Exchange Standard* (Regulation D-1) and *Ballast Water Performance Standard* (Regulation D-2). There is also a stipulated year of implementation for the various sizes of ballast water tanks and year of construction of ship.

The most widely adopted management procedure is *Ballast Water Exchange (BWE)* also known as Mid-Ocean Exchange (MOE). The BWE process entails the replacement of the biologically rich water of the coastal environment loaded at the port with the comparatively species and nutrient-poor waters of the mid-ocean (Dabroski et al., 2009). As a consequence of the difference in biology (competition, predation, food availability) and oceanography (temperature, salinity, turbidity, nutrient levels) between coastal and mid-ocean environments, coastal organisms used to the coastal conditions are not expected to thrive in mid-ocean conditions (Dabroski et al., 2009). The IMO over the years has recommended BWE as a stopgap panacea to the problem posed by the translocation of Harmful Aquatic Organisms and Pathogens (HAOP) (Hillman et al., 2004).

An illustration of a typical BWE is shown in Figure 1.5, where a hypothetical ship (an oil tanker) leaves position A, the Port of Halifax, in central Nova Scotia, Canada, travels through the Great Lakes to position B, the Port of Miami, in Florida, United States, where she discharges her cargo and takes up ballast water prior to crossing the Atlantic Ocean on a voyage to Nigeria, West Africa. BWE would occur at position C in the Atlantic Ocean prior to the ship entering Nigeria’s territorial waters to pick up cargo (crude oil) from position D, Port Harcourt Port, in Nigeria for transport to the receiving port in position E on the Great Lakes that is the Port of Oswego, New York, in the United States.

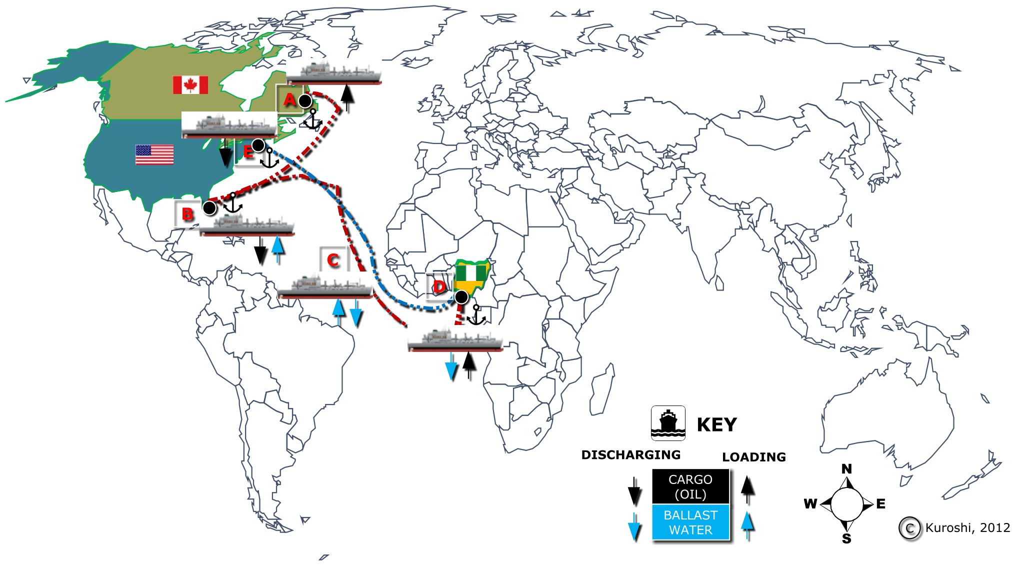

Figure 1.5: Illustration of Ballast Water Exchange.

Coastal ballast water is replaced with open ocean water during BWE by one of two methods: (i) *flow-through exchange* or (ii) *empty-refill*.

a) *Flow-through exchange* means to flush out ballast water in a ballast water tank by pumping in oceanic water at the bottom of the tank and overflowing the ballast water tank from the top in other to exchange up to three full volumes of water, to minimise the number of organisms remaining in the tank (Waite & Kazumi, 2001a).

b) *Empty/refill exchange* means to pump out the ballast water taken on in ports, estuarine or territorial waters until the tank is empty, then refilling it with mid-ocean water (Waite & Kazumi, 2001a).

Changing ballast water may be an acceptable and effective control method under certain circumstances, but it is neither universally applicable nor totally effective, and alternative strategies are needed (NRC, 1996). Research has demonstrated that the percentage of ballast water exchanged does not necessarily correlate with a proportional decrease in organism abundance (Dobroski et al., 2009, Ruiz, Smith, & Systma, 2006). For example, experimental and computational fluid dynamics (CFD) methods used by Wesley, Chang, Verosto, Atsavapranee, Reid and Jenkins (2006) to examine the flow behaviour inside ballast tanks during BWE and to examine the exchange efficiency, showed that the predicted exchange efficiency did not meet IMO's required 95% replacement after three tank volume exchanges for the particular tank geometry that was simulated. It was also clear from Wesley et al. (2006) that perfect mixing assumptions are not valid for exchange efficiency. In another study by Ruiz and Reid (2007) on commercial oil tankers, no difference was found between 100% empty-refill and 300% flowthrough BWE in removing coastal water from ballast tanks, as both methods removed 99% of added dye tracer. The latter had a lower efficacy in removing coastal zooplankton, as the results were more variable than observed for empty-refill exchange: however, both methods had efficacies > 90% on average for coastal zooplankton.

Regulation D-2 or Ballast Water Performance Standard, is a concentration-based discharge standard for organisms in ballast water adopted by the IMO in 2004. This regulation requires the introduction of ballast water treatment methods that will meet the requirements of IMO standards for ballast water discharge. The requirements of the standard are far more stringent than the requirements of the Ballast Water Exchange standards and numerically quantitative in nature.

1.3.6.1 Some Ballast Water Management (BWM) Regulations (IMO, 2005).

The two ballast water discharge standards; D-1 (ballast water exchange) and D-2 (ballast water treatment) as defined by the BWM Convention are as follows:

Regulation D-1: Ballast Water Exchange Standard

Regulation D-1 requires performance of ballast water exchange with 95% volumetric efficiency at a location at least 200 nautical miles offshore and in at least 200 m depth of water or at a location at least 50 nautical miles offshore and in at least 200 m depth of water.

Regulation D-2: Ballast Water Performance Standard

Regulation D-2 requires ballast water treatment results to have less than 10 viable organisms per cubic meter for organisms of size greater than or equal to 50 microns and less than 10 viable organisms per milliliter for organisms of size less than 50 microns. Less than one colony-forming unit (cfu) of toxicogenic *vibrio cholerae* per 100 ml or less than one cfu per gram (wet weight); less than 250 cfu of Escherichia coli per 100 ml; and less than 100 cfu of intestinal enterococci per 100 ml as summarized in Figure 1.6.

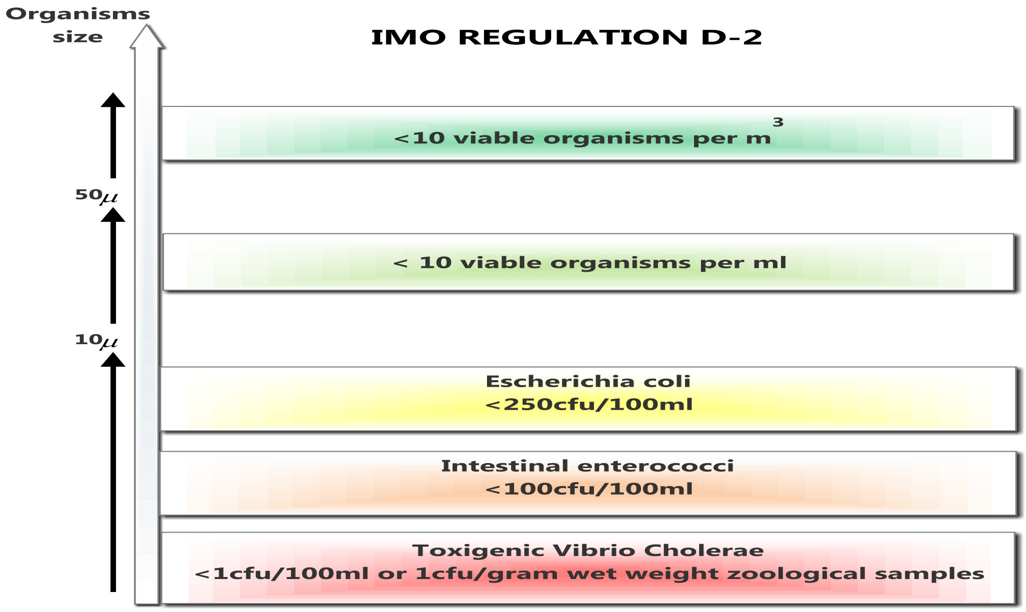

Figure 1.6: Summary of the IMO Ballast Water Performance Standard Requirements (Source: adopted from IMO, 2005).

Due to limited biological efficiency as stated earlier, the ***Exchange Standard*** (D-1) is regarded as an interim measure or a stop gap. Compliance with the ***Performance Standard*** (D-2) seems to be achievable only by use of a *Ballast Water Treatment System (BWTS).*

Regulation B-3 Ballast Water Management for Ships:

For ships constructed before 2009, D-1 or D-2 must be conducted, while for those constructed in or after 2009; D-2 must be conducted. For those with ballast water capacity between 1500 and 5000 m^3, D-2 must be conducted from 2014. 2016 is the D-2 enforcement year for those with capacity of less than 1500 or greater than 5000 m^3 (IMO, 2005; see also Appendix F for full text of relevant BWM regulations). The BWM Convention implementation schedule is summarised in Figure 1.7.

IMO REGULATION B-3

BWM Convention Implementation Schedule as revised by resolution A.1005(25) & MEPC. 188(60)

BALLAST CAPACITY (m^3)	BUILD DATE	*First Intermediate or Renewal Survey, whichever occurs first, after the anniversary date of delivery in the respective year.								
		2009	2010	2011	2012	2013	2014	2015	2016	2017
<1,500	<2009	D1 or D2								D2*
	in 2009	Note: D1;D2 by 2nd Annual but not beyond 31 Dec. 2011 or EIF, whichever is later								
	>2009	D2 (at delivery or EIF, whichever is later)								
≥1,500 or ≤5,000	<2009	D1 or D2						D2*		
	in 2009	Note: D1;D2 by 2nd Annual but not beyond 31 Dec. 2011 or EIF, whichever is later.								
	>2009	D2 (at delivery or EIF, whichever is later)								
≥ 5,000	<2012	D1 or D2								D2*
	≥ 2012	N/A			D2 (at delivery or EIF, whichever is later)					

Note: EIF= Entry into force

Figure 1.7: Summary of the IMO Ballast Water Convention Implementation Schedule (Source: ABS, 2012 from IMO, 2005).

1.4 PROBLEM STATEMENT

The Convention on Biological Diversity (CBD) recognizes five major threats to biodiversity: habitat change, loss and fragmentation; *harmful aquatic organisms (bio-invasion)*; overexploitation; pollution and nutrient loading; and climate change and global warming (United Nations, 1992a; INTOSAI, 2007).The IMO on the other hand sees HAOP as one of the four greatest threats to the world's ocean. According to Akeh et al. (2004) at least one foreign marine species is introduced into a new environment every nine weeks, meaning that without effective management systems in place, about six species will be introduced into that environment in a year.

The IMO has identified ballast water as an important vector for the transfer of Harmful Aquatic Organisms and Pathogens (HAOP) globally. It acts as an inoculation mechanism for these nuisance species (NRC, 1996). During sea transport, millions of animals or plant organisms are transported in the ballast water and are taken to alien environments. Many of these species according to studies can survive in the ballast water and sediment even after journeys of several weeks resulting in the species becoming established and ultimately becoming invasive which can seriously alter the existing ecological status quo (INTERTANKO, 1997).

The potential for ballast water discharge to cause harm has been recognised not only by the IMO, but also by the World Health Organization (WHO) which is concerned about the role of ballast water as a medium for the spread of epidemic bacterial disease (INTERTANKO, 1997; California Environmental Protection Agency, 2002).

When ballast water is discharged into a new environment, the non-native organisms released during the discharge can survive if the new environment is similar to their native environment. Non-indigenous species are, therefore, introduced into the local ecosystem where they can proliferate or mutate unhindered (Hydac, 2008). In the absence of natural competition or predators, these non-native organisms could thrive and outgrow the native species.

There are documented facts of these impacts in different parts of the world, some examples were enumerated earlier. Unfortunately, the same cannot be said about Nigeria, as the issue of ballast water as a source of marine pollution remains largely an un-researched and un-documented field of interest.

Although prevention of the spread of HAOP is not possible with the extensive trade around the world, some practical management measures, if undertaken, will certainly reduce the overall risk (Minchin, 1997). The IMO has had ballast water issues on its agenda for some years now. However, to date, limited progress has been made with regard to the development of processes and procedures for halting the transport of unwanted species via ships' ballast.

Regulation D1 as noted earlier has obviously not been satisfactory in minimizing the transfer of HAOP. Some invasive species have succeeded in slipping through the cracks in the system, and this has continued the contamination process in new port environments. There is still no universally applicable option for controlling ballast water that can totally prevent the unintentional introduction of HAOP (NRC, 1996). More research on ballast water management (BWM) is, therefore, needed to identify new methods, systems, management styles or procedures to reduce this menace to a sustainable level that will satisfy IMO's requirements for treatment systems in Regulation D-5.2 for *safety, environmental acceptability, technical feasibility, practicability, biological* and *cost effectiveness* (IMO, 2005). This study's overarching objective is the identification of such management systems that will meet most if not all of the requirements of IMO.

1.4.1 Management of Harmful Aquatic Organisms (HAOP) Invasions

According to Mack, Simberloff, Lonsdale, Evans, Clout, and Bazzaz (2000), the management of aquatic invasions can be divided into four stages:

i) Identification,
ii) Prevention,
iii) Eradication, and
iv) Control.

Identification is recognized by the scientific community as the first step in HAOP management, largely because of the diversity of species and their different responses to different treatment methods (Humphrey, 2008). Prevention, according to Wittenberg and Cock (2005) is the first and most effective defence against HAOP. This study will focus on the identification and prevention stages of the HAOP management which are obviously the first lines of defence against HAOP introduction.

Ballast Water Treatment (BWT), therefore, remains the best available management procedure that can address the *identification* and *prevention* stages and also outperform ballast water exchange (BWE) and meet the requirements of IMO's Performance Standard, provided the range of HAOP in the study area are identified, as each specie responds to different treatments differently.

Aside from the BWM Convention of the IMO, other international instruments such as article 8(h) of the *Convention on Biological Diversity (CBD)* and Article 196 of the *United Nation's Convention on the Law of the Sea (UNCLOS)* also mentioned the need for parties to prevent and control the introduction of HAOP in their jurisdictions (see Appendix F for full text of conventions).

In response to this, quite a number of research efforts have been made around the world on the issue of the translocation of harmful aquatic organisms via ship's ballast water and on the treatment options for different species in order to reduce and control their introduction into new environments. A review of some research work on the subject matter is the objective of the next chapter.

CHAPTER TWO
REVIEW OF RELATED RESEARCH

The discharge of ballast water is the single largest known source of introduction of HAOP into new environments (Amoaka-Atta & Hicks, 2002). The uncontrolled discharge of ballast water and sediments from ships has led to the transfer of HAOP, causing injury to public health and damage to property and the environment (Pavliha, David & Andrijasic , 2003).

According to Waite and Kazumi (2001a), the ballast water issue is 'an invasive species problem'. Management focus is on the prevention of invasions by organisms substantially larger and more biologically complex than bacteria or viruses. This human-mediated transfer of organisms across the globe according to Ruiz et al. (2006) is a 'potent force of change' and once established, HAOP populations can become numerically or functionally dominant in invaded communities.

2.1 LITERATURE REVIEW OF SOME PHYSICOCHEMICAL PARAMETERS OF BONNY AND CONTIGUOUS RIVERS IN NIGERIA.

The study of physical and chemical characteristic of water is very important as they may directly affect its quality and suitability for utility, and productivity of aquatic organisms (Swingle, 1969; Moses, 1983). The abundance and distribution of the organism can be influenced by the physical and chemical qualities of water. Oyewo and Don Pedro (2003) reported that variability of water quality influences the toxicity of trace heavy metals on estuarine organisms as it affects the physical and chemical composition of the ecosystem.

The physicochemical report of Okpoke creek, off Bonny river system of Niger-Delta, Nigeria (George, 2009 cited in Oyewo & Don Pedro, 2003) revealed that surface water temperature ranges between 28.98^oC-29.77^oC, pH (6.68-7.03), salinity (4.75-12.65ppt), DO (3.72-5.10mg/l), BOD (1.97-2.69mg/l) and electrical conductivity (10788.75-24877.92). Also, Tyokumbur, Okorie and Ugwumba's (2002) research results revealed that mean water temperature varied between 25.8^oC- 32.5^oC, DO (1.4mg/l-8.0mg/l), Hardness (119.7-100.4mg/l), CO_2 (30.0-52.2mg/l) while trace heavy metal concentrations showed slight variations with the following ranges; copper (0.29-0.31mg/l), zinc (0.38-0.48mg/l) and lead (0.65-2.03mg/l), all values were below Nigeria's National Environmental Standards and Regulations Enforcement Agency (NESREA) guidelines.

In Bonny River, Niger-Delta, Dublin-Green (1990) gave the results of some physico-chemical variables, for surface water in wet and dry seasons as temperature (27.5-31.2^oC), conductivity (30800-45500ms/cm), pH (7.7-7.6), salinity (25%-30%), DO (6.0-52mg/l), and total alkalinity (90.0-12mg/l). It has been stated by some environmentalists such as NEDECO (1980), Dangana (1985) and Zabbey (2002) that in the Bonny estuary of the Niger-Delta, the physicochemical parameters such as electrical conductivity, dissolved oxygen, pH, temperature, salinity and tidal range vary seasonally. In a study conducted by Mitchell-Innes and Pitcher (1992), changes in abundance of organisms are related to changes in physicochemical parameters of the water body.

2.1.1 Water Temperature

In general terms, temperature may be defined as the degree of hotness or coldness in a body (Lucinda & Martin, 1999). It can also be defined as the condition of a body which determines the transfer of heat to or from another body. Temperature is usually measured either by mercury-in-bulb thermometer or thermistor in Celsius (^oC). Physical, biological and chemical processes in surface and sub-surface water are influenced by temperature (McNeely, Neimanis, & Dwyer, 1979). A rise in water temperature may lead to reduction of solubility of oxygen in water thereby increasing the oxygen demands of fish. Higher temperatures increase the solubility of many chemical substances and may influence the effect of pollution on the aquatic system. Boyds reported in 1979 that temperature affects the physical, chemical and biological processes in surface water thereby increasing the concentration of dissolved oxygen and photosynthetic activity.

Variation of surface water temperature depends on latitude, elevation, season, period of the day, wind, wave action or water current, depth, cloud/vegetation cover among others. It is also subject to season. Meanwhile, McKee, Levi, and Movshon (2003) reported that an increase in water temperature may lead to reduction of aquatic plants and increase the population of phytoplankton organisms.

Aquatic organisms have both an upper and lower temperature limit for proper growth, spawning, egg incubation and migration depending on the species. Boyd and Lichkoppler (1979) reported that the rate of biochemical reactions doubled with every 10^oC rise in temperature. Fish have been reported to grow faster at temperatures between 25^oC- 32^oC (Parker & Davis, 1981; Sikoki & Venn, 2004). High temperature or sudden changes are often dangerous to fish. These limits vary from species to species. Changes in temperature regime may therefore alter the distribution and species composition of aquatic communities. Fish had ecologically been classified according to their ability of tolerance to temperature as stenothermal "lower" or eurythermal "higher" (Boyds, 1979)

Temperature ranges between 27-31^oC were recorded by Hart and Chindah (1998) in the mangrove swamp of the Bonny estuary, whereas Sikoki and Zabbey (2006) reported a narrow temperature range of between 26.0-27.8^oC. Ademoroti (1996) reported that water temperature can strongly affect feeding patterns, growth rate and breeding periods of aquatic organisms. Miserendino (2001) observed that species richness was positively correlated with temperature and altitude.

2.1.2 pH levels

pH indicates a balance between the acids and base in water. It is a measure of the hydrogen ion concentration in a solution. The value of pH reflects the solvent ability of water. The pH values of water are measured on a scale ranging from 0 to 14. The pH values below 7 are an indication of acidic conditions and values greater than 7 indicate alkaline conditions in water. The range of pH in natural fresh water varies from 4-9. It is controlled by bi- carbonates in the aquatic system. The general trend of surface water tends to be alkaline, whereas ponds and swamps are more acidic. The range of pH in fresh water is greater than that of sea water. Sea water values, for example, range from 8.0 to 8.3 pH units. pH is considered an ecological factor, which has a strong relationship with the physiology of most aquatic organisms (Boltovskoy & Wright, 1976; Boyds, 1979).

Water pH is usually measured by the use of an inglass meter with electronic glass electrode. Boyd and Lichkoppler (1979) observed an increase in surface water pH during the day and decrease at night due to the temporary removal of bicarbonates by aquatic macrophytes during photosynthesis. The pH of water may influence the species composition of an aquatic environment and affect the availability of nutrients and the relative toxicity of many trace elements. Chindah, Braide and Izundu (2005) reported pH range from acidic to slightly above neutral for both dry and wet seasons in the surface brackish water wetland embayment of the Bonny River.

2.1.3 Electrical Conductivity

The conductivity of a water system is an index of the total ionic content of that water; thus it provides an index of the freshness or ionized electrolytes in water. It is usually measured in scale and expressed as micro Siemens per centimeter (μscm^{-1}). The general trend of conductivity values of $1000\mu scm^{-1}$ indicates fresh water; above $40{,}000\mu scm^{-1}$ are marine waters while those between the two values indicate brackish water. Conductivity values can be used to explain productivity of an aquatic system both chemically and biologically.

Conductivity varies according to season. A conductivity value of 900-15000 for dry season indicates greater sea influence in the dry season than in the wet season (Chindah et al., 2005). The values of conductivity recorded by Chindah et al. (2005) in a brackish wet-land embayment of the Bonny estuary differs significantly between seasons ($P<0.05$). Total density of macro-invertebrates in the Andean Ptagonian River and streams were correlated with conductivity, temperature and altitudes (Miserendino, 2001).

2.1.4 Salinity

Salinity is the total sum of all solid substances in solution contained in 1 kg of water. It is usually measured and expressed in scale weight of salt per volume of water. The unit of measurement is grams per liter (gm/l) or parts per thousand (PPT). Similarly, it could also be measured as parts per million (PPM) or percentage of salt (%). Salinity is an important factor in the life of aquatic organisms. A slight variation in salt content of any aquatic ecosystem may subject organisms to serious stress conditions especially in a situation where the internal fluids of the organisms are not in balance with the external salinity of the water where they live. The distribution, abundance and composition of species may be affected or influenced by salinity (Pombo, Elliot & Rebelo, 2005).

Water with a salinity level between 0.5-30percent had been classified as brackish, while between 30 and slightly above 34% is referred to as marine water. Romane and Schlieper (1971) stated that salinity is the major environmental factor restricting the distribution of marine and lacustine taxa, resulting in pronounced decrease in species of aquatic organisms in brackish water. Jones (1987) also reported a relationship between the number of individuals and salinity. He concluded that changes in oxygen and sediment were of less importance than salinity influencing the benthic communities of Hawkesbury estuary. Hart and Chindah (1998) recorded a salinity of 12.5-26% in the mangrove swamp of the Bonny estuary.

2.1.5 Turbidity

Turbidity is the measure of the suspended particles such as silt, clay, organic matter, plankton, and microscopic organisms in the water held in suspension by turbulent flow and Brownian movement (O'Neill, McKim, Allen & Choate, 1994). It is determined by comparing the optical interferences of suspended particles to the transmission of light in water using instruments previously standardized for analysis of samples for standard turbidity units (USEPA, 1999). The unit of measurement is usually referred to as Natural Turbidity Unit (NTU) or Jackson Turbidity Unit (JTU). The amount of solid material suspended in water may result from erosion, wind action, runoff, algal blooms as well as from human activity. Turbidity values vary according to water type, source and season. Egborge (1994) recorded higher values of turbidity in all stations sampled in wet season months than in dry season months along the Bonny estuary. This was attributed to surface water runoff during the wet season.

High turbidity reduces photosynthesis of benthic plants and algae thereby reducing plant growth and productivity. Rapid increase in turbidity may affect aquatic biological communities; therefore, turbidity is an important factor in surface water (McNeely et al., 1979).

2.1.6 Total Dissolved Solids

Total Dissolved Solids (TDS) is an index of the amount of dissolved substances in water. The presence of such solutes alters the physical and chemical properties of water. Natural water ways acquire mineral constituents in dissolved form as dissolved salts in solution such as sodium, magnesium, sulphate, nitrate, phosphate, and chloride.

The range of dissolved solids varies in different types of surface water as follows: 0-1,000mg/l in typical fresh water, 1,001-10,000mg/l in brackish water, 10,001-100,000mg/l in marine and above 100,000mg/l in brine water. The contributing factors are natural and anthropogenic sources such as high surface runoff, flooding, municipal and industrial effluents, and agricultural activities (Odokuma & Okpokwasili, 1996).

2.1.7 Dissolved Oxygen (DO)

Dissolved oxygen is an important gas that is found in natural surface water. Its solubility in water is very slow as such; it is a factor that limits the life of aquatic organisms. The amount of dissolved oxygen in natural waters varies according to the type of water body and seasons. Concentration of dissolved oxygen is dependent on some key factors of the environment such as temperature, salinity, turbulence of water, and atmospheric pressure (decreasing altitude). Dissolved oxygen concentration subject to diurnal and seasonal fluctuations, is due to variations in temperature, photosynthetic activities that take place in water and river discharge (Ministry of Environment, Lands and Parks Land Data BC, 1998).

Coimbra, Graca, and Cortes (1996) studied the effects of effluents on the macro invertebrate community in a Mediterranean river and revealed that the effluent discharge caused a significant decrease in the dissolved oxygen requirement of the river water and a significant increase in conductivity, sulphate and nitrate. They observed further that in reference to sites, four species were abundant, whereas in effluent discharge areas, most of the organisms were replaced by two different species.

The composition of organic wastes and oxidation of organic products may reduce the dissolved oxygen levels to amounts equivalent to zero. Macro invertebrate responses along a recovery gradient of a regulated river receiving an effluent (Carmago, 1992) reflected greater diversity and total biomass at a station upstream to the discharge point than at downstream sampling sites where oxygen depletion was pronounced.

Snowden and Ekweozor (1990) studied the littoral fauna of the Bonny River estuary and reported low density and biomass of enryhaline species recovered in the middle reaches. They attributed the reduction in density and biomass to oxygen depletion due to pollution from oil terminals, and outboard engines. Oxygen depletion as a consequence of oil spillage in the Niger Delta (Bonny estuary) was further investigated by Snowden and Ekweozor (1987), and they observed a near to total elimination of littoral in fauna and a highly significant oyster mortality. Mortality of macro fauna during oil spills and pollution may be directly due to depletion of oxygen (asphyxia) which could result in death of organisms or total loss of bio-diversity and loss of habitat (Ekweozor, 1989).

Swingle (1969) and Moses (1983) both agreed that these physical and chemical parameters of water are very important determinants of the abundance and distribution of organisms in marine environments and hence determinants of the treatment mechanism to be deployed in treating such water. Therefore, the objective of this study cannot be successfully achieved without the knowledge of these important characteristics.

2.2 USE OF SURROGATE ORGANISMS/ PROXY GROUP

In research to address the diversity of organisms in ballast water, surrogates or proxy groups were used as representatives of the different taxa. Surrogates are hardy, least susceptible to treatment and tolerant across a wide range of conditions, such that if they succumbed most other organisms would be eliminated as well (Ruiz et al., 2006; Hillman et al., 2004). In a study by Hillman et al. (2004) the pilot plant largely used existing technologies: filtration, ultraviolet light and chlorine dioxide dosing. The authors also agreed with Ruiz et al. (2006) that, potential treatment systems should be tested on surrogate species which are representative of the likely spectrum of invader types.

In an effort to standardize results, Dobroski et al. (2009) evaluated any data on zooplankton abundance as representative of the largest size class of organisms (greater than 50 μm in size). Phytoplankton abundance was evaluated on par with organisms in the 10 – 50 μm size class and culturable heterotrophic bacteria were selected as a proxy for total bacterial count because, unlike total bacteria, according to the authors, there are reliable, well-accepted standard methods to both enumerate and assess viability of these organisms.

Hillman et al. (2004) ran tests using primarily the brine shrimp, *Artemia salina*, which is readily and cheaply cultured, has a tough, encysted stage as well as a stage where it represents many planktonic organisms as a particularly useful surrogate for many of the organisms of concern carried in ballast water. The adult *Artemia salina* is commonly used as surrogate in many tests.

Voigt and Gollasch (2001) also carried out a research using the same species where four different life-stages were used: adults, cysts, developing eggs and nauplii, to cover most of the trophic levels of the organisms usually found in ballast water tanks. The authors concluded that the cysts of *Artemia salina* could be used as a surrogate for the cysts of any species, where treatment chemicals would have to pass a thick shell to influence the organisms. Peracetic acid was successful on *Artemia* cysts while a 25% solution of glutaraldehyde was not (Voigt et al., 2001).

Hillman et al. (2004) also ran tests on a rotifer, *Brachionus rotundiformes* and the phytoplankton *Nanochloropsis*. The researchers found out that filtration using 50 micron screens is 100% effective in removing *Artemia* cysts and nauplii (the newly hatched animal) and 85% effective for *Brachionus*.

2.3 REVIEW OF TREATMENT METHODS

In February 2004 in London, it was decided, through the adoption of the BWM Convention of the IMO, that the treatment of ballast water on ships will be compulsory from 2009 (Hydac, 2008) but the deadline had to be extended by Resolution A.1005 (25) to 1st January 2012 because there were uncertainties regarding the immediate availability of ballast water treatment technology to ships to which regulation B-.3.3 would first apply, i.e. ships constructed in 2009 (Globallast, 2012).

Physical treatment methods that remove organisms from ballast water such as filtration and hydrocyclone may be used as primary treatment to be followed by additional secondary treatment systems, such as exposure to UV or chemical treatments, to inactivate the remaining load of organisms in the water.

The Marine Environment Protection Committee (MEPC) of the IMO requires ballast water treatment options to meet the following criteria: they must be *biologically effective*, *environmentally acceptable*, *safe for the crew*, and *cost effective* (IMO, 2005). The following treatment methods have been identified: *filtration systems*, *oxidizing and nonoxidizing biocides*, *thermal treatment*, *electric pulse and pulse plasma techniques*, *ultraviolet (UV) treatment*, *acoustic systems*, *magnetic fields*, *deoxygenation*, *biological techniques,* and *anti-fouling coatings.* Four of these treatments according to NRC (1996) were identified to have met the requirements for safety and effectiveness*: filtration*, *biocides*, *heat*, and *electric pulse/pulse plasma systems*, and these will be discussed in the following sections.

2.3.1 Filtration and Physical Separation Systems

Physical separation systems are perhaps the most environmentally friendly methods for the removal of HAOP from water, as they do not leave any residual effect in the water, which is not the situation with biocides for example. Physical separation methods like filtration and hydrocyclones have limitations as to the sizes of organisms they can effectively remove (Kazumi, 2007).

a) *Filtration:* Philips (2006) noted that filtration can effectively remove ichthyoplankton, zooplankton, larger phytoplankton and heterotrophic protists, but it has not been successful in reducing the concentration of most microorganisms. Hillman et al. (2004) observed that the method will be possibly effective in removing dinoflagellate cysts but it will not remove most of the organisms since their specific gravity is very close to that of water.

   According to Chase et al. (2000) ballast water can be filtered before it enters the tanks or while it is being discharged. They observed that the advantage of filtration is that organisms that are filtered out may be retained in their native habitat. Media filtration using a sand/anthracite filter according to Kazumi (2007) can remove particles down to 1µm in size, and this has been achieved in other water treatment processes. The researcher reported that crumb rubber made from waste tires may be suitable for potential particle separation. Xie and Chen (2004) observed that for the sand/anthracite filter, the removal efficiencies for particles larger than 10 µm and 15 µm was 89.4% and 94.5%, respectively, while for crumb rubber it was 86.8% and 93.6%, respectively.

b) *Hydrocyclone*: In a research by Rigby and Taylor (1998), hydrocyclone which is meant to be a substitute to filtration, gave inconclusive test data in small prototype cyclones. Parsons and Harkins (2002) discovered that hydrocyclones was successful in trapping particles in the 50 to 100 µm size range. The drawback to this method, however, is the difficulty in separating small aquatic organisms that have similar density to sea water using centrifugation.

2.3.2 Biocides

According to Kazumi (2007), the efficient use of biocides in the removal of HAOP from ballast water should satisfy both the need for effectiveness in inactivating the potential HAOP and degradability or removability of any form of residual effect of the biocides in the discharged water. The following chemicals; chlorine, chlorine dioxide, hydrogen peroxide, glutaraldehyde, menadione, peracetic acid, phenol, and cationic surfactants (such as C16-alkyltrimethylammonium chloride) according to the author, showed a satisfactory result against a wide range of organisms in both marine and freshwater environments. Menadione and phenol are the only biocides not used to disinfect water systems.

Most oxidizing chemicals used in waste water treatment are effective in destroying the cell membranes and other organic structures of the organisms they come in contact with, while non-oxidising biocides, on the other hand, are reported by Dobroski et al. (2009) to work like pesticides by interfering with neural, reproductive or metabolic processes of organisms. Biocides (e.g., chlorine dioxide, ozone) used to treat drinking water according to Philips (2006), can effectively kill microorganisms. Effectiveness of some biocides like hydrogen peroxide, chlorine, chlorine dioxide, ozone, gluteraldehyde, copper/silver ion systems on some organisms in the Marine Target Species List (MTSL) were tested and reported by Rigby et al. (1998). The outcomes were generally satisfactory, although high concentrations were required in some of the cases which could pose significant safety, environmental or operational problems.

Laboratory studies aimed at ballast water treatment by Rigby et al. (1998 & 1999), Kazumi (2007), Hillman et al. (2004), and Dobroski et al. (2009) have shown various biocides to be effective against a wide taxonomic range, though none were 100 % effective in terms of targeted organisms.

For the most part, biocidal effectiveness was reported by Rigby et al. (1998) as LC_{90}, (lethal concentration required to kill 90 % of the population of test organisms), or LD_{50} (lethal dose required to kill 50 % of the population of test organisms) after a set period of time of usually 24 hours. The findings above cannot be easily evaluated on the basis of the IMO discharge standard which is based on organism size and number discharged per quantity of water: however, the effectiveness of the treatment is not in doubt. For the purpose of this research work (onshore treatment), the finding is very important. Rigby et al. (1998) concluded that the findings shall provide a basis from which future efforts on biocidal effectiveness in the context of IMO regulations can be carried out.

Furthermore, for reliable and effective treatment of ballast water with biocides, Kazumi (2007) concludes that *biocide dose vs. contact times* must be known. CT values are used in the treatment of potable water, where C is the residual disinfectant concentration in mg l^{-1} and T is the time (in minutes) that water is in contact with the disinfectant to meet microbial disinfection profiling and benchmarking provisions of the CT tables of the water boards (Kazumi, 2007). Mortality, therefore, increases with increased value of CT.

Chick's Law is the underlying principle whereby municipal water is reliably and effectively disinfected. Therefore, to inactivate unwanted organisms transported by ballast water and to meet the requirements of IMO regulation, it is envisioned by Kazumi (2007) that CT values and tables could be established for use in this application.

A). Oxidizing Biocides***:***

(i) Chlorine dioxide: Chlorine dioxide at a concentration of 3 parts per million according to Hillman et al. (2004) was 97% effective in reducing the hatching rate of cysts after 40 hours.

(ii) Sodium Hypochlorite: Kazumi (2007) reported that sodium hypochlorite was effective in freshwater with a 24 h LC_{90} value of 5 mg l^{-1} against the oligochaete, *Lumbricus variegatus* and the cladoceran, *Daphnia magna*. Whereas against adult zebra mussels the author reported that hypochlorite was not as effective with a 24 h LC_{90} value of 130 mg l^{-1}. The ability of adult mussels to close their shell valves when exposed to toxic substances could account for the low efficacy of the chemical on the organism.

(iii) Hydrogen Peroxide: Kuzirian, Terry, Bechtel and James (2001) found that 1, 3 and 10ppm of hydrogen peroxide were successful against a wide spectrum of marine plankton. Depending on the concentration of H_2O_2, the time for 100 % mortality ranged between 5 to 35 min according to Kazumi (2007). Gollasch (1997) found that 1% H_2O_2 was effective against the cysts of phytoplankton as e.g. *Gymnodinium catenatum*.

(iv) Ozone: Laboratory studies with ozone (O_3) by Kazumi (2007) showed that dosages of 9 mgl^{-1} (at pH 7) and 14 mgl^{-1} (at pH 8.2) and 24 h contact time in seawater was successful against *Bacillus subtilis* spores, an indicator organism used for biocidally resistant spore-forming organisms in ballast water. In a similar experiment the author stated that for a similar success rate against marine dinoflagellate cysts, *Amphidinium* sp., ozone doses of 5 to 11 mg l^{-1}, and 6 h of residual contact were needed.

Larger scale studies reported by Gollasch (1997) demonstrated that ozone gas diffused into a ballast tank for 5 and 10 h inactivated up to 99.99 % of the culturable bacteria, > 99 % for dinoflagellates and 96 % for zooplankton. Kazumi (2007) reported that extended contact times of up to a couple of days were needed for effective treatment of organisms in seawater with ozone. A study by Prince William Regional Citizens' Advisory Council (PWSRCAC, 2005) reported that between 5 to10 hours of ballast water ozonation resulted in 71-99% mortality of most marine phytoplankton, zooplankton, and bacteria. Gollasch (1997) on the other hand had a more rapid ballast water ozonation outcome than PWSRCAC (2005) at a dosage of 1-2 mg per liter with contact times of just 5 to 10 minutes. The results by Sassi, Viitasalo, Rytkonen, and Leppakoski (2005) showed mortality rates of 96.10% for copepods, 98.10% for copepod nauplii and 99.10% for rotifers with ozone dosage of 17 mg/l. At a dosage of 7 mg/l, according to the authors, the results were 95.10% for copepods, 96.10% for copepod nauplii, 97.10% for rotifers and 99.10% for barnacle nauplii.

B). Non-Oxidizing Biocides***:***

(*i). Glutaraldehyde:* Kuzirian et al. (2001) reported glutaraldehyde to have a variable biocidal effectiveness against oligochaetes, cladocerans and amphipods. In another experiment, the researchers reported 90% mortality of organisms when treated with at least 500 mg l^{-1} of glutaraldehyde for 24 hours.

(ii) Menadione (vitamin k3): Reports from laboratory studies by Sano, Maupili, Krueger, Garcia, Gossiaux, Phillips and Landrum (2004) have shown menadione to

be effective against a freshwater amphipod, *Hyalella azteca* and an oligochaete, *Lumbriculus variegates,* with an estimated 24 h LC_{90} for these organisms at less than 2.5 mg l^{-1}. Kazumi (2007) also reported that menadione was also toxic to eggs of *Brachionus plicatilis* (a marine rotifer), *Daphnia mendotae* (a freshwater cladoceran), and *Artemia* sp. (a marine brine shrimp). *Daphnia* eggs were found by the researchers to be the least sensitive, with a 24 h LD_{90} of 8.7mg l^{-1}.

A laboratory efficacy of 24 h LD_{50} in the range of 0.11 – 7.62 mg l^{-1} were reported by Kazumi (2007) when tests were performed on some ballast water surrogate organisms from different trophic levels (bacteria, dinoflagellates, green algae, and larvae of crustaceans and mollusks) using menadione nicotinamide bisulphite (MNB) which is a highly water soluble and extremely photodegradable chemical, with a half-life of < 6 h.

(iii) A combination of Peracetic acid and Hydrogen peroxide has been reported by Kazumi (2007) to be effective in the killing marine organisms. The main bioreactive component in the combination is peroxyacetic acid (PAA), with hydrogen peroxide (H_2O_2) as the secondary active ingredient that acts as a weak biocide for bacteria.

C). Ultraviolet (UV) Light:

UV light is effective against pathogens (Waite & Kazumi, 2001a), it is low maintenance, and no residuals are formed as in chemical biocide applications. Its effectiveness is lowered by turbidity and colour (Hillman, et al., 2004; Chase, et al., 2000), so ballast water may need to be filtered before treatment. It is currently used in hospitals, homeless shelters, and prisons to kill microorganisms and prevent the spread of disease (Hillman et al., 2004). Ultraviolet treatment works to achieve sterilization by exposing target organisms to ultraviolet light (UV) energy waves (California Environmental Protection Agency, 2002). The technology inactivates microorganisms by disrupting the DNA within cells, thereby prohibiting their replication (Dobroski et al., 2009; Kuzirian et al., 2007). Between 97-99% inactivation was achieved when different bacteria and viruses were irradiated with 20-MW/cm^2/sec dose (California Environmental Protection Agency, 2002).

2.3.3 Other Treatment Methods

(a) *Deoxygenation:* Deoxygenation involves the displacement of oxygen with inert gas such as nitrogen or carbon dioxide. Most aquatic organisms require oxygen for survival: therefore, any treatment method that can deprive the organisms of oxygen might suffice as a good treatment method. Deoxygenation as a treatment method basically uses oxygen deprivation to kill HAOP contained in ballast water. Current research by PWSRCAC (2005) revealed that lowering the level of oxygen to less than 3 milligrams per liter will result in effective kill rates for HAOP.

In the laboratory, as reported by Kazumi (2007), researchers exposed three invasive invertebrates (*Ficopomatus enigmaticus*, a polychaete;*Carcinus maenas,* the European green shore crab; and *Dreissena polymorpha*, the zebra mussel) to hypoxic conditions (O_2 levels of 0.8 mg l^{-1}) for 2 to 3 days, and observed that there was 20 % survival of the polychaete and the zebra mussel.

Deoxygenation, while mainly a physical process also has a chemical component. The component is the addition of carbon dioxide which produces a reduction in pH that enhances killing efficacy (Dobroski, et al., 2009).

According to Hillman et al. (2004) deoxygenation or hypoxia could remove many organisms of interest, and may also stimulate corrosive anaerobes, which is an important disadvantage of this method. Also Kazumi (2007) reported that deoxygenation kills metazoans (i.e., all animals except protozoans and sponges), but not bacteria or protists. These outcomes were also supported by the outcome of research by Tamburri, Wasson, and Matsuda (2001).

To prove that aquatic organisms are sensitive to oxygen levels, the experiment by Tamburri et al. (2001) explored the effect of nitrogen ballast water treatment as a deterrent to non-native species introductions. They examined the oxygen tolerance of larvae from three known nuisance invasive species now found in U.S. waters—an Australian tubeworm, European green crab, and European zebra mussel. The low oxygen condition created was toxic to all of the larvae after only two to three days.

*(b) Thermal treatment**:*** Rigby et al. (1999) based on microscopic observation of heated ballasted water concluded that temperatures of 38 °C for several days could

kill all zooplankton and a greater percentage of phytoplankton. Gollasch (1997) reported that temperatures of 40 to 45^{o}C on the Vessel, IRON WHYALLA effectively killed both phytoplankton and zooplankton and exposure to temperatures of 36 to 38^{o}C over a period of 2 to 6 hours was sufficient to kill zebra mussels in pipes.

Chase et al. (2000) in another study reported that temperatures between 35^{o}C (95^{o}F) and 45^{o}C (113^{o}F) maintained for a long enough period of time is effective at killing larger organisms, such as fish, but not as effective at killing microorganisms as shown in Figure 2.1. The author also reported a study in Australia where most organisms were destroyed as ship ballast water reached temperatures of close to 40^{o}C (104^{o}F).

(c) Advanced Oxidation Technologies: Tamburri et al. (2001) reported that when dissolved hydroxyl concentration was 0.63 mg l^{-1}, the kill efficiencies of bacteria, phytoplankton and protozoans reached 100 % within 2.67s.

2.3.4 Combination of Treatment Methods

With many treatment methods under investigation, researchers have not as yet discovered any method that could singly achieve satisfactorily the IMO's treatment systems objectives of *safety*, *environmental acceptability*, *technical feasibility*, *practicability*, and *cost effectiveness*. Some treatments may need to be accompanied by another treatment that covers another category of organism.

Figure 2.1 shows the organism sizes covered by the various methods. The primary treatment, as the first line of defence in the treatment system, first removes the larger organisms and particles like zooplankton and turbidity. Afterwards, the water is subjected to secondary treatment such as UV or biocidal treatments to remove smaller organisms like bacteria and phytoplankton. Although BWE can remove organisms of all classes, it is short of meeting the IMO Performance Standards requirements.

In an experiment conducted with water from Biscayne Bay (FL), USA using either hydrocyclone or filtration as a primary treatment stage, Waite and Kazumi (2001b) reported that hydrocyclonic treatment was ineffective, while a 50µm screen removed most of the zooplankton. Secondary treatment with UV showed an initial reduction in the viable counts of microorganisms, but bacterial regrowth was observed after 18 hours.

In a study where hydrocyclone, screen and biocides were combined, Kazumi (2007) reported that the treated water was found to comply with IMO performance standard. These and other study results have given credence to the notion that no single treatment system can satisfactorily achieve IMO's performance standard, a combination of treatment systems is therefore required.

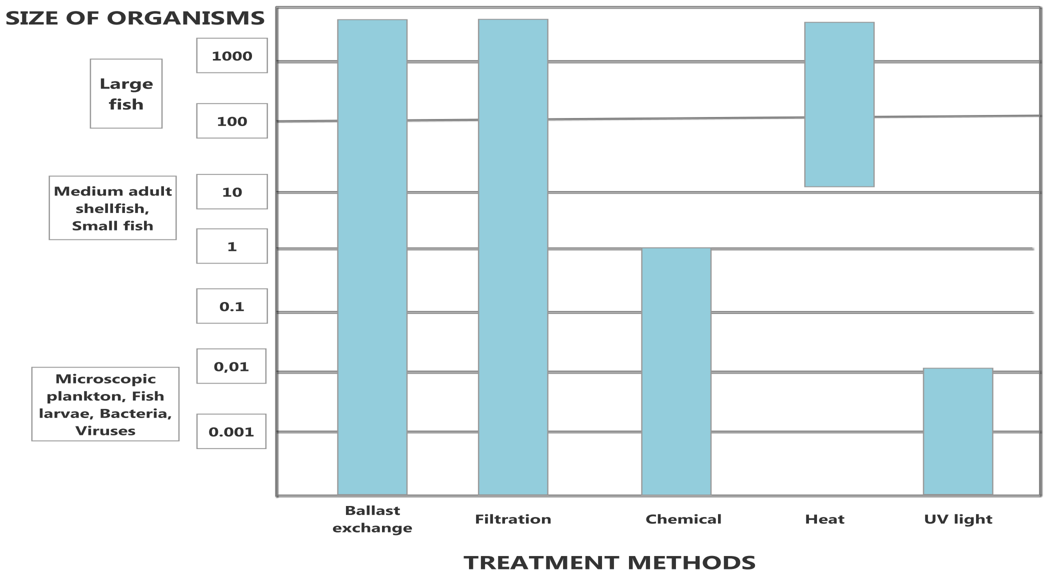

Figure 2.1: Ballast Water Management Methods for specific Organism Sizes (adopted from Chase et al., 2000).

In view of the fact that BWE as a stop gap option has failed to satisfactorily address the issue of HAOP translocation via ballast water, ballast water treatment has remained the only available viable option for the maritime industry. This chapter reviewed literature on research related to ballast water management or treatment which is the general theme of this study. There are a lot of research done and a lot more in progress on treatment methods from which selection can be made for the most appropriate method for the study area. The next chapter shall look at the methodology deployed to collect and analyze both the samples and the data in this study.

CHAPTER THREE
METHODOLOGY AND DATA COLLECTION

3.1 DESCRIPTION OF THE STUDY AREA

The study area is the Port Harcourt Harbour General Cargo Terminal and the Oil Terminal (also known as Okrika Jetty). Both are located in the mangrove swamp vegetation belt of Nigeria's Niger-delta, along the Bonny estuary which drains into the Gulf of Guinea in the Atlantic ocean (see Figure 3.1). The General Cargo Terminal lies between latitude $4^o46'17''$ and $4^o45'33''$N and between longitude $7^o00'21''$ and $7^o00'13''$E. The Terminal has a total of ten berthing spaces covering a total length of 2.55km (1.59 miles), whereas the Okrika Oil Terminal lies between $4^o45'11''$ and $4^o44'48''$N and between longitude $7^o00'10''$ and $7^o00'08''$E. It has a total of 4 berthing spaces covering a total length of 0.57km.

Figure 3.1: Map of Nigeria, West Africa. Source: http://www.waado.org.

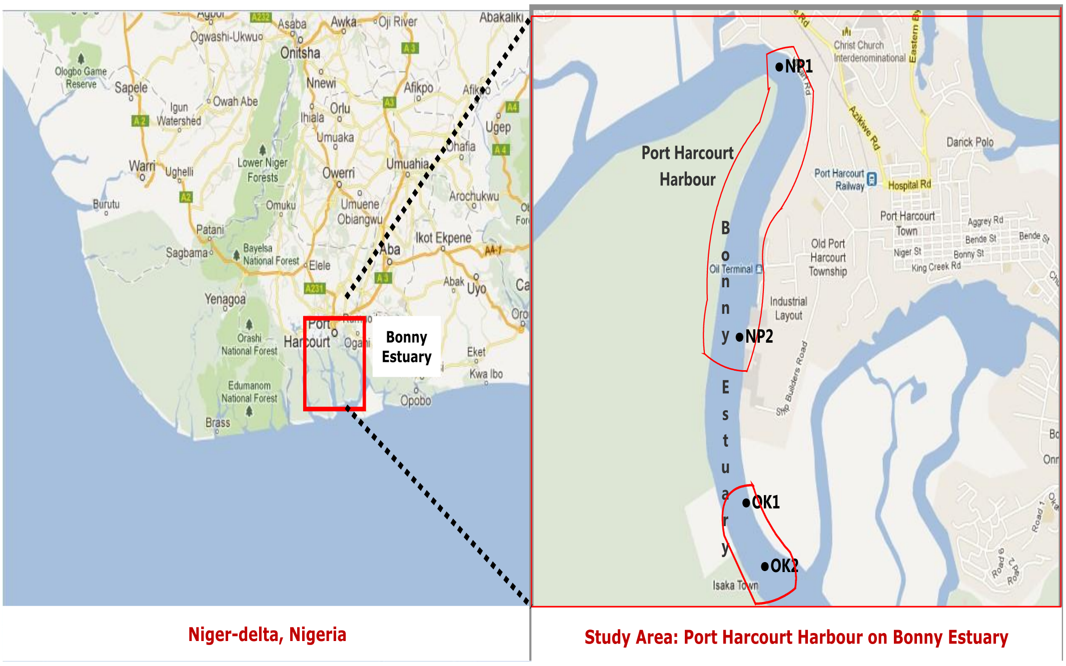

Figure 3.2: Map of the Niger-delta Region of Nigeria (left) and a zoomed Map of the Study Area showing Sampling Stations; General Cargo Terminal (NP1 & NP2) and Oil Terminal (OK1 & OK2), in Port Harcourt Harbour (encircled in red) on the Bonny Estuary (right). Source: Google maps.

3.2 THE SCOPE OF THE STUDY

The data used for this study were collected by direct field measurements. The study covered sampling of the surface water marine environment of Port Harcourt Harbour (General Cargo Terminal and Okrika Oil Export Terminal). Each terminal had two sampling locations; NP1 and NP2 for the General Cargo Terminal and OK1 and OK2 for the Oil Terminal (see Figure 3.2). The samples were subjected to taxonomic laboratory analysis, and different classes of planktonic organisms were identified. As a result, a more ideal treatment procedure was eventually proposed by this study for Port Harcourt Harbour, based on the ballast water treatment research literature reviewed in the course of this study.

3.3 SAMPLING LOCATION

The sampling locations for this research were situated at the Port Harcourt Harbour. The Harbour has both a General Cargo Terminal consisting of ten (10) berths, and an oil terminal consisting of four (4) terminals. The export terminals are centers of contamination from other ports around the world as they are basically loading terminals, where ballasted water is discharged in order to load cargo (petroleum products). The General Cargo Terminals are basically import terminals where ballast water is loaded from the port after cargo discharge, making them sources of contamination for other ports.

On the basis of the expected difference in both biological and physicochemical characteristics of different harbours around the world, it would be expected that the treatment facilities in different regions of the world should have different treatment processes. Treatment plant in a port in West Africa for example, should not be expected to be exactly the same with that of a port in Sweden.

3.3.1 Sampling Stations

Four (4) sampling stations were established along the stretch of the study area (Port Harcourt Harbour); two each at both the General Cargo Terminal and Okrika Oil Terminal. The sampling locations were selected because they are situated in some of the major import and export terminals along the Bonny estuary.

Port Harcourt Harbour

General Cargo Terminal:

Station I referred to as NP1 (Upstream) -Samples of the General Cargo Terminal ambient surface water were collected at berth 8 in the following position; 4^{o}46’12.20’’N, 7^{o}00’14.09’’E and at elevation of 3 meters above sea level.

Station II referred to as NP2 (Downstream) -Sample was collected at the General Cargo Terminal at position 4^{o}45’38.41’’N, 7^{o}00’16.04’’E and at elevation of 2 meters above sea level.

Okrika Oil Terminal

Station III referred to as OK1 (Upstream) -Sample of the Oil Terminal ambient water was collected at the following position; 4^{o}45’03.29’’N, 7^{o}00’07.72’’E and at elevation of 3 meters above sea level. This sampling was done further towards the bank of the river. This accounts for the higher elevation above sea level in Station III than Station II.

Station IV referred to as OK2 (Downstream) -Sample was collected at position $4^{o}44'51.69''N$, $7^{o}00'08.43''E$ and at elevation of 1meter above sea level.

Collection of port ambient surface water samples was carried out between 3rd January 2012 and 6th January 2012. The harbour or ambient water samples were collected using two methods; scooping the nets through the harbour water and also by filtering collected harbour water through the nets. The net types used were 63µm plankton net for phytoplankton and 100µm plankton net for zooplankton.

3.4 SAMPLE ANALYSIS

3.4.1 Methodology for Physicochemical Characterization of Study Area

The physical and chemical quality of water according to Swingle (1969) has a direct effect on the quality and suitability for utility, productivity and distribution of aquatic organisms. Oyewo and Don Pedro (2003) also reported that the toxicity of trace heavy metals on estuarine organisms is controlled by the variability of water quality and this determines the physical and chemical composition of the ecosystem. This makes the study of the physical and chemical characteristics of the water in the study area very essential to this research.

The physical and chemical parameters that have been studied in this research are; temperature, hydrogen ion concentration (pH), electrical conductivity, salinity, turbidity, and dissolved oxygen (DO). The methods described by APHA: Standard Methods for the Examination of Water and Waste Water (1998) were employed (APHA, 1998).

3.4.1.1 Temperature

The water temperature was measured in-situ in the field using mercury in glass thermometers (0-50^{o}C) graduated at 0-01^{o}C intervals. The sensitive part of the thermometer was immersed directly into the water and the instrument was allowed to stabilize. At stability, the temperature value was read. Three instrument readings were measured and the mean value of the three was calculated and recorded as the surface water temperature for the station. The same procedure was repeated in all the sampling stations.

3.4.1.2 pH levels

The water hydrogen ion concentration pH was measured in-situ directly in the field using a multiple-parameter Horiba water checker (model U-10µ). The instrument was first calibrated with the standard Horiba solution; the measurement for pH was done as soon as possible by dipping the probe into the water. The switch button was put on while the arrow key moved to pH command displaying the values. After the value stabilized, the reading was taken. This was repeated three times and the average recorded. The same was done for all sampling stations.

3.4.1.3 Electrical Conductivity

The electrical conductivity of the sample at the four stations was measured in-situ instrumentally using the same Horiba multimeter. The same procedure was adopted as in pH but the arrow key was positioned on electrical conductivity parameter. When the instrument stabilization was completed, the value was taken and recorded and then the calculation of the mean value was recorded.

3.4.1.4 Total Dissolved Solids (TDS)

The TDS for each sample at the four stations was calculated by multiplying the electrical conductivity (EC) of each station sampled by a factor of 0.7 as the conversion factor. Standard formula for TDS= 0.7 x EC.

3.4.1.5 Salinity

Salinity of the water sample from each of the three stations was determined similar to that of electrical conductivity. The measurements were done in-situ in the field by the use of the same instrument (Horiba). The instrument was rinsed properly several times with distilled water at each station before measurement was taken; this was to ensure accurate readings. The instrument was allowed to standardize for about 20 minutes before salinity values were taken, calculated and recorded.

3.4.1.6 Turbidity

Turbidity of the water in each of the sampled stations was carefully measured with the multi-meter (Horiba) in-situ in the field, after the instrument had been standardized with reagent and distilled water. It was then rinsed with the harbour water sample of the station at which the sample was collected. The probe was dipped directly into the water and allowed to stabilize at turbidity parameter before the value was taken and recorded.

3.4.1.7 Dissolved Oxygen (DO)

Surface water samples for the measurement of dissolved oxygen (DO) were collected and determined according to the modified Azide or Winkler's method (APHA, 1998). A well labeled clean 70ml DO bottle initially rinsed with a water sample from the station was dipped below the water surface and allowed to fill to overflow in order to completely remove trapped air bubbles. In the bottle filled with the sample, 0.5ml manganous sulphate (Winkler-I) solution and fixed with 0.5ml alkali-iodide azide reagent (Winkler-II) were added, stopper placed (excluding air bubbles) and mixed with several inversions. The sample was allowed to stand for few minutes and was packed in a cool box containing ice blocks for onward transportation to the laboratory for further analysis.

Winkler titration methods were used to carry out the determination of DO concentration as recommended by the standard methods for the examination of water and wastewater 20th edition APHA-AWWA-WPC, Washington DC (APHA, 1998).

To the DO sample in the laboratory previously treated with Winkler I and II was added 0.5ml concentration of H_2SO_4, stopper placed and mixed for complete dissolution of precipitate.

A 50ml portion of the sample was placed in an Erlenmeyer flask, 5 drops of freshly prepared starch solution were added and titrated with 0.025N Na_2SO_4 (Sodium thiosulphate) solution. The titration was continued to the first disappearance of the blue colour. DO in mg/l was calculated using:

$$\frac{V \times N \times 8000}{\text{ml of sample}}$$

Where V is volume of sample in ml and N is normality of sodium thiosulphate solution used in the titration.

A table summary of all the physicochemical results for the samples is found in Appendix A.

3.4.2 Methodology for Biological Characterization of Study Area

3.4.2.1 Phytoplankton

A plankton net (mesh aperture = 63 µm) was used for the quantitative (10 liters) filter-sampling of the phytoplankton. The phytoplanktons on the sides of the net were washed down into the collection bottle with the water from the outside. Samples were put in a 250 ml labeled container and preserved with 5% neutral formalin and kept in the dark. The samples were later filtered through a 0.45µm membrane filter paper (with a vacuum of less than 0.5 atm) and preserved with 70% ethanol in the laboratory. Volume was made up to 100 ml. The size of the sub-sample was 1/100.

3.4.2.2 Zooplankton

A simple conical filter-net (mesh aperture = 100 µm) was used for the quantitative (10 liters) filter - sampling of the plankton. The zooplankton on the sides of the net was also washed down into the collection bottle. Samples were put into a 250 ml labeled container and preserved with 5% ethanol and kept in the dark. In the laboratory the samples were concentrated immediately and preserved with 70% ethanol (5% glycerin also added) and volume made up to 100ml. The size of the sub-sample was 1/100 and the estimated volume sampled per station was 7 m^3.

The plankton (zooplankton and phytoplankton) population was enumerated using a counting chamber {Sedgwick – *Rafter (S-R) counting cell}* which limits the volume and area for the ready calculation of population densities (Verma & Agarwal, 2006; APHA, AWWA, & WPCF, 1976; Newell & Newell, 1977). The tally system was also adopted in this method. After counting, the number of cell per ml was then multiplied by a correction factor so as to adjust for dilution of the sample. The organisms were identified using standard bench references and reported as number of individuals per ml (APHA, AWWA, & WPCF, 1976). The individual organisms were identified with the aid of a Ziess binocular microscope at x40/100x, a standard bench reference (Newell & Newell, 1977; APHA, AWWA, & WPCF, 1976) and CD–ROM from the Intergovernmental Oceanographic Commission of U.N.E.S.C.O.

A table summary of the plankton taxonomic count results for all the samples can be found in Appendices B and C.

3.5 DATA ANALYSIS

The relative dominance (RDO) of species was calculated using Excel Descriptive Statistical Tools (see Appendices B & C). Densities of the abundant species were analyzed for each of the sampled stations as follows:

$$\text{Density} = \frac{\text{Total number of species}}{\text{Area of sampling unit}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

3.5.1 Statistical Analysis

All statistical analyses in this study were performed using GraphPad Instat® version 3.10 statistical software created July 10th 2009 (see Appendix E). Where necessary, group variances were tested to assure homogeneity (Bartlett's test) and the residual were examined for normality using the Kolmogorov-Smirnov test (Motulsky, 2007; Humphrey, 2008; see also Appendix E). Plankton density was heterogenous across factor levels. In an effort to normalize and equalize the variances and enhance the power of the parametric statistical tests, plankton densities were reciprocal (1/x) transformed and in other cases log (log x) transformed prior to statistical analysis of sampling stations relationship. In this case the skewness of the data was reduced, but did not always satisfactorily homogenize the variances.

The important factors of interest in this study are the sampling stations which are located in the General Cargo Terminal (NP1 and NP2) and the Oil Terminal (OK1 and OK2). The terminals could not be sampled across the predominant seasons in Nigeria, i.e. dry and rainy season. Samples were collected during only one season; dry season, due to time constraints.

Regression and correlation analysis and one-way Analysis Of Variance (ANOVA) with *Tukey's posttest* were performed using GraphPad Instat® version 3.10 for Windows, GraphPad Software, San Diego California, USA, www.graphpad.com. One-way ANOVA's were used to test for differences in plankton densities as a function of water temperature, pH, TDS, DO, electrical conductivity, turbidity and salinity between sampling stations. It was assumed that an effect of any test was significant using an a *priori* α level of 0.05. If ANOVA models proved to be significant, unplanned multiple comparisons (Tukey test) were used to distinguish group differences (Motulsky, 2007; Humphrey, 2008; Chiplonkar & Rao, 2007).

The next chapter shall consider a review and statistical analysis of the data obtained from the field study to see how the identified characteristics of the study area interact with each other to give an overall characteristic of the study area (harbour) and hence determine the appropriate treatment system.

CHAPTER FOUR
ANALYTICAL REVIEW OF FIELD DATA

Eight samples were collected from Port Harcourt Harbourr surface water, four each from the General Cargo Terminal and Okrika Oil Terminal. All water samples collected were filtered through 63µm plankton net for phytoplankton and 100µm plankton net for zooplankton.

4.1 PHYSICOCHEMICAL PROPERTIES OF STUDY AREA

A one sample t-test to determine the mean, the standard error of mean (SEM) and the 95% confidence interval (CI) of the physicochemical parameters of sampled stations was performed using GraphPad Instat 3 for Windows, GraphPad Software, San Diego California, USA, www.graphpad.com (see Appendix E). The following is the outcome of the one sample t-test:

4.1.1 Temperature (^{o}C)

On station by station, spatial water temperature had maximum value at NP2 (29.200±0.041^{o}C) while lowest was at OK2 (29.000±0.041^{o}C). Confidence interval ranges between 28.970±0.041 ^{o}C and 29.230±0.041 ^{o}C.

4.1.2 pH level

The pH of sampled water was slightly alkaline between 7.510 and 7.730 across the stations (Appendix A). The highest value (7.730) was recorded at NP2, while the lowest pH value (7.510) was in NP1. The mean pH value was 7.6275 and the 95% confidence interval recorded ranged between 7.771±0.045 and 7.484 ±0.045.

4.1.3 Electrical Conductivity (µscm^{-1})

Values observed ranged between 33600 µscm^{-1} and 34900 µscm^{-1}in NP1 and OK2 respectively. The conductivity values confidence interval recorded varied from

33169±324.04 µscm^{-1} to 35231±324.04 µscm^{-1} across the stations thus, characterizing the water as brackish (Appendix A).

4.1.4 Turbidity (Natural Turbidity Units (NTU))

The range of turbidity was between 1.00 and 3.00 NTU (Appendix A) with confidence interval varying between 0.1629±0.5774 to 3.837±0.5774 NTU across the stations (Appendix A).

4.1.5 Salinity (PSU)

It was observed that the highest salinity value was obtained at OK2 (22.100±0.2213psu) and the lowest at NP1 (21.200±0.2213psu). The confidence interval was between 20.921±0.221 and 22.329±0.221psu.

4.1.6 Dissolved Oxygen (mg/l)

The results of dissolved oxygen values are shown in Appendix A. The values ranged between 6.600mg/l and 7.700mg/l. The lowest values were recorded at NP2 while the highest values were observed at both OK1 and OK2. The Confidence Interval of the dissolved oxygen was between 6.208±0.3038mg/l and 8.142±0.3038mg/l across the stations (Appendix A).

4.1.7 Total Dissolved Solids (mg/l)

The result of TDS has 23520mg/l at NP1 as the lowest and 24430 mg/l at OK2 as the highest. The mean was 23940mg/l: the lower 95% confidence limit was at 23218±226.83 and the upper 95% confidence limit was at 24662±226.83 across the stations.

As determinants of the quality and suitability for utility, productivity and distribution of aquatic organisms, the physical and chemical characteristics of the Port Harcourt Harbour water as established by the results above and from the literature studied in Chapter two have characterized the harbour water as brackish (with range of salinity=21.20-22.10psu, conductivity=33600-34900µscm^{-1} and TDS=23520-24430mg/l); slightly alkaline (with range of pH=7.51-7.73); and rich in nutrients or rich in planktons (with range of temperature=29.00-29.20^{o}C),

4.2 BIOLOGICAL CHARACTERISTICS OF STUDY AREA WATER SAMPLES

4.2.1 Composition, Distribution and Relative Dominance of Plankton

A total of 29 species were identified, 15 were zooplanktons and 14 were phytoplankton. Quantitative analysis of all water samples revealed that the subclass calanoid copepod numerically dominated the zooplankton community (see Figure 4.1 and Appendix C).

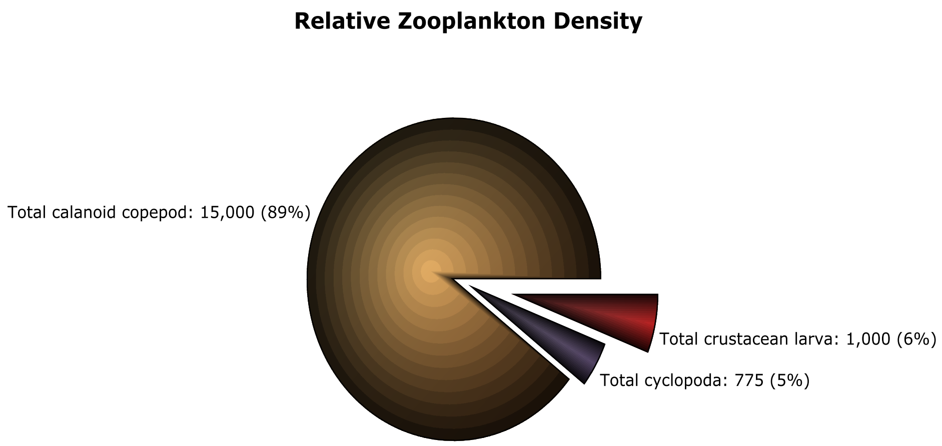

Figure 4.1 Relative Zooplankton Density in Sample.

The subclass calanoid copepod represented 89.4% of the entire zooplankton communities sampled; cyclopoda copepod 4.6% and total crustacean larva were relatively numerically rare with 6% of observed taxa. *Paracalanus pygmaeus* and *Calanus finmarchicus* with numerical abundance of 34.3% and 20.1% respectively and both belonging to the subclass calanoid copepode are the two most abundant zooplankton species sampled from all the stations in terms of numerical abundance, relative dominance and density (see Appendix C).

Based on relative abundance, relative dominance and density, the subclass centricae, predominates in the phytoplankton community with 34.0%, with *Cosinodiscus lineatus* as the most numerically abundant species in the subclass (see Appendix B and Figure 4.2). The subclass pennatae makes up 32.3%, desmidiaceae 18.1% and harmful dinoflagellates make up the remaining 15.6% of the total phytoplankton sampled in the four stations (Figure 4.2).

On a species bases, the harmful dinoflagellates cyst, *Alexandrium minutum* responsible for red tides which cause paralytic shell fish poisoning (PSP) is the most numerically abundant phytoplankton species sampled (see Appendix B).

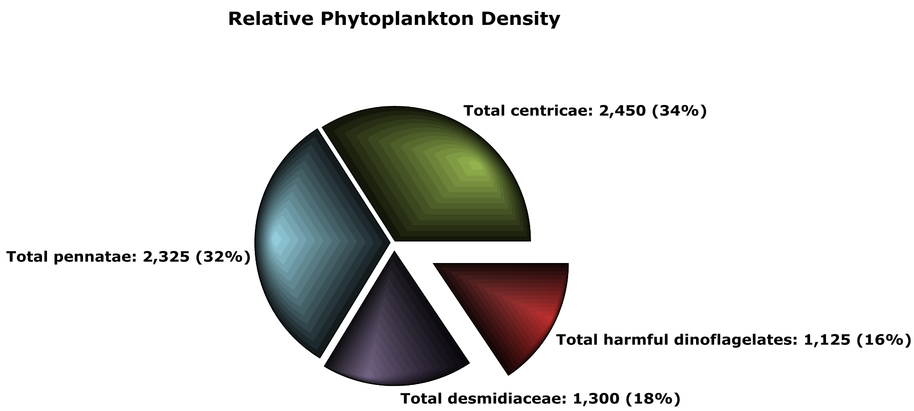

Figure 4.2 Relative Phytoplankton Density in Sample.

4.2.2 Biological Differences

Differences in relative plankton abundance existed between sampling stations. One-way ANOVA's were used to test for the differences in plankton densities between the sampling stations OK1, OK2, NP1 and NP2. Since ANOVA assumes that samples are drawn from populations that are Gaussian and with equal SDs, to achieve a Gaussian distribution species density data were, therefore, in some cases either reciprocal transformed (1/x) or log transformed (log x), where x is number of organisms/ml. On an *a priori* α level of 0.05, any test is assumed to be significant.

4.2.2.1 Difference in Phytoplankton Abundance between Stations.

A very significant difference exists between the phytoplankton densities of the stations sampled (Figure 4.3; ANOVA, F_{calc}=6.650; df= 3,52; p=0.0007; see also Appendix E). ANOVA always assumes that the data are sampled from populations with identical standard deviation (SD). This assumption was tested using the method of Bartlett. Bartlett's test suggests that the differences among the SDs is very significant (Bartlett’s test p=0.0110).

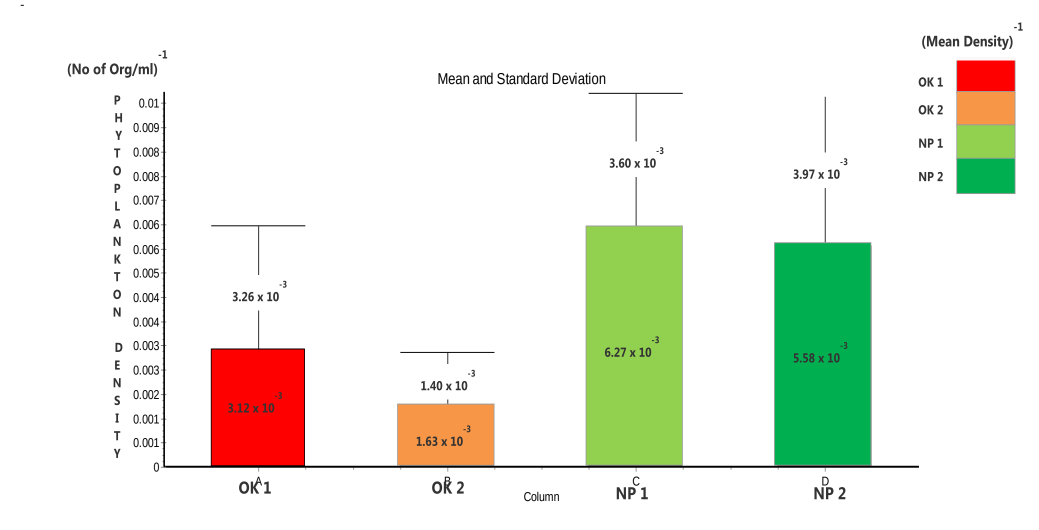

Figure 4.3: Summary of Mean and SD of Phytoplankton Density in General Cargo Terminal (NP 1 & NP 2) and Oil Terminal (OK 1 & OK 2) of Port Harcourt Harbour.

Using Tukey-Kramer Multiple Comparisons Test, significantly higher phytoplankton densities ($p<0.01$) were observed in the sample from OK2 (downstream) than in samples from both NP1 and NP2 (upstream of OK2) (see Figure 4.3 and Appendix E). This phenomenon could be as a consequence of nutrient enrichment of the water or acquired mineral constituents in dissolved form as dissolved salts in solution from high surface runoff, flooding, municipal and industrial effluents and agricultural activities downstream between OK1 and OK2. A lot of the domestic and industrial effluents around that precinct are discharged into the main stream of the estuary somewhere between OK1 and OK2. This conclusion is also supported by the positive correlation of phytoplankton density with salinity, conductivity and TDS which will be discussed next.

The relationship between phytoplankton density (no of org/ml) and salinity (psu) is very significant. A strong positive correlation exists between density and salinity (Figure 4.4; regression analysis, r^2= 0.9034, df=3, p= 0.0495). Conductivity and total dissolved solids (TDS) both also have a positive correlation with organism density (log (mg/l)) (linear regression, r^2= 0.9196, p= 0.0411). This means that salinity, conductivity and TDS are all individual determinants of phytoplankton density in the sampling stations ($p<0.05$) with organism density increasing with an increase in the value of each parameter. It therefore means that as we move seaward away from the harbour, phytoplankton density should be expected to increase, since from the data and logically as expected, salinity, conductivity and TDS should increase seaward, which also agrees with the Tukey-Kramer's test result (see Appendix E).

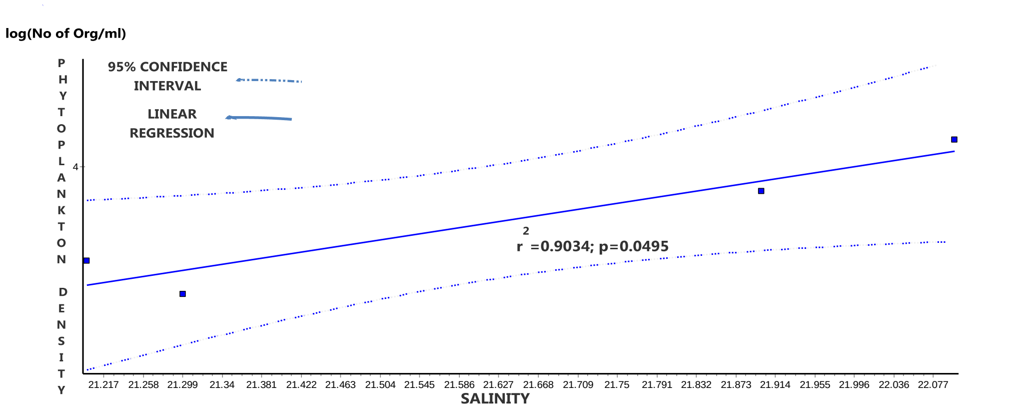

Figure 4.4: Total Phytoplankton Density log(mg/l) as a function of Salinity.

Linear regression analysis shows that the relationship between the density of phytoplankton and DO is not quite significant (p=0.0555). The other measured physicochemical parameters; temperature, pH, and turbidity do not show any significant relationship with phytoplankton density ($p>0.05$).

4.2.2.2 Difference in Zooplankton Abundance between Stations.

There were no significant differences between densities of zooplankton in the samples from all the stations (Figure 4.5; ANOVA, F_{calc}= 0.4094, df=3,56, $p>0.05$; see also Appendix E).

No statistically significant relationship was established also between zooplankton densities and all the measured physicochemical parameters (temperature, dissolved oxygen, TDS, conductivity, pH and turbidity) when they were subjected to the correlation test (Figure 4.6; $p>0.05$).

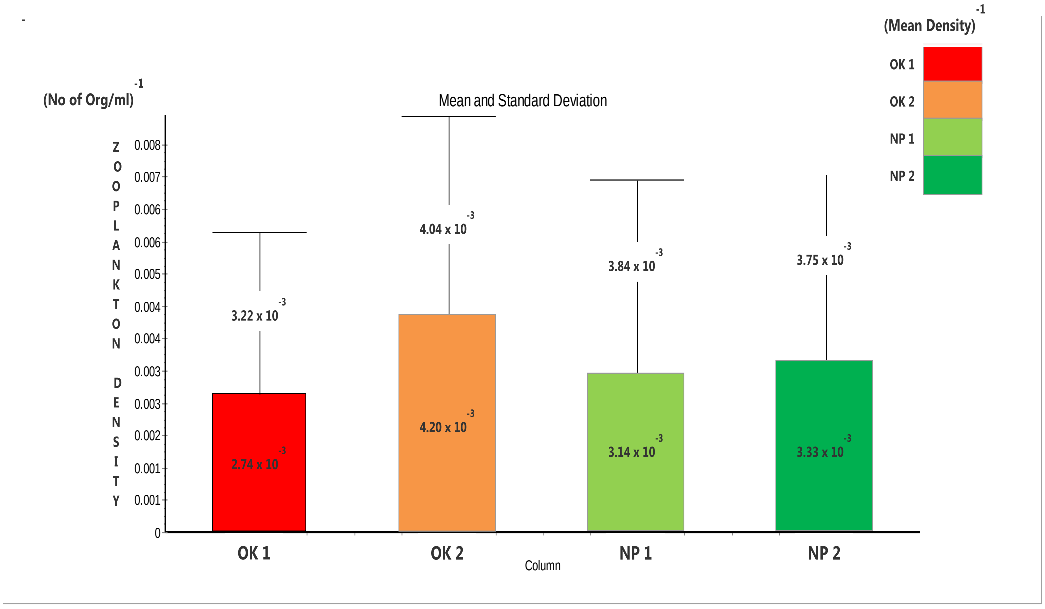

Figure 4.5: Summary of Mean and SD of Zooplankton Density in General Cargo Terminal (NP 1 & NP 2) and Oil Terminal (OK 1 & OK 2) of Port Harcourt Harbour.

It therefore means that none of these physicochemical parameters is a factor in determining zooplankton density in the sampling stations.

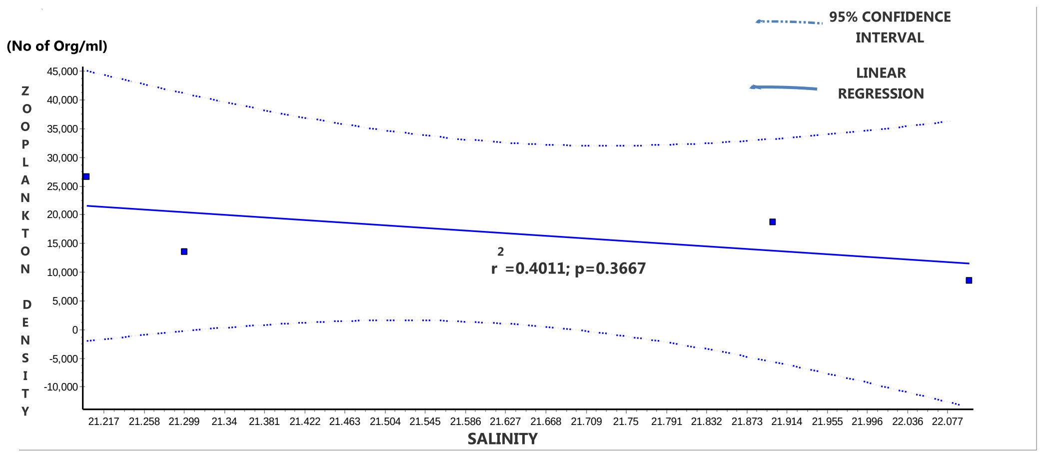

Figure 4.6: Total Zooplankton Density (mg/l) as a function of Salinity.

The study of the physical and chemical characteristics of the sampling stations and how they influence the biological characteristics (plankton densities) of the stations was the main objective of this chapter. From the physicochemical results, the study area water is characterized based on observed salinity and electrical conductivity (EC) as brackish (see 2.1.3 & 2.1.4), slightly alkaline based on the observed pH (see 2.1.2) and based on the temperature (see 2.1.1) as supporting an abundance of aquatic organisms, which is predominated by the zooplankton taxa; calanoid copepod and phytoplankton taxa; centricae, pennatae, desmidiaceae and harmful dinoflagellates.

The study of these characteristics is not necessary unless the knowledge acquired can aid in achieving the main objective of this study, which is to propose a unique treatment system that best suits the established characteristics of the study area, which is Port Harcourt Harbour in Nigeria and any port with similar environmental characteristics.

The next chapter shall discuss the different ballast water treatment options, the advantages of the proposed system over the traditional systems, how to manage the risk of HAOP introduction from the host harbour and the responsibilities of States to put in place a management procedure to minimise the potential risk of HAOP introduction from their ports and how the knowledge of the physical, chemical and biological characteristics of the study area is a necessary tool in determining the uniqueness or specificity of the treatment system for the harbour.

CHAPTER FIVE
DISCUSSION

5.1 ONSHORE VERSUS SHIPBOARD TREATMENT SYSTEMS

The goal of every ballast water management programme is to control the spread of HAOP from one region of the world to another. BWE (Regulation D-1) as a management method has been unable to satisfactorily minimise species introduction and transfer. Various treatment methods were therefore, introduced as alternatives (Lafontaine, Despatie & Wiley, 2008; NRC, 1996). The performance standard (Regulation D-2) as a management procedure for ballast water management has a primary target of reduction of taxa densities in transported ballast. Total annihilation of HAOP is not economically feasible, but according to NRC (1996) implementing a system of ballast water management and controls reduces the probability of HAOP introduction. Four treatment methods that have the potential of satisfying IMO's criteria for *safety, environmental acceptability, technical feasibility, practicability,* and *cost effectiveness* while achieving the set goal of organism density reduction were identified by NRC (1996). These treatment methods are: *filtration, biocides, heat* and *electrical pulse/pulse plasma system*. Out of these four methods, the first three are the most feasible and practicable for Port Harcourt Harbour considering the harbour's physical, chemical and biological characteristics identified by this study as well as the financial and technical constraints of such a project in a developing economy as Nigeria.

Treatment of ballast water can be carried out either onboard a ship or onshore in a port. Figure 5.1 shows three types of ballast water treatment options; *pre-loading, shipboard* and *post-loading treatment systems*. *Shipboard* and *post-loading* are already in use around the world by ships and some harbours respectively. *Shipboard* *treatment* is a ballast water treatment system (BWTS) where the treatment equipment and procedure are wholly or partially situated onboard the ship.

The requirements of Regulation D-1 (ballast water exchange) and D-2 (performance standards) in the BWM convention were meant to be strictly addressed onboard ships. The entire convention according to Donner (2010a) has placed all operational obligations for ballast water management on the ship rather than the ports, a situation he referred to as “the solution of least resistance”.

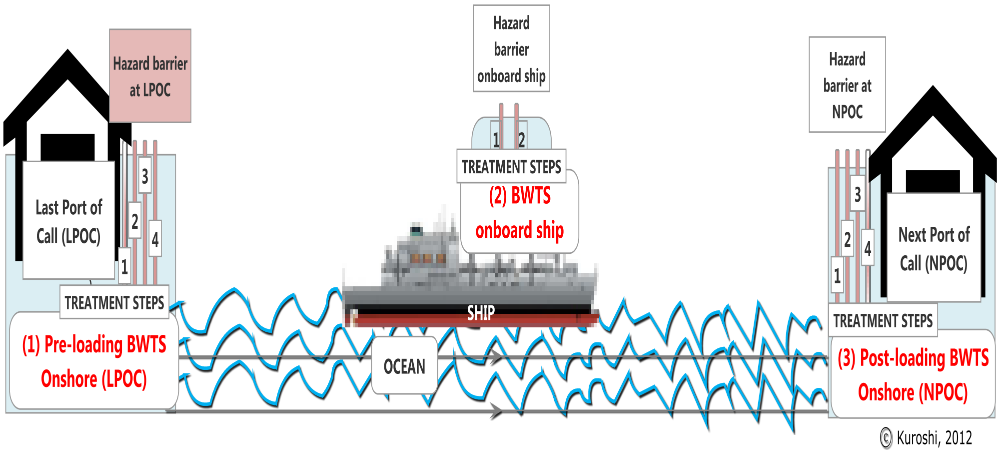

Figure 5.1: Ballast Water Treatment Options: Onshore (proposed and existing) and Shipboard Treatment Systems.

There is no mention anywhere in the convention of onshore treatment except onshore reception facilities for sediments in Article 5. In fairness to the convention however, there are provisions in Regulation B-3.7 and Article 4.2 for alternative ballast water management methods and permission for parties to develop programmes for Ballast Water Management in their ports and waters that promote the attainment of the objectives of the convention. This is an obvious authorization by the IMO for researchers to think outside the box, to explore and design management methods not necessarily confined to shipboard. To encourage this, an exemption from regulation D-2 for five years was given in regulation D-4 for ships participating in programmes to develop prototype ballast water technologies.

Onshore treatment is a BWTS where the treatment equipment and procedures are wholly or partially situated onshore in the harbour. The system is considered by this study to have the capacity to satisfactorily meet IMO's requirements in Regulation D-2 as well as the criteria for safety, environmental acceptability, technical feasibility, practicability, and cost effectiveness, and there are a number of reasons to support this assertion. Personnel in the treatment facility, for example, are employed by the port authority and not shipping companies, reducing financial pressures on shipping companies. The treatment system is under the control of the port authority, which allows for better control of both the treatment system and the training of the operators. The relative spatial advantage a harbour has over a ship allows for the application of more comprehensive treatment steps in a harbour than on a ship. Figure 5.1 shows two of the onshore treatment options (*pre-loading* and *post-loading*) both having more treatment steps or hazard barriers than the shipboard treatment model. Also there is the advantage of greater storage availability for water and chemicals in a harbour than onboard a ship.

The requirement for safety of the crew is also guaranteed by the onshore treatment system as no ship crew is involved in the operation of the system because it is operated onshore by trained port authority operators or approved contractors. Donner (2010a) mentioned improved operational expertise as one of the advantages of *shore treatment* over *shipboard treatment*. The number of operators will be adequate and will receive training to be proficient in operating the treatment facility as their core job function unlike in the case of a ship where that function is just one of the many functions handled by a few crew members. According to Donner (2010a), the crew will lack expertise in the optimal use of the facility if it is onboard a ship. Regulation B-6 of the convention requires officers and crew on duty to be familiar with the ship's BWM plan, but that will not be likely especially in an industry like shipping where there is a multicultural mix on board most ships and some crew members might not be able to understand clearly the safety procedures associated with, for example, the use of hazardous materials, if they are written in another language. Also, mobility of labour is a tradition in the shipping industry. Ship's crews are always on a constant move to different ships or companies, and different ships have different treatment equipment from perhaps different suppliers and therefore different management plans. This however, is not the case for *onshore treatment*, where there exists one treatment facility, one management plan, operated by the same personnel (well trained) and serving many ships visiting the harbour affording the facility the advantages of economies of scale, a fact also noted by Donner (2010a).

The system will bring about a reduction in the quantum of paper work onboard ships which has definitely resulted in additional workload on the ship's crew; a factor identified by researchers on the MARTOB project as contributory to fatigue and unsafe conditions onboard ships (MARTOB, 2004). Most of the ballast water management related paper work will now be the responsibility of port authorities and not ships. Monitoring and verification of treatment results in onshore facility according to Donner (2010b) could be a mere routine procedure, which is not the case for shipboard where a more detailed and conscientious monitoring is required. This is so because of the dubious "magic pipes" installed to by-pass the oily-water separator of some ships discovered by some port state control inspectors monitoring MARPOL regulation compliance of ships.

Donner (2010a) mentioned the financial commitment required to install the system as one of the reasons states are often not interested in investing on the system. Looking at the big picture, the system is quite affordable considering the fact that almost every community in the world where a port is situated has a municipal water treatment plant installed and operated by that community. Such communities should be encouraged to install and operate BWTS's for their harbours as well. Alternatively, they could designate the responsibility to private entities and recover their investments over time. The knowledge gained in municipal water treatment, which is a very efficient water treatment technology, can be transferred into the onshore ballast water treatment system.

Primary treatment (filtration) which should be a mandatory aspect of this system, can filter back into the host environment organisms that could not go through the filtration process, allowing them to be retained in their original environment, making the system a more environmentally friendly system.

The facility can be self-sustaining, as the cost for maintenance could be paid by ships or shipping companies in the form of environmental levies for such services rendered by the ports. This levy should cover part of the cost for the installation and running of the facility, this view is also corroborated by Donner (2010a).

Treatment methods requiring heat or biocides often require extended time frames for optimal effectiveness. Onshore treatment has that time advantage over shipboard treatment. Onshore treatment also provides the opportunity to easily plug any available hole in the defense barriers or treatment steps in the system. This could come in the form of an additional treatment stage or just an improvement in some aspects of the treatment system (see Figure 5.1). This will lead to improvements in the performance of the system, thus ensuring an effective BWTS.

Also, when for example, the IMO or a regional maritime organization sees a need to introduce new regulations as a result of say a discovery of a new and better method of treatment that will enhance the entire global ballast water treatment practice, which will require retrofitting the existing treatment systems around the world or in a region, it will comparatively be easier, less time consuming and cheaper to retrofit an onshore treatment facility that can serve several ships in a harbour than retrofitting each of the nearly 100, 000 global ship fleet. This view was also discussed extensively and analyzed by Donner (2010b).

From the points stated so far, it is obvious that onshore ballast water management practice has, potentially, the capacity for feasibility as well as the potential to ensure that greater harm than it prevents does not result from its deployment in any harbour, thus satisfying the requirement of Article 2.7 of the BWM convention (see Appendix F for full text of Article).

5.2 PROPOSED TREATMENT SYSTEM

The conventional onshore treatment style discussed above is a post-loading treatment system or a Next Port of Call (NPOC) solution. In this system, ballast water treatment is carried out at the end of a ship's voyage. The ship arrives at berth in-ballast to load cargo and discharges its ballast water content (deballast) into a port reception facility where it is treated before it is discharged into the surrounding port environment.

This study, however, is proposing a different kind of onshore treatment system known as a *harbour specific pre-loading treatment system,* which is a Last Port of Call (LPOC) solution (Figure 5.1a). It is a preventative treatment option and it allows for the treatment of the harbour water of the port before it is uploaded as ballast water into a ship. Guiding principle 2 of UNEP (1999) recognizes prevention as far more cost effective and environmentally desirable than measures taken after introduction of HAOP. Why a harbour specific treatment is needed is because the conditions of the host port (referred to in this study as last port of call or LPOC) is relatively stable and the biological, chemical and physical characteristics of the port are well known to the port authority. The system, therefore, is aimed at removing planktons that are characteristically native or resident in that port aquatic environment before the water is loaded as ballast into the ballast water tank of the ship. This system is quite novel, and certainly has some advantages over the post-loading system.

The concern expressed by Pereira, Botter, Brinati and Trevis (2010), for example about onshore treatment increasing ships turnaround time and congestion in ports as a consequence of ballast water collection and storage processes, should be resolved in the harbour specific pre-loading treatment style. Resident time constraints (i.e. maximum time available to treat ballast water) imposed by voyage time will be greatly cut down by this method, because by the time the ship arrives at the next port of call (NPOC), there will be treated port water ready for loading as ballast water. The possible insufficient capacity in many harbours to receive, store and treat ballast water, which was noted as a potential disadvantage of the onshore treatment facility by Donner (2010b) should not be an issue with the pre-loading onshore treatment system, especially in a case where the ship's ballast water has already been treated from the last port of call (LPOC). Ships involved in pre-loading treatment do not need to queue in port in order to discharge their ballast water tank contents into the port's reception facility; they can simply discharge it into the harbour environment since their ballast water has already been treated from the last port of call (Figure 5.1a).

The system will further shorten the turnaround time of ships because most port state control functions regarding ballast water management onboard ships might no longer be necessary. The discharge of ballast water into surrounding water by ships either as a result of an accident or for safety reasons will no longer present any danger to the environment as the discharged water has already being treated. Also, the treated ballast water can be used as a source of potable water for communities that have problems with water. This of course will depend on the electrical conductivity of the water (<1000µscm^{-1} means fresh water) and also on the level of treatment the water is subjected to.

Port Harcourt Harbour shows a predominance of copepods in the zooplankton class (see Figure 4.1 and Appendix C) and *Alexandrium minutum* as the most predominant phytoplankton species (see Figure 4.2 and Appendix B). A unique combination of three out of the four treatment methods identified by NRC (1996) as treatment procedure for Port Harcourt Harbour can effectively remove these organisms from the harbour. These methods are *filtration*, *temperature* and *biocides* in that order (Figure 5.2).

The literature reviewed on ballast water treatment in chapter two showed the following outcomes: Filtration using sand/anthracite as a filter was successful in removing 89.4% and 94.5% of particles larger than 10µm and 15µm, respectively. Using crumb rubber as a filter has 86.8% and 93.6% success for the same particle sizes. Using biocides such as chlorine dioxide reduces hatching rate of cysts by 97% after 40 hours. Ozone gas gave over 99% and 96% inactivation for dinoflagellates and zooplanktons respectively after 5 to 10 hours. 96.10% and 98.10% mortality were measured for copepods and copepod nauplii respectively when treated with 17mg/l of ozone. 1% ozone was also recorded to destroy phytoplankton cysts. Heating to temperature of 38 °C for several days was discovered to kill all zooplankton and a major portion of the phytoplankton. Filtration with 50µm material as well as heating to temperature above 35^{o}C could remove larger organisms (i.e.

zooplanktons). 96.10% of copepods and 99% of harmful dinoflagellates similar to the ones found in Port Harcourt Harbour were destroyed by ozone.

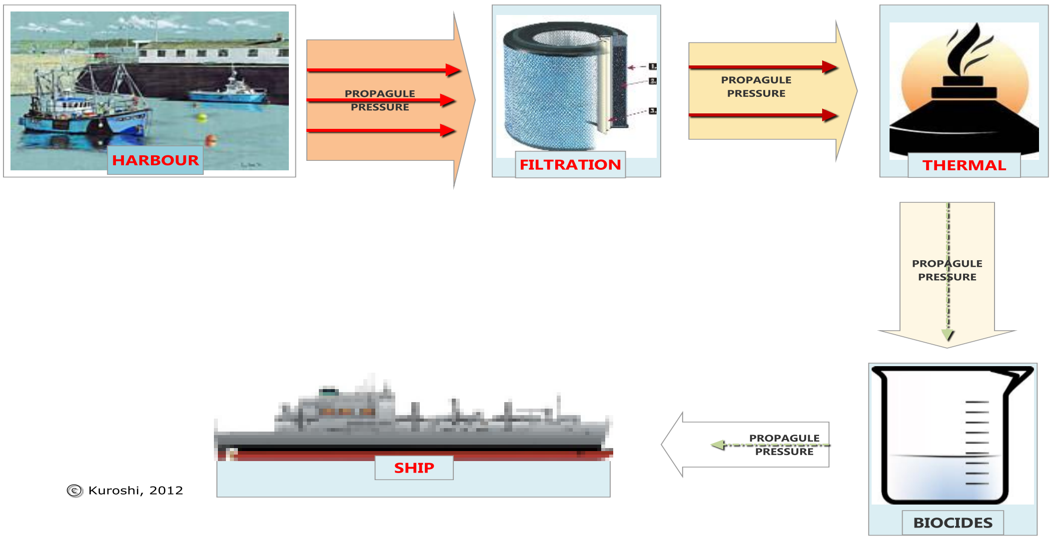

Figure 5.2: Proposed Onshore Ballast Water Treatment System Stages for Port Harcourt Harbour, Nigeria.

On the basis of this evidence, the most feasible, economical (i.e. affordable) and effective BWTS for Port Harcourt Harbour therefore, should follow the order; *filtration, temperature* and then *biocides* as shown in Figure 5.2. The Figure shows propagule pressure (discussed in chapter one) reducing with every treatment procedure in the proposed ballast water treatment system for Port Harcourt Harbour. At the end of the treatment cycle, the water loaded as ballast unto a visiting ship in the harbour will have a relatively reduced propagule pressure, which should be sufficiently killed by the harsh conditions within a typical ballast water tank (Figure 5.2). The ship's ballast water tank can be said to be a treatment system in its own right, since studies have reported high levels of organism mortality inside the ballast water tank. Humphrey (2008) reported significant reduction in plankton densities within the ballast tank with longer voyages. Gollasch, Lenz, Dammer, and Andres (2000) reported about 90% reduction within the first 4 days of a voyage. Wonham, Walton, Ruiz, Frese, and Galil (2001) on the other hand reported a 99% reduction in a ballast water tank after sixteen days. It is expected, therefore, that the residual propagule pressure in the ballast water tank after the onshore (harbour) treatment should be reduced to insignificance; a level where a release will not result in eventual invasion. This is because the release of HAOP according to NRC (1996) constitutes their inoculation and not necessarily their introduction.

5.3 HARBOUR RISK MANAGEMENT

Risk in a harbour as defined in chapter one has to do with the likelihood and magnitude of an HAOP invasion. Risk management according to Orr (2003) is the pragmatic decision-making process concerned with what to do about the risk (of an HAOP invasion).

Based on the literature on ship mediated HAOP invasions, this study presumes there is a risk in every ballast water translocation and discharge, until proven otherwise. The precautionary approach set out in Principle 15 of the Rio Declaration and Principle 1 in the *UNEP guiding principles for the prevention, introduction and mitigation of impacts of HAOP* supports this presumption of risk. The precautionary approach requires that preventative action be taken to prevent HAOP introduction even when there is scientific uncertainty about the environmental risk posed by the HAOP (United Nations, 1992b; UNEP, 1999). It is on the basis of this burden of proof that the harbour specific onshore pre-loading BWTS is proposed by this study to manage the potential risks of invasions by HAOP from the host or source port.

Orr (2003) mentioned *entrainment potential*, *entry potential*, *colonization potential* and *spread potential* as the probability elements in HAOP establishment. To effectively manage the risk of HAOP translocation from Port Harcourt Harbour (host harbour) therefore, the first two elements should be checked by the proposed onshore BWTS. The elements are thus;

1) *Entrainment potential* –this refers to the likelihood of any of the organisms found in Port Harcourt Harbour slipping through the protective treatment barriers into the ballast tank and
2) *Entry potential*- is the likelihood of entrained organisms surviving the voyage.

The probability of entrainment of HAOP from the harbour into the ballast tank of a visiting ship should be the most essential element the harbour's Ballast Water Treatment System (BWTS) should curtail. The BWTS curtails this by introducing barriers to the risk in the form of treatment methods (Figure 5.3). The second element which is entry potential or the probability of entrained organisms surviving the voyage will be determined by how effective the pre-loading onshore BWTS is. Addressing the last two elements (*colonization* and *spread potential*) may not be necessary as long as the first two elements have been curtailed by the BWTS at the Last Port of Call (LPOC) or source port, which in the case of this study is Port Harcourt Harbour.

The *entrainment potential* of HAOP will be greatly undermined by the three treatment stages proposed by this study. Since invasibility is a game of numbers and frequency, as explained earlier by the propagule pressure concept, the treatment barrier arrangements (filtration, temperature and biocides) in Figure 5.3 will reduce the possible number and density of organisms that can be uploaded into the ballast tank, thereby greatly undermining the potential of HAOP entrainment.

Figure 5.3 shows the probability of HAOP establishment and the propagule pressure of potential HAOP invasion reducing with every treatment stage. The probability of taxon invasion depends on propagule pressure (Rejmanek, Richardson, Higgins, Pitcairn & Grokopp, 2005).

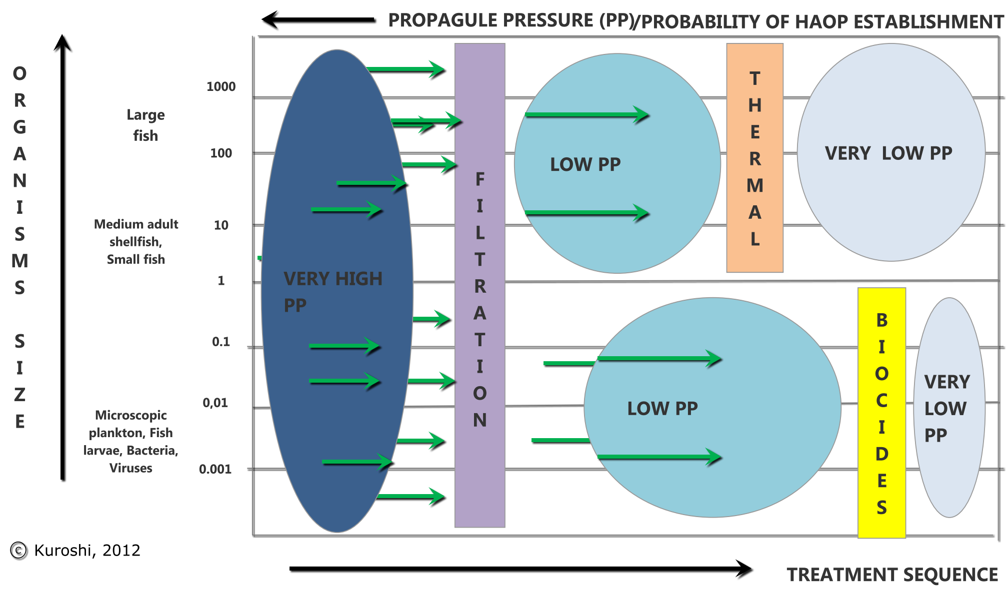

Figure 5.3: Relationship between proposed treatment sequence for the Study Area and Propagule Pressure /Probability of HAOP Invasion.

Each treatment stage is targeted at different classes of organisms as illustrated in Figure 5.3. For example filtration is effective in removing all sizes of organism especially larger organisms of size 10µm and above. The use of temperature is also effective in removing larger organisms but not the smaller ones. The application of chemicals (biocides) is effective in removing the smaller organisms that have escaped the first two layers of treatment. By the end of the treatment procedure (in Figure 5.3), the propagule pressure which is a major determinant of invasion risk and the probability of establishment of the organisms would have been minimised to the extent that the likelihood of the organisms that have survived the treatment process and are eventually uploaded into the ballast tank surviving the voyage is crippled.

Research mentioned earlier in this chapter has shown 90% and 99% mortality for organisms in ballast tanks on voyages of 4 and 16 days respectively. Following the logic of the 'tens' rule, it therefore means that only 1/1000th of those that survive the treatment and voyage will eventually get to the stage of becoming invasive or pestiferous in a new environment, thus making the likelihood of invasion negligible.

5.4 STATE RESPONSIBILITY

Guiding principle four of the *UNEP guiding principles for the prevention, introduction and mitigation of impacts of HAOP*, require States to "recognize the risk that they may pose to other States as a *potential source* of alien invasive species (Harmful Aquatic Organisms and Pathogens), and should take appropriate actions to minimize that risk" (UNEP, 1999). This notion is also corroborated by both Article 3 of the Convention on Biological Diversity (United Nations, 1992a) and principle 2 of the 1992 Rio Declaration on Environment and Development (United Nations, 1992b).

Figure 5.4 shows the transportation pathway and destination for HAOP entrained in the ballast water tank of a hypothetical ship which has not undergone port specific pre-loading ballast water treatment. The ship was involved in a trade between Port Harcourt Harbour in Nigeria, located in the South Atlantic and Port of Halifax in Canada and the Ports of Miami and Oswego both in the United States. These ports are located in the North Atlantic, one of Port Harcourt Harbour's leading trading regions in the world. This scenario is from the hypothetical trade route mentioned and illustrated in Figure 1.5 earlier in Chapter one of this study.

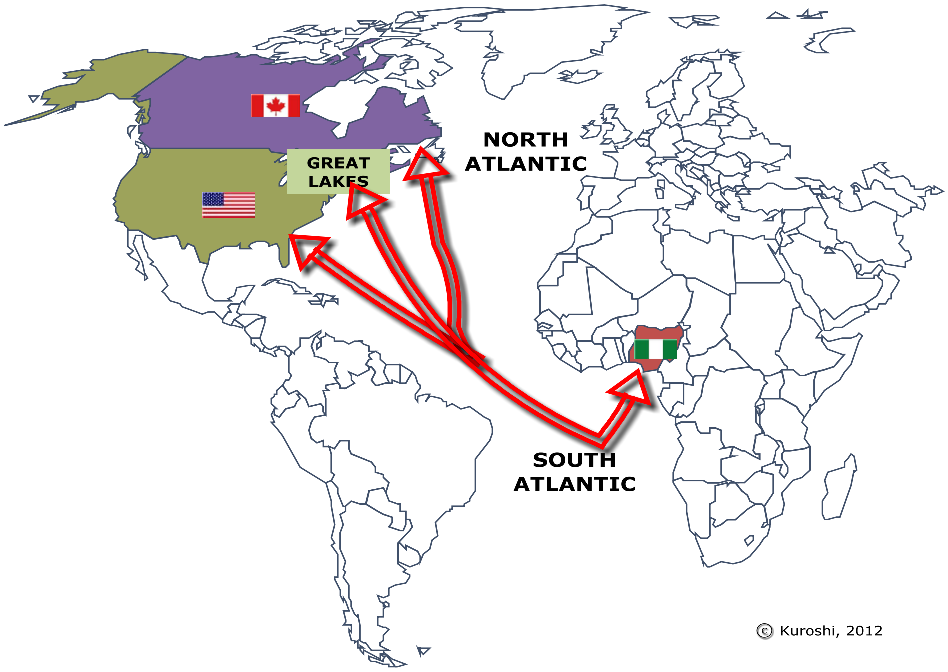

Figure 5.4: Hypothetical Shipping Trade Route between a port in Nigeria and some ports in North America.

From the results of the surface water samples collected in this study (see Figure 4.1 and 4.2; see also Appendices B and C), 29 planktonic species were identified, 5 were nonindigenous to the Great Lakes, and 2 each were nonindigenous to Atlantic and Pacific North America as shown in Table 1. Port Harcourt Harbour serving as a donor port in this hypothetical case could be a potential source of HAOP to the mentioned ports in North America with the harmful dinoflagellates, *Alexandrium minutum* as the most predominant phytoplankton species sampled in the harbour and also the following zooplankton species of copepod; *Acartia clausi*, *Pseudocalanus elongatus*, *Tortanus sp.* and *Oncaea sp.* (a cyclopoida) which are non-indigenous to the North American aquatic clime (Table 1). The contamination could hypothetically be via any ship that has not undergone a ballast water management procedure such as the pre-loading treatment. Many studies have already shown that BWE is not sufficiently effective in stopping the HAOP menace.

Table 1: Planktons Identified as Non-indigenous to North America Sampled in Port Harcourt Harbour.

		ATLANTIC N/AMERICA	GREAT LAKES	PACIFIC N/AMERICA
ZOOPLANKTON	*Acartia clausi*		Non-indigenous	Non-indigenous
	Pseudocalanus elongatus	Non-indigenous	Non-indigenous	
	Tortanus sp.		Non-indigenous	
	Oncaea sp.		Non-indigenous	
PHYTOPLANKTON	*Alexandrium minutum*	Non-indigenous	Non-indigenous	Non-indigenous

Nigeria as a State party according to guiding principle four of UNEP (1999) is required to take 'appropriate actions to minimise that risk' of contamination. The proposed management procedure for Port Harcourt Harbour could serve as that 'appropriate action' to lower the risk of HAOP invasion from Port Harcourt Harbour as illustrated in Figure 5.5.

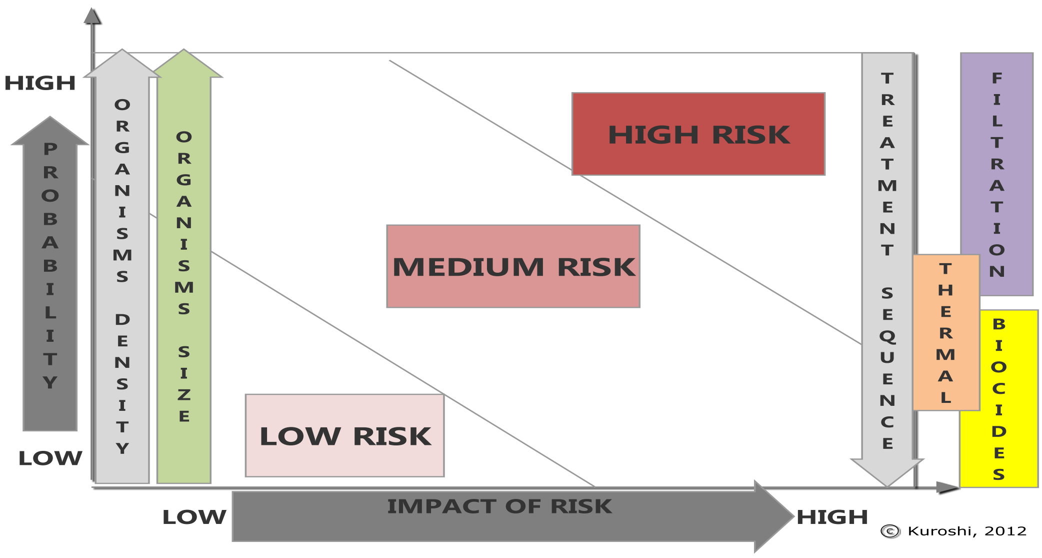

Figure 5.5: Risk Impact/Probability Chart for Proposed BWTS.

The proposed treatment arrangement (filtration, temperature and biocides) as illustrated in Figure 5.5 is shown to lower the risk of invasion further from high to low risk by reducing the organism's density and their probability of entrainment. Conversely, Port Harcourt Harbour when serving as a receiver port could also be contaminated by ships visiting from any of the ports in North America if they also do not have a harbour specific onshore pre-loading treatment system or an 'appropriate action' or a viable ballast water management process that is substantially equivalent to an " appropriate action".

5.5 MANAGEMENT DECISION FLOW CHARTS

The decision as to the type of treatment system a port should have should ultimately be the responsibility of the port authority. Risk analysis according to NRC (1996) can be used as a strategic decision aid to help decision makers in the port authority in choosing the appropriate treatment system for their port. Proper risk assessment of a harbour cannot be carried out without a good and up to date scientific baseline dataset of the harbour.

Guiding principle five of UNEP (1999) on *Research and Monitoring*, require States to undertake research and monitoring of HAOP in order to address the problem. Scientific baselines according to Andow (2005) are criteria used to set a presumption of risk for alien introductions or harbour to harbour contamination (in the case of this study). The basic scientific baseline information about the port should be on the physical, chemical and biological characteristics of the port. For example, a slight change in the study area which, as stated earlier, is located along the Bonny estuary in Nigeria (Figure 3.2) was observed. On account of the physicochemical parameter data obtained from this study (see Chapter four) and those reviewed from previous research on the Bonny estuary in chapter two, there is an observed shift in some physicochemical characteristics of the estuary. The average temperature, conductivity and pH recorded during this study were observed to be higher than those recorded along the estuary by researchers in 1998, 2003 and 2006. This underscores the importance of continuous environmental monitoring of the harbour to update the baseline information.

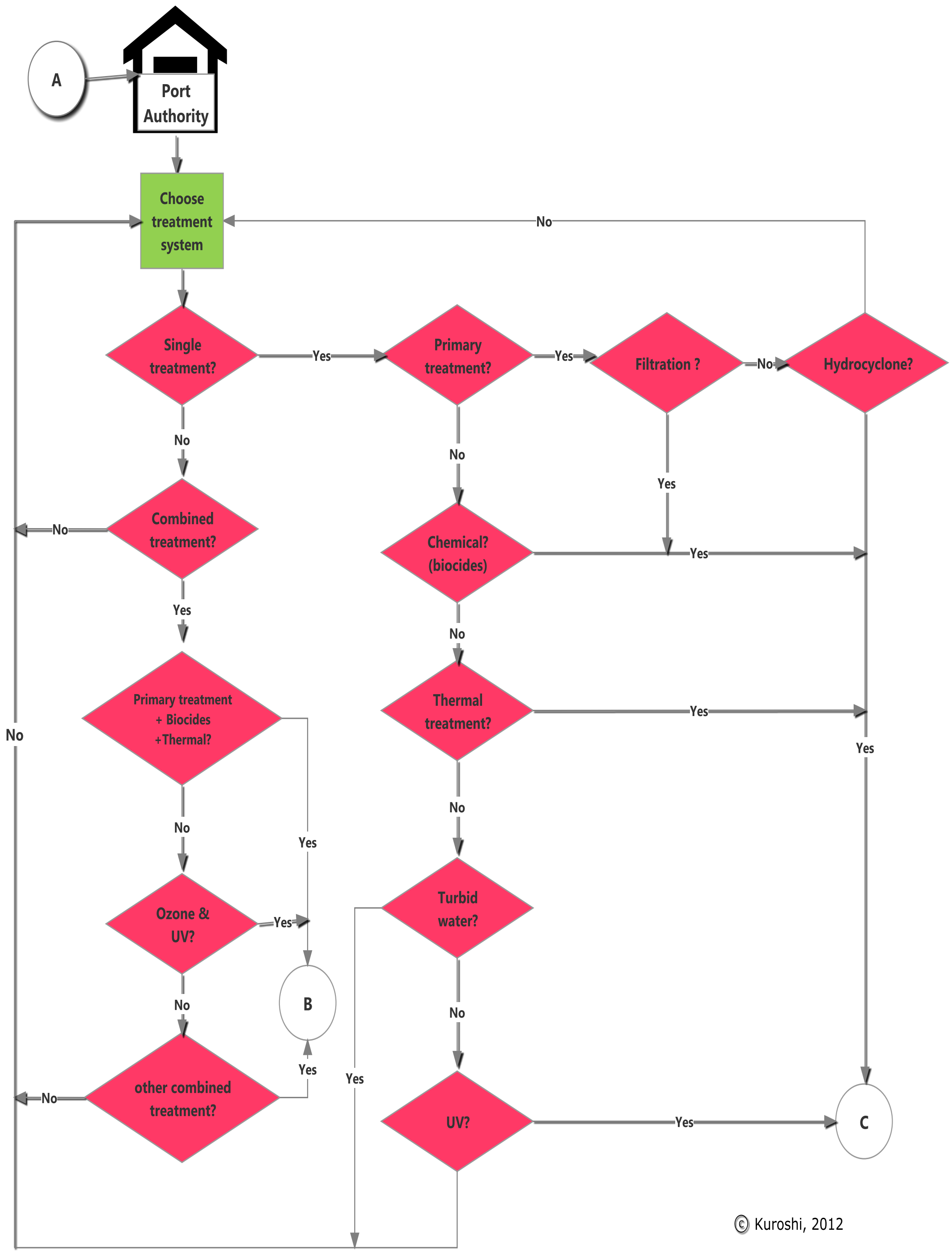

Figure 5.6: Port Authority's (Port of call) Onshore Ballast Water Management Decision Flowchart Model.

Figure 5.6 shows a proposed conceptual management decision flow chart model for Port Harcourt Harbour which is also applicable to any port that has an onshore pre-loading BWTS. The port authority decides the type of treatment system A to be installed in the port that is based on the specific baseline information on the port. For example, Figure 4.1 and 4.2 showed copepods and harmful dinoflagellates predominance and Figure 4.6 shows a strong positive correlation between plankton density and salinity, TDS and conductivity in the samples collected from Port Harcourt Harbour ($p<0.05$).

This unique baseline information should guide the port authority in deciding whether to go for a single treatment system C or a combination of systems B and what kind of combination is appropriate for the harbour. In the case of this study the appropriate decision, considering the Harbour's unique physical, chemical and biological characteristics as well as its financial capacity, is to go for a combination of treatment methods (filtration, temperature and biocides) which is treatment system B from the flow chart (Figure 5.6).

Figure 5.7 is a proposed onshore ballast water management decision flowchart model for ships visiting Port Harcourt Harbour. If a ship arrives in the harbour in-ballast to load cargo and she is from a port operating the pre-loading treatment system, from the flow chart, the decision will be to discharge the treated ballasted water into the harbour environment or to a potable water reception facility if it is available in the harbour as illustrated in the flowchart. But where the ballast water is untreated, it is discharged into a port reception facility for treatment before it is discharged into the harbour environment or to a potable water reception facility if the treated water is meant for human consumption or other domestic uses that need more stringent treatment requirements. This is economically feasible only in cases where the water is from a fresh water harbour which means having a conductivity of less than $100\mu scm^{-1}$.

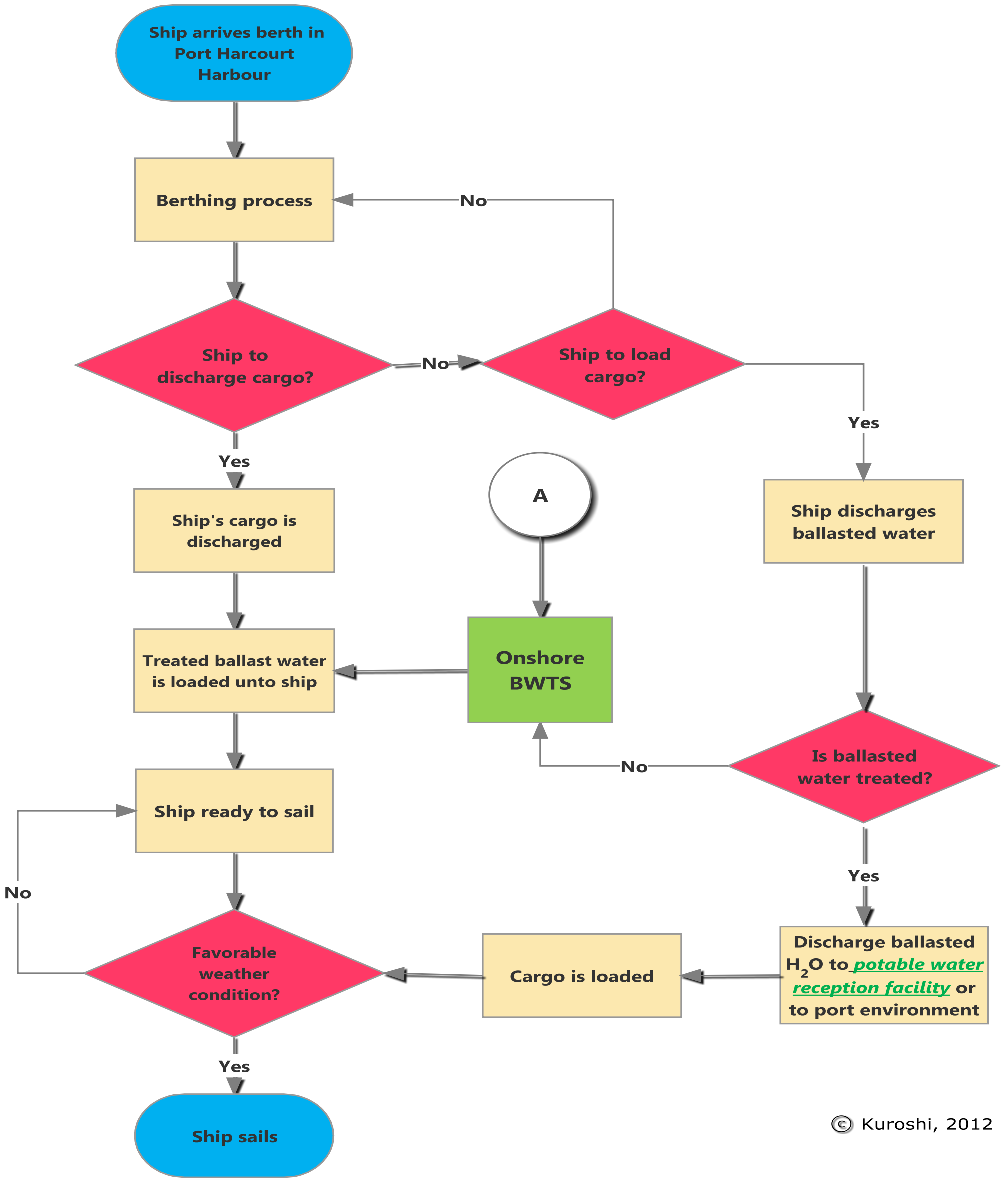

Figure 5.7: Ship's Onshore Preloading Ballast Water Management Decision Flowchart Model.

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Risk reduction for Port Harcourt Harbour as stated earlier can be achieved through filtration of harbour water, application of temperature of above 35^{o}C to the water being treated and the introduction of biocides (ozone is recommended by this study) into the water. This was shown from literature to achieve an over 95% kill rate for all identified planktons sampled in Port Harcourt Harbour in this study.

A harbour that possesses similar physicochemical characteristic with the study area should be expected to harbour organisms with similar environmental tolerance and, therefore, similar treatment systems can be applicable to both. Survivability of marine organisms in any environment is determined by the suitability of that environment to support the organisms. Suitability is a function of the physical, chemical and biological (presence of predators, and competitors) characteristics of that environment.

This proposal does not claim to have found the answers to the global menace of HAOP, but rather it is suggesting another angle for consideration in tackling the issue. The proposal has its inherent draw backs. The system does come with its own unique need for retrofitting ships with special ducts to upload the treated ballast water from the treatment plant and also some unique piping systems need to be installed in the harbours, resulting in both ships and harbours incurring costs for new infrastructure. The use of biocides in the system could leave some residual effect in the water which portents greater harm to the environment than it may resolve especially when proper dosage and disposal requirements are not followed. The system might also not completely eliminate the menace of ballasted HAOP, because safety requires that ballast water should be taken by ships in these cases; when the ship needs to clear a bridge and when she needs to compensate for weight lost as a result of fuel and water usage. It is considered, however, that ballast water taken at sea to compensate for weight loss is not as species rich as coastal water taken from a harbour. The system still has the potential to significantly reduce the menace, perhaps much more than all other alternative systems before it, as all the other possible alternatives have a number of inherent problems.

In conclusion, because only dry season samples and four stations were sampled, conclusive generalizations about the characteristics of Port Harcourt Harbour are not expected to be made based on this study's outcome alone.

6.2 RECOMMENDATION

Further studies should be encouraged by the authorities in Nigeria to establish a more detailed and reliable baseline data for Port Harcourt Harbour and the other harbours in the country. This will enable researchers and the port authorities in the country to make decisions regarding the design of a harbour treatment system more accurately. It is also recommended that periodic studies of Port Harcourt Harbour's marine environment to identify environmental changes overtime should be carried out by the Port Authority as part of the harbour risk analysis.

It is envisaged by this study that in the future, ballast water treatment could shift from shipboard to onshore treatment in view of the potential for success in onshore treatment. This study is, therefore, proposing to the IMO for consideration, the adoption of an amendment to the BWM Convention to clearly include regulations on onshore treatment systems because of the system's potential to compliment or even substitute for shipboard treatment.

This study recommends that strong trading partner nations should be encouraged to cooperate amongst themselves (in line with Article 2.4 of BWM Convention on cooperation) to have pre-loading treatment systems in their ports thereby exempting their ships from the requirements of regulation D-2 until perhaps the year 2020 (according to regulation D-4.2 on exemption) within which period the proposal of the co-operating parties to the IMO for amendment to the convention in accordance with

Article 19 would have been considered for global or regional applicability. Ships coming from ports that do not have a pre-loading BWTS can still employ either regulation D-1 or D-2, whichever is most applicable to their ships. But ships trading between ports with treatment systems can continue to enjoy the inherent benefits the system affords.

Finally, it is recommended also that further research to validate and establish the applicability in the maritime industry of this hypothetical conclusion on the effectiveness of the proposed treatment method should be undertaken by ballast water management researchers.

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APPENDICES

Appendix A: PHYSICOCHEMICAL PARAMETERS
Using Multi Parameter Water Checker (Horiba), Spec: U-10 µ

Date of sample collection: Tue 3rd January 2012 and Fri 6th January 2012

Port Harcourt Harbour, Nigeria

S/N	STATION CODE	PARAMETERS						
		PH	COND (µscm^{1})	TURB (NTU)	TEMPT (^{o}C)	SALINITY (0/00)	DO (mg/l)	TDS (mg/l)
1	NP1	7.51	33600	3.0	29.1	21.2	6.7	23520
2	NP2	7.73	33700	3.0	29.2	21.3	6.6	23590
3	OK1	7.63	34600	1.0	29.1	21.9	7.7	24220
4	OK2	7.64	34900	1.0	29.0	22.1	7.7	24430

KEY:

NP1: Main Harbour (Upstream), Port Harcourt, Nigeria

NP2: Main Harbour (downstream), Port Harcourt, Nigeria

OK1: Okrika Oil Terminal (upstream), Port Harcourt, Nigeria

OK2: Okrika Oil Terminal (downstream), Port Harcourt, Nigeria

Appendix B: PHYTOPLANKTON TAXONOMIC LIST

Table 1: The Phytoplankton taxonomic list and the number of individuals in the different stations within the study area [No. of individual organisms / mL] in Dry season .

	STATION				
	OK1	OK2	NP1	NP2	TOTAL
BACILLARIOPHYCEAE (C)					
CENTRICAE (Sc)					
Cosinodiscus lineatus	200	3000	100	500	3800
Cosinodiscus radiatus	1000	400	100	100	1600
Cyclotella sp.,	0	0	500	100	600
Cyclotella meneglunii	500	1500	200	300	2500
Hyalodiscus subtilis	200	1000	100	0	1300
TOTAL CENTRICAE	**1900**	**5900**	**1000**	**1000**	**9800**
PENNATAE (Sc)					
Gyrosigma acuminatum	1300	1000	300	500	3100
Hydrosira triquetra	400	1000	100	200	1700
Navicula sp.,	0	0	0	0	0
Nitzschia hungarica	500	300	200	100	1100
Pinnularia microstauron	0	0	0	0	0
Pinnularia sp.,	0	0	0	0	0
Stauroneis sp.,	0	0	0	0	0
Surirella sp.,	0	0	0	0	0
Synedra acus	100	200	500	100	900
Synedra ulna	500	1000	200	100	1800
Synedra sp.	100	300	100	200	700
TOTAL PENNATAE	**2900**	**3800**	**1400**	**120 0**	**9300**
CYANOPHYCEAE					
Anabaena sp.,	0	0	0	0	0
Spirulina sp.,	0	0	0	0	0
TOTAL CYANOPHYCEAE	**0**	**0**	**0**	**0**	**0**
DESMIDIACEAE					
Closterium sp.	1200	1000	200	100	2500
Closterium ehrenbergii	1700	600	100	300	2700
TOTAL DESMIDIACEAE	**2900**	**1600**	**300**	**400**	**5200**
HARMFUL DINOFLAGELLATES					
Alexandrium minutum - Cyst (Lebour) Balech	500	1000	2000	1000	**4500**
TOTAL HARMFUL DINOFLAGELATES	**500**	**1000**	**2000**	**1000**	**4500**
Phytoplanktons	***8200***	***12300***	***4700***	***3600***	***28800***
No. of ocurring Species	*13*	*13*	*14*	*13*	

Note **:Class (C); Subclass (Sc); R.A-Relative Abundance; RDO-Relative Dominance (Cover);D-Density OK=Okrika Oil Jetty NP= General Cargo Terminal**

Appendix C: ZOOPLANKTON TAXONOMIC LIST

Table 2: Zooplankton taxonomic list and the number of individuals in the different stations within the study area (No. of individual organisms/mL) in Dry season .

	STATION						
	OK1	**OK2**	**NP1**	**NP2**	**TOTAL**	**D**	**RDO**
TAXA							
PROTOZOA							
CRUSTACEA (C)							
CALANOID COPEPODA (Sc)							
Acartia clausii	500	100	3000	1000	***4600***	**1150.0**	***6.9***
Calanus sp.	1000	700	1300	600	***3600***	**900.0**	***5.4***
Calanus finmarchicus	3000	500	9000	1000	***13500***	**3375.0**	***20.1***
Candacia pachydactyla	500	100	1000	600	***2200***	**550.0**	***3.3***
Eucalanus sp.	4000	200	800	1000	***6000***	**1500.0**	***8.9***
Microcalanus pusillus	200	1000	200	100	***1500***	**375.0**	***2.2***
Paracalanus pygmaeus	3000	5000	10,000	5000	***23000***	**5750.0**	***34.3***
Pseudocalanus elongatus	1000	300	100	200	***1600***	**400.0**	***2.4***
Temora turbinate	300	0	0	2000	***2300***	**575.0**	***3.4***
Tortanus sp.,	100	100	500	1000	***1700***	**425.0**	***2.5***
Total Calanoid Copepod	***13600***	***8000***	***25900***	***12500***	***60000***	**15000.0**	***89.4***
CYCLOPODA COPEPOD							
Oncaea sp.,	3000	0	100	0	***3100***	**775.0**	***4.6***
Total Cyclopoda	***3000***	***0***	***100***	***0***	***3100***	**775.0**	***4.6***
CRUSTACEAN Larva							
Nauplius larva	1000	100	0	500	***1600***	**400.0**	***2.4***
Ostracod larva	400	0	300	100	***800***	**200.0**	***1.2***
Cirripede cypris larva	100	200	0	200	***500***	**125.0**	***0.7***
Penaeid nauplius	500	200	300	100	***1100***	**275.0**	***1.6***
Total Crustacean Larva	**2000**	**500**	**600**	**900**	***4000***	**1000.0**	***6.0***
Total Zooplanktons	***18600***	***8500***	***26600***	***13400***	***67100***	**16775.0**	***100.0***
No. of species	*15*	*12*	*12*	*14*			

Note **;Phylum (P) ;Subphylum (Sp) ; Class (C); Subclass (Sc); Suborder (So) ;Order (O): D- Density: RDO-Relative Dominance (Cover)**

OKJ=Okrika Oil Jetty

NP= General Cargo Terminal

Appendix D: SUMMARY OF THE ORIGIN, ECOLOGICAL, ECONOMIC, AND HEALTH IMPACTS OF SOME HARMFUL AQUATIC ORGANISMS AND PATHOGENS (HAOP):

POLYGENY	EXOTIC SPECIES	ECOLOGICAL IMPACT	ECONOMIC IMPACT	OTHERS	COMMON NAMES	ORIGIN
MOLLUSC	***Dreissena polymorpha***	*They compete with zooplankton for food, thus affecting natural food webs. They also interfere with the ecological functions of native molluscs.*	*cause great economic damage*		*Zebra mussels*	*native to the Caspian and Black Seas*
	Euglandina rosea	*It's a biological control agent. Many Partulid tree snails have been lost already and today the survivors exist in zoos and in the world's first wildlife reserves for snails. This invasion by a biological control agent has caused a significant loss of biodiversity*		*a biological control agent for another alien species, the giant African snail (Achatina fulica) and the the Partulid tree snails*	*cannibal snail, rosy wolf snail*	*Native to the southeastern United States*
	Mytilus galloprovincialis			*It has succeeded in establishing itself at widely distributed points around the globe, with nearly all introductions occurring in temperate regions and at localities where there are large shipping ports (Branch and Stephanni 2004). Ship hull fouling and transport of ballast water have been implicated in its spread and its impact on native communities and native mussels has been suggested by a number of studies and observations*	*bay mussel, blue mussel, Mediterranean mussel*	*native to the Mediterranean coast and the Black and Adriatic Seas*
	Pomacea canaliculata	*poses a serious threat to many wetlands around*	*a freshwater snail with a voracious*		*apple snail, channeled apple snail,*	*native South America*

		the world through potential habitat modification and competition with native species.	*appetite for water plants including lotus, water chestnut, taro and rice , it is a major crop pest in south east Asia (primarily in rice) and Hawaii (taro)*		*golden apple snail, miracle snail*	
	Corbula amurensis	*it has been designated as a major bilogical disturbance with significant ecological consequences in the San Francisco Bay area of California where large populations have become established.*			*Amur river clam, Amur river corbula, Asian bivalve, Asian clam, brackish-water corbula, Chinese clam, marine clam*	*native to Japan, China and Korea*
FISH						
	Clarias batrachus	*C. batrachus has been described as a benthic, nocturnal, tactile omnivore that consumes detritus and opportunistically forages on large aquatic insects, tadpoles, and fish.*	*During a drought large numbers of walking catfish may congregate in isolated pools and consume other species. They are known to have invaded aquaculture farms, entering ponds where they prey on fish stocks*	*is an opportunistic feeder and can go for months without food*	*clarias catfish, climbing perch, freshwater catfish, Thailand catfish, walking catfish,*	*native to southeastern Asia*
	Cyprinus carpio	*It is considered a pest because of its abundance and its tendency to destroy and uproot the aquatic vegetation used as habitat by a variety of species.*		Reduces water clarity	*Common carp, scale carp, grass carp, wild carp, German carp, European carp.*	*Native of Western Europe.*

	Gambusia affinis	*It has become a pest in many waterways around the world following initial introductions early last century as a biological control of mosquito. Mosquito fish are difficult to eliminate once established,*	*The highly predatory mosquito fish eats the eggs of economically desirable fish and preys on and endangers rare indigenous fish and invertebrate species.*		*Live-bearing tooth-carp, Mosquito fish, Topminnow, western mosquitofish, Western mosquitofish*	*a small fish native to the fresh waters of the eastern and southern United States*
	Micropterus salmoides	*places introduced Micropterus salmoides have affected populations of small native fish through predation, sometimes resulting in the their decline or extinction*	*Its diet includes fish, crayfish, amphibians and insects.*		*American black bass, black bass,green bass, largemouth bass, largemouth black bass*	*has been widely introduced throughout the world due to its appeal as a sport fish and for its tasty flesh*
	Salmo trutta	*It is blamed for reducing native fish populations, especially other salmonids, through predation, displacement and food competition*		*It is a popular angling fish.*	*brook trout, brown trout, orange fin, peal, salmon trout, sea trout, whiting*	*Salmo trutta has been introduced around the world for aquaculture and stocked for sport fisheries*
CRUSTACEAN						
	Carcinus maenas	*in some locations of its introduced range it has caused the decline of other crab and bivalve species*	*It is a voracious food generalist*		*European shore crab, green crab*	*is native to Europe and northern Africa*
	Cercopagis pengoi	*Cercopagis pengoi is a voracious predator and may compete with other planktivorous invertebrates and vertebrates.*	*Through this competition, Cercopagis pengoi has the potential to affect the abundance and condition of zooplanktivorous fish and fish larvae. It*		*fishhook waterfle*	*is a water flea native to the Ponto-Aralo-Caspian basin in South Eastern Europe, at the meeting point of the*

			also interferes with fisheries by clogging nets and fishing gear.			*Middle East, Europe and Asia*
	Eriocheir sinensis	*It contributes to the local extinction of native invertebrates and modifies habitats*	*the crab may cost fisheries and aquaculture industries several of hundreds of thousands of dollars per year by stealing bait and feeding on trapped fish.*	*has invaded Europe and, more recently, North America, causing erosion by its intensive burrowing activity,*	*Chinese freshwater edible crab, Chinese mitten crab*	*Chinese*
ALGAE						
	Caulerpa taxifolia	*Caulerpa taxifolia forms dense monocultures that prevent the establishment of native seaweeds*	*excludes almost all marine life, affecting the livelihoods of local fishermen.*	*widely used as a decorative plant in aquaria*	*killer alga, sea weed*	*French*
	Undaria pinnatifida	*It is an opportunistic weed which spreads mainly by fouling ship hulls. It forms dense underwater forests, resulting in competition for light and space which may lead to the exclusion or displacement of native plant and animal species.*		*it is cultivated for human consumption.*	*apron-ribbon vegetable, Asian kelp, Japanese kelp*	*The kelp (Undaria pinnatifida) is native to Japan*
FUNGUS						
	Aphanomyces astaci	*The parasitic fungus A. astaci was introduced into Europe by imports of North American species of crayfish. Native European crayfish populations are not resistant to the fungus.*	*It has since devastated native crayfish stocks throughout the continent.*		*is commonly referred to as crayfish plague*	*This fungus is endemic of North America and it is carried by North American species, i.e. signal crayfish Pacifastacu s*

						leniusculus, Procambarus clarkii and Orconectes limosus.
AQUATIC PLANT						
	Eichhornia crassipes	*Water hyacinth also prevents sunlight and oxygen from reaching the water column and submerged plants. Its shading and crowding of native aquatic plants dramatically reduces biological diversity in aquatic ecosystems.*	*Water hyacinth is a very fast growing plant, with populations known to double in as little as 12 days. Infestations of this weed block waterways, limiting boat traffic, swimming and fishing*	*Eichhornia crassipes is one of the worst aquatic weeds in the world. Its beautiful, large purple and violet flowers make it a popular ornamental plant for ponds. It is now found in more than 50 countries on five continents*	*floating water hyacinth, water hyacinth, water orchid*	*Originally from South America*
COMB JELLY						
	Mnemiopsis leidyi	*The ctenophore, Mnemiopsis ledyi, is a major carnivorous predator of edible zooplankton (including meroplankton), pelagic fish eggs and larvae.* *In the early 1980s, it was accidentally introduced via the ballast water of ships to the Black Sea, where it had a catastrophic effect on the entire ecosystem*	*is associated with fishery crashes*		*American comb jelly, comb jelly, comb jellyfish, sea gooseberry, sea walnut, Venus' girdle, warty comb jelly*	*it is indigenous to temperate, subtropical estuaries along the Atlantic coast of North and South America.*
AMPHIBIAN						
	Rana catesbeiana	*Primary concerns are competition with, and predation upon, native herpetofauna.*		*has been widely distributed via aquaculture and the aquarium trade. It is one of the most frequently cultivated edible frogs world-wide*	*bullfrog, North American bullfrog*	*North American*
SEA STAR						

	Asterias amurensis	*The seastar will eat a wide range of prey and has the potential for ecological harm.*	*The seastar will eat a wide range of prey and has the potential for economic harm in its introduced range*		*Flatbottom seastar, Japanese Seastar, Japanese starfish,North Pacific seastar, northern Pacific seastar, purple-orange seastar*	*Originally found in far north Pacific waters and areas surrounding Japan, Russia, North China, and Korea,*

Appendix E: SUMMARY OF STATISTICAL ANALYSIS RESULTS OF FIELD DATA USING GRAPHPAD INSTAT® VERSION 3.10 STATISTICAL SOFTWARE.

Summary of Statistical Analysis of Physiochemical Properties

T-test (one sample T-test)

Group	Number of Points	Mean	Standard Deviation	Standard Error of Mean	Median
PH	4	7.628	0.09032	0.04516	7.635
COND	4	34200	648.07	324.04	34150
TURB	4	2.000	1.155	0.5774	2.000
TEMPT	4	29.100	0.08165	0.04082	29.100
SALINITY	4	21.625	0.4425	0.2213	21.600
DO	4	7.175	0.6076	0.3038	7.200
TDS	4	23940	453.65	226.83	23905

Group	Minimum	Maximum	95% Confidence Interval From	To
PH	7.510	7.730	7.484	7.771
COND	33600	34900	33169	35231
TURB	1.000	3.000	0.1629	3.837
TEMPT	29.000	29.200	28.970	29.230
SALINITY	21.200	22.100	20.921	22.329
DO	6.600	7.700	6.208	8.142
TDS	23520	24430	23218	24662

Summary of Results of Statistical Analysis of Phytoplankton Data

One-way Analysis of Variance (ANOVA)

The P value is 0.0007, considered extremely significant.
Variation among column means is significantly greater than expected by chance.

Tukey-Kramer Multiple Comparisons Test
If the value of q is greater than 3.759 then the P value is less than 0.05.

Comparison	Mean Difference	q	P value
OK1 vs OK2	0.001494	1.739	ns P>0.05
OK1 vs NP1	-0.003151	3.667	ns P>0.05
OK1 vs NP2	-0.002708	3.151	ns P>0.05
OK2 vs NP1	-0.004645	5.406	** P<0.01
OK2 vs NP2	-0.004202	4.890	** P<0.01
NP1 vs NP2	0.0004429	0.5154	ns P>0.05

Difference	Mean Difference	95% Confidence Interval From	To
OK1 - OK2	0.001494	-0.001735	0.004724
OK1 - NP1	-0.003151	-0.006380	7.906E-05
OK1 - NP2	-0.002708	-0.005938	0.0005219
OK2 - NP1	-0.004645	-0.007875	-0.001415
OK2 - NP2	-0.004202	-0.007432	-0.0009724
NP1 - NP2	0.0004429	-0.002787	0.003673

Assumption test:: Are the standard deviations of the groups equal?

ANOVA assumes that the data are sampled from populations with identical SDs. This assumption is tested using the method of Bartlett.

Bartlett statistic (corrected) = 12.452
The P value is 0.0060.
Bartlett's test suggests that the differences among the SDs are very significant.
Since ANOVA assumes populations with equal SDs, you should consider transforming your data (reciprocal or log) or selecting a nonparametric test.

Assumption test:: Are the data sampled from Gaussian distributions?

ANOVA assumes that the data are sampled from populations that follow Gaussian distributions. This assumption is tested using the method Kolmogorov and Smirnov:

Group	KS	P Value	Passed normality test?
OK1	0.2897	0.0023	No
OK2	0.3160	0.0005	No
NP1	0.2784	0.0043	No
NP2	0.2817	0.0036	No

At least one column failed the normality test with $P<0.05$.
Consider using a nonparametric test or transforming the data (i.e. converting to logarithms or reciprocals).

Intermediate calculations. ANOVA table

Source of Variation	Degrees of freedom	Sum of squares	Mean square
Treatments (between columns)	3	0.0002062	6.874E-05
Residuals (within columns)	52	0.0005376	1.033E-05
Total	55	0.0007438	

F = 6.650 =(MStreatment/MSresidual)

Summary of Data

Group	Number of Points	Standard Mean	Standard Error of Deviation	Mean	Median
OK1	14	0.003121	0.003264	0.0008725	0.002000
OK2	14	0.001626	0.001396	0.0003732	0.001000
NP1	14	0.006271	0.003600	0.0009622	0.005000
NP2	14	0.005829	0.003973	0.001062	0.005000

Group	Minimum	Maximum	95% Confidence Interval From	To
OK1	0.000	0.01000	0.001236	0.005005
OK2	0.000	0.005000	0.0008204	0.002432
NP1	0.0005000	0.01000	0.004193	0.008350
NP2	0.000	0.01000	0.003535	0.008122

* * *

Summary of Results of Statistical Analysis of Zooplankton Data

One-way Analysis of Variance (ANOVA)

The P value is 0.7468, considered not significant.
Variation among column means is not significantly greater than expected by chance.

Post tests
Post tests were not calculated because the P value was greater than 0.05.

Assumption test: Are the standard deviations of the groups equal?

ANOVA assumes that the data are sampled from populations with identical SDs. This assumption is tested using the method of Bartlett.

Bartlett statistic (corrected) = 0.7438
The P value is 0.8628.
Bartlett's test suggests that the differences among the SDs is not significant.

Assumption test: Are the data sampled from Gaussian distributions?

ANOVA assumes that the data are sampled from populations that follow Gaussian distributions. This assumption is tested using the method
Kolmogorov and Smirnov:

Group	KS	P Value	Passed normality test?

NP1	0.2625	0.0065	No
NP2	0.1910	>0.10	Yes
OK1	0.2218	0.0455	No
OK2	0.3058	0.0005	No

At least one column failed the normality test with P<0.05.
Consider using a nonparametric test or transforming the data (i.e. converting to logarithms or reciprocals).

Intermediate calculations. ANOVA table

Source of variation	Degrees of freedom	Sum of squares	Mean square
Treatments (between columns)	3	1.706E-05	5.685E-06
Residuals (within columns)	56	0.0007776	1.388E-05
Total	59	0.0007946	

F = 0.4094 =(MStreatment/MSresidual)

Summary of Data

Group	Number of Points	Mean	Standard Deviation	Standard Error of Mean	Median
NP1	15	0.002736	0.003221	0.0008316	0.002000
NP2	15	0.004195	0.004044	0.001044	0.003300
OK1	15	0.003137	0.003840	0.0009914	0.001250
OK2	15	0.003336	0.003751	0.0009684	0.001670

Group	Minimum	Maximum	95% Confidence Interval From	To
NP1	0.0002500	0.01000	0.0009521	0.004520
NP2	0.000	0.01000	0.001956	0.006435
OK1	0.000	0.01000	0.001011	0.005264
OK2	0.000	0.01000	0.001259	0.005413

* * *

Appendix F: FULL TEXT OF IMO AND UN CONVENTIONS MENTIONED IN THE STUDY

International Maritime Organization (IMO) Conventions

Ballast Water Management Convention (BWMC)

Regulation D-1: Ballast Water Exchange (BWE)

Regulation D-1 requires ballast water exchange with 95% volumetric efficiency, which is assumed to be achieved after a throughput of three times the ballast water volume. The regulation stipulates also that, whenever possible, ballast water exchange must occur at least 200 nautical miles offshore and in at least 200 m depth of water. If this is not possible due to the ship's route, exchange must occur at least 50 nautical miles offshore and in at least 200 m depth of water. Port States are required also by this regulation to designate "exchange zones" with a lesser distance and depth.

Regulation D-2: Ballast Water Performance Standard

Regulation D-2 requires ballast water treatment results to have less than 10 viable organisms per cubic meter for organisms of size greater than or equal to 50 microns. It also requires ballast water treatment to result in less than 10 viable organisms per milliliter for organisms of size less than 50 microns as summarized in Figure 1.6.

The regulation sets three indicator micron discharge limits (human health standard): Less than one colony-forming unit (cfu) of toxicogenic vibrio cholerae per 100 ml or less than one cfu per gram (wet weight); less than 250 cfu of Escherichia coli per 100 ml; and less than 100 cfu of intestinal enterococci per 100 ml (Figure 1.6).

Regulation B-3 Ballast Water Management for Ships

1 A ship constructed before 2009:

.1 with a Ballast Water Capacity of between 1,500 and 5,000 cubic metres, inclusive, shall conduct Ballast Water Management that at least meets the standard described in regulation D-1 or regulation D-2 until 2014, after which time it shall at least meet the standard described in regulation D-2;

.2 with a Ballast Water Capacity of less than 1,500 or greater than 5,000 cubic metres shall conduct Ballast Water Management that at least meets the standard described in regulation D-1 or regulation D-2 until 2016, after which time it shall at least meet the standard described in regulation D-2.

2 A ship to which paragraph 1 applies shall comply with paragraph 1 not later than the first intermediate or renewal survey, whichever occurs first, after the anniversary date of delivery of the ship in the year of compliance with the standard applicable to the ship.

3 A ship constructed in or after 2009 with a Ballast Water Capacity of less than 5,000 cubic metres shall conduct Ballast Water Management that at least meets the standard described in regulation D-2.

4 A ship constructed in or after 2009, but before 2012, with a Ballast Water Capacity of 5,000 cubic metres or more shall conduct Ballast Water Management in accordance with paragraph 1.2.

5 A ship constructed in or after 2012 with a Ballast Water Capacity of 5000 cubic metres or more shall conduct Ballast Water Management that at least meets the standard described in regulation D-2.

6 The requirements of this regulation do not apply to ships that discharge Ballast Water to a reception facility designed taking into account the Guidelines developed by the Organization for such facilities.

7 Other methods of Ballast Water Management may also be accepted as alternatives to the requirements described in paragraphs 1 to 5, provided that such methods ensure at least the same level of protection to the environment, human health, property or resources, and are approved in principle by the Committee.

Regulation D-4 Prototype Ballast Water Treatment Technologies

1 For any ship that, prior to the date that the standard in regulation D-2 would otherwise become effective for it, participates in a programme approved by the Administration to test and evaluate promising Ballast Water treatment technologies, the standard in regulation D-2 shall not apply to that ship until five years from the date on which the ship would otherwise be required to comply with such standard.

2 For any ship that, after the date on which the standard in regulation D-2 has become effective for it, participates in a programme approved by the Administration, taking into account Guidelines developed by the Organization, to test and evaluate promising Ballast Water technologies with the potential to result in treatment technologies achieving a standard higher than that in regulation D-2, the standard in regulation D-2 shall cease to apply to that ship for five years from the date of installation of such technology.

3 In establishing and carrying out any programme to test and evaluate promising Ballast Water technologies, Parties shall:

.1 take into account Guidelines developed by the Organization, and

.2 allow participation only by the minimum number of ships necessary to effectively test such technologies.

4 Throughout the test and evaluation period, the treatment system must be operated consistently and as designed.

Regulation D-5 Review of Standards by the Organization

1 At a meeting of the Committee held no later than three years before the earliest effective date of the standard set forth in regulation D-2, the Committee shall undertake a review which includes a determination of whether appropriate technologies are available to achieve the standard, an assessment of the criteria in paragraph 2, and an assessment of the socio-economic effect(s) specifically in relation to the developmental needs of developing countries, particularly small island developing States. The Committee shall also undertake periodic reviews, as appropriate, to examine the applicable requirements for ships described in regulation B-3.1 as well as any other aspect of Ballast Water Management addressed in this Annex, including any Guidelines developed by the Organization.

2 Such reviews of appropriate technologies shall also take into account:

.1 safety considerations relating to the ship and the crew;

.2 environmental acceptability, i.e., not causing more or greater environmental impacts than they solve;

.3 practicability, i.e., compatibility with ship design and operations;

.4 cost effectiveness, i.e., economics; and

.5 biological effectiveness in terms of removing, or otherwise rendering not viable, Harmful Aquatic Organisms and Pathogens in Ballast Water.

3 The Committee may form a group or groups to conduct the review(s) described in paragraph 1. The Committee shall determine the composition, terms of reference and specific issues to be addressed by any such group formed. Such groups may develop and recommend proposals for amendment of this Annex for consideration by the Parties. Only Parties may participate in the formulation of recommendations and amendment decisions taken by the Committee.

4 If, based on the reviews described in this regulation, the Parties decide to adopt amendments to this Annex, such amendments shall be adopted and enter into force in accordance with the procedures contained in Article 19 of this Convention.

Article 2 General Obligations

1 Parties undertake to give full and complete effect to the provisions of this Convention and the Annex thereto in order to prevent, minimize and ultimately eliminate the transfer of Harmful Aquatic Organisms and Pathogens through the control and management of ships‘ Ballast Water and Sediments.

2 The Annex forms an integral part of this Convention. Unless expressly provided otherwise, a reference to this Convention constitutes at the same time a reference to the Annex.

3 Nothing in this Convention shall be interpreted as preventing a Party from taking, individually or jointly with other Parties, more stringent measures with respect to the prevention, reduction or elimination of the transfer of Harmful Aquatic Organisms and Pathogens through the control and management of ships‘ Ballast Water and Sediments, consistent with international law.

4 Parties shall endeavour to co-operate for the purpose of effective implementation, compliance and enforcement of this Convention.

5 Parties undertake to encourage the continued development of Ballast Water Management and standards to prevent, minimize and ultimately eliminate the transfer of Harmful Aquatic Organisms and Pathogens through the control and management of ships‘ Ballast Water and Sediments.

6 Parties taking action pursuant to this Convention shall endeavour not to impair or damage their environment, human health, property or resources, or those of other States.

7 Parties should ensure that Ballast Water Management practices used to comply with this Convention do not cause greater harm than they prevent to their environment, human health, property or resources, or those of other States.

8 Parties shall encourage ships entitled to fly their flag, and to which this Convention applies, to avoid, as far as practicable, the uptake of Ballast Water with potentially Harmful Aquatic Organisms and Pathogens, as well as Sediments that may contain such organisms, including promoting the adequate implementation of recommendations developed by the Organization.

9 Parties shall endeavour to co-operate under the auspices of the Organization to address threats and risks to sensitive, vulnerable or threatened marine ecosystems and

biodiversity in areas beyond the limits of national jurisdiction in relation to Ballast Water Management.

Article 4 Control of the Transfer of Harmful Aquatic Organisms and Pathogens Through Ships‘ Ballast Water and Sediments

1 Each Party shall require that ships to which this Convention applies and which are entitled to fly its flag or operating under its authority comply with the requirements set forth in this Convention, including the applicable standards and requirements in the Annex, and shall take effective measures to ensure that those ships comply with those requirements.

2 Each Party shall, with due regard to its particular conditions and capabilities, develop national policies, strategies or programmes for Ballast Water Management in its ports and waters under its jurisdiction that accord with, and promote the attainment of the objectives of this Convention.

Article 5 Sediment Reception Facilities

1 Each Party undertakes to ensure that, in ports and terminals designated by that Party where cleaning or repair of ballast tanks occurs, adequate facilities are provided for the reception of Sediments, taking into account the Guidelines developed by the Organization. Such reception facilities shall operate without causing undue delay to ships and shall provide for the safe disposal of such Sediments that does not impair or damage their environment, human health, property or resources or those of other States.

2 Each Party shall notify the Organization for transmission to the other Parties concerned of all cases where the facilities provided under paragraph 1 are alleged to be inadequate.

Article 19 Amendments

1 This Convention may be amended by either of the procedures specified in the following paragraphs.

2 Amendments after consideration within the Organization:

(a) Any Party may propose an amendment to this Convention. A proposed amendment shall be submitted to the Secretary-General, who shall then circulate it to the Parties and Members of the Organization at least six months prior to its consideration.

(b) An amendment proposed and circulated as above shall be referred to the Committee for consideration. Parties, whether or not Members of the Organization, shall be entitled to participate in the proceedings of the Committee for consideration and adoption of the amendment.

(c) Amendments shall be adopted by a two-thirds majority of the Parties present and voting in the Committee, on condition that at least one-third of the Parties shall be present at the time of voting.

(d) Amendments adopted in accordance with subparagraph (c) shall be communicated by the Secretary-General to the Parties for acceptance.

(e) An amendment shall be deemed to have been accepted in the following circumstances:

(i) An amendment to an article of this Convention shall be deemed to have been accepted on the date on which two-thirds of the Parties have notified the Secretary-General of their acceptance of it.

(ii) An amendment to the Annex shall be deemed to have been accepted at the end of twelve months after the date of adoption or such other date as determined by the Committee. However, if by that date more than one-third of the Parties notify the Secretary-General that they object to the amendment, it shall be deemed not to have been accepted.

(f) An amendment shall enter into force under the following conditions:

(i) An amendment to an article of this Convention shall enter into force for those Parties that have declared that they have accepted it six months after the date on which it is deemed to have been accepted in accordance with subparagraph (e)(i).

(ii) An amendment to the Annex shall enter into force with respect to all Parties six months after the date on which it is deemed to have been accepted, except for any Party that has:

(1) notified its objection to the amendment in accordance with subparagraph (e)(ii) and that has not withdrawn such objection; or

(2) notified the Secretary-General, prior to the entry into force of such amendment, that the amendment shall enter into force for it only after a subsequent notification of its acceptance.

(g) (i) A Party that has notified an objection under subparagraph (f)(ii)(1) may subsequently notify the Secretary-General that it accepts the amendment. Such amendment shall enter into force for such Party six months after the date of its notification of acceptance, or the date on which the amendment enters into force, whichever is the later date.

(ii) If a Party that has made a notification referred to in subparagraph (f)(ii)(2) notifies the Secretary-General of its acceptance with respect to an amendment, such amendment shall enter into force for such Party six months after the date of its notification of acceptance, or the date on which the amendment enters into force, whichever is the later date.

3 Amendment by a Conference:

(a) Upon the request of a Party concurred in by at least one-third of the Parties, the Organization shall convene a Conference of Parties to consider amendments to this Convention.

(b) An amendment adopted by such a Conference by a two-thirds majority of the Parties present and voting shall be communicated by the Secretary-General to all Parties for acceptance.

(c) Unless the Conference decides otherwise, the amendment shall be deemed to have been accepted and shall enter into force in accordance with the procedures specified in paragraphs 2(e) and (f) respectively.

4 Any Party that has declined to accept an amendment to the Annex shall be treated as a non-Party only for the purpose of application of that amendment.

5 Any notification under this Article shall be made in writing to the Secretary-General.

6 The Secretary-General shall inform the Parties and Members of the Organization of:

(a) any amendment that enters into force and the date of its entry into force generally and for each Party; and

(b) any notification made under this Article.

United Nations (UN) Conventions

The United Nation's Convention on the Law of the Sea (UNCLOS)

The United Nation's Convention on the Law of the Sea (UNCLOS); Article 196 paragraph 1 provides that:

"States shall take all measures necessary to prevent, reduce and control . . . the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto" (UNCLOS, 1982).

United Nation's Environment Programme (UNEP):

Guiding principle 5: Research and monitoring (UNEP)

In order to develop an adequate knowledge base to address the problem,

States should undertake appropriate research on and monitoring of alien invasive species. This should document the history of invasions (origin, pathways and time-period), characteristics of the alien invasive species, ecology of the invasion, and the associated ecological and economic impacts and how they change over time. Monitoring is the key to early detection of new alien species. It requires targeted and general surveys which can benefit from the involvement of local communities.

Convention on Biological Diversity (CBD):

The *Convention on Biological Diversity (CBD)*; Article 8(h) requires Parties:

"As far as possible and appropriate, (to) prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" (IMO, 2009).

Appendix G: GLOSSARY

“Active Substance” means a substance or organism, including a virus or a fungus that has a general or specific action on or against harmful aquatic organisms and pathogens (IMO, 2008a).

“Ballast” any solid or liquid weight placed in a ship to increase the draft, to change the trim, or to regulate the stability (NRC, 1996).

“Ballast tank” a water tight enclosure that may be used to carry liquid ballast (NRC, 1996).

“Ballast Water Management System” means any system which processes ballast water such that it meets or exceeds the ballast water performance standard. This system includes ballast water treatment equipment, all associated control equipment, monitoring equipment and sampling facilities (IMO, 2008b).

“Biodiversity” the variety of different types of organisms living in a given area (NRC, 1996).

"Biological diversity" means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part ; this includes diversity within species, between species and of ecosystems (United Nations, 1992b).

“Bow” the forward end of a vessel (NRC,1996).

“Copepod” small crustacean of the order Copepoda

“Deballasting” releasing ballast by gravity or pumping from a vessel

“Diatom” microscopic autotrophic organism of the algae class Bacillariophyceae

“Dinoflagellate” microscopic organism of the order Dinoflagellata

“Dispersal vector” mechanism that transports organisms from one region to another (NRC, 1996)

“Estuary” a partially enclosed coastal embayment where fresh water and sea water meet and mix (NRC, 1996).

“Euryhaline” an organism able to live in an environment of widely varying salinity (NRC, 1996).

“Euryhaline” species are organisms able to tolerate a wide range of salinities (IMO, 2007).

“Eurythermal” species are organisms able to tolerate a wide range of temperatures (IMO, 2007).

“General cargo” goods to be transported in a mixture of forms, but usually packaged in some way other than container boxes (NRC, 1996).

“Non-indigenous species” is any species outside its native range, whether transported intentionally or accidentally by humans or transported through natural processes (IMO, 2007).

“In ballast” the condition in which a vessel is operating with ballast and no cargo (NRC, 1996)

“Inoculation” release of an organism in a new environment.

“Introduction” establishment of a reproducing population of an organism in a novel environment.

“Maritime Dependence Factor” is an index to measure the reliance of a country’s economy on sea-borne trade.

“Meroplankton” planktonic organisms that spend only part of their life cycles in the plankton stage and the other as benthic or other forms.

“Nonindigenous” non- native to an area.

“NOBOB” No Ballast On Board

“Phytoplankton” planktonic plants.

“Plankton” otherwise non as drifters because they are that are free-floating or drifting in water whose movements are determined primarily by water motion.

“Plankton net” fine mesh conical nets dragged in the water to collect plankton during sampling.

“Port state” a nation in whose port a vessel enters, as contrasted to a flag state, which is the nation in which the vessel is registered (NRC, 1996).

“Potable” fit for drinking.

“Propagule Pressure” refers to the potential for invasion of a novel environment by non-native species. This potential is a function of the number and density of species introduced.

"Propeller" revolving screw like device used for propelling ships through water (NRC, 1996).

"Protists" eukaryotic organisms comprised of a single cell (NRC,1996).

"Reballast" to load water ballast back on a vessel after deballasting (NRC, 1996).

"Red tide" refers to massive dinoflagellates blooms where the water changes colour and toxic.

"Salinity" amount of salt dissolved in water.

"Sea chest" an enclosure attached to the inside of the shell plating and open to the sea, providing the connection of a piping system to overboard (NRC,1996).

"Slamming" heavy impact resulting from a vessel's bottom near the bow making sudden contact with the sea surface after having risen above the surface due to relative motion (NRC, 1996).

"Stability" the condition to which a body will move back to a condition of equilibrium when given a small initial movement away from this condition (NRC, 1996).

"Stern" the after end of a ship

"Strain" deformation resulting from stress on a body (NRC, 1996).

"Stress" force per unit section area producing deformation in a body (NRC, 1996).

"Tanker" a cargo vessel designed for carriage of liquid cargo in bulk.

"Tens Rule" states that in the event of a bio-invasion, only 10% of invading species become introduced, only 10% of those introduced become established and only 10% of those established become invasive.

"Trim" the difference between the drafts: the after draft minus the forward draft (NRC, 1996).

"Turbidity" amount of light-reflecting material in suspension in water.

"Zooplankton" planktonic animals.