Present & Future of Ballast Water Management for Offshore and Inshore Exchanges

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Abstract

Ballast water uptakes and discharges transfer nonnative, and potentially invasive aquatic species on the natural environment, public health, the global economy, ecosystems, and the stakeholders of maritime vessels on the open sea. The researcher proposes an examination of ballast water management for offshore and inshore exchanges in the context of current practices, future mandates, and how the stakeholders, environment, economy, and associated processes are verified. The effect of the ballast water transfers based upon temperature changes from warm to cold will be investigated by multi-criteria analysis of a data series based upon criteria associated with the different temperature regimes during travel and corresponding ballast water transfers in Arctic conditions. A recommendation of best practices will be provided based upon the creative project results and findings.

Key Terms: Ballast Water, biofouling, maritime, temperature, aquatic invasive treatment

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Introduction: Present & Future of Ballast Water Management for Offshore and Inshore Exchanges

Global and national governments have conducted research and implemented controls to protect the marine environment from adverse effects of maritime vessel activities (Ndlovu, 2016; Hasanspahic and Zec, 2017; Sandstrom et al 2014; Ghosh & Rubly, 2017; ShipInsight, 2018). Environmentalists have proven theories that ballast water that has not been treated properly will invoke the introduction of alien species, as well as environmental pollution from the discharge (Ndlovu, 2016). Therefore, the impact of ballast water uptakes and discharges which transfer nonnative, and potentially invasive aquatic species on the natural environment, public health, the global economy, ecosystems, and the stakeholders of maritime vessels on the open sea has drawn the interest of national government leaders, environmental scientists and researchers.

The topic of this capstone research project is ballast water management for both offshore and inshore exchanges. The project will examine the current practices and protocols, future mandates and conventions, environmental and financial impacts, and verification processes in place for ballast water exchanges and transfers. It is evident that more attention must be dedicated to ballast water management as it pertains to the transfer of ballast water into various ecosystems. Moreover, the focus should be on how these transfers impact the environment, and best practices for overcoming the problem and protecting the natural environment. The proposed research capstone aims to:

- Define the problem; discuss significance of problem that requires ballast water treatment.
- Identify and discuss the stakeholders.
- Discuss solutions to the problems of ballast water management.
- Lay out best practices for ballast water management.

- Provide potential solutions for current problems with ballast water management

Background

Transport by maritime vessels play a critical role in global trade. Hasanspahic and Zec (2017) hold that the ballast water treatment system (BTWS) market was valued at $5.2 billion in 2015, with a projected value of $36 billion toward the year 2020. However, the surfaces of the marine vessel are target areas for biofouling organisms (Brown et al. 2017). Aquatic invasive species (AIS) transfer to foreign waters, reproduce rapidly, and disrupt the natural food chain (Van den Heuval et al 2014). Moreover, the foreign species have the capacity to cause irreversible damage to the natural food chain as well as human health.

Aquatic nuisance species (ANS) of animals and plants which most commonly pester the foreign environment include a diversity of weeds and reeds, crabs and catfish, lion fish, snails, gobies, water spinach and lettuce, zebra mussels, carp, and jellyfish (World Shipping Council, 2018). All international maritime traffickers will be forced to acknowledge the impact of ANS transfers, and to cross the ballast water treatment system threshold and conform to the IMO D-2 standard. However, the new equipment has not been accommodated with sufficient expertise required to train the vessel crews. Therefore, the pressures of non-compliance and sub-standard installations are compounded by problems which expand beyond costs.

Studies of the ballast water transfer have been conducted using different approaches to understand the how the ballast water transfer may be controlled and the future implications of environmental sustainability and public health that should be addressed in government regulations (ShipInsight, 2018). Ballast water system treatments in the Arctic have been associated with risks of low pressure UV; filter loss of sensitivity; ice blocking filters; slow chemical reactions; and less effective de-oxygenation (Van den Heuvel-Greve et al 2014).

Advancements in technology have empowered the researcher with access to invaluable forms of environmental data which may be assessed to develop solutions or recommendation. Researchers must capitalize on data collected by GPS, and other disruptive technologies that may be used in the aquatic environment to improve the ballast water treatment systems.

The United States Environmental Protection Agency (EPA) has advocated for international ballast management laws in regard to dumping ballast water (World Shipping Council, 2018). Around the world, the ballast water problem has also been addressed by agencies such as the International Maritime Organization (IMO), Baltic and International Maritime Council (BIMCO), and the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM). Nonetheless, further research is required in order to improve the present state of aquatic pollution.

Defining the Problem

Evidence has shown far-reaching effects that even minor shifts in the balance of ocean waters have on the ecosystems and marine life. The transfer of ballast water is shown to be highly problematic, particularly as water is introduced into areas where it is not compatible, along with the species that live in the water. Moreover, the problem is not limited or insignificant; instead, it is far-reaching and impacting ecosystems and habitats throughout the globe. According to Werschkun (2014):

> Based on an estimation that the world seaborne trade in 2013 amounted to 9.35 billion tons of cargo, the global ballast water discharges in 2013 are estimated to be about 3.1 billion tonnes. There is significant transfer of ballast water between different continents and oceans, and it has been known for decades that ballast water also transports

organisms into new ecosystems, where, under favorable conditions, they can become invasive.

To better understand the impact, the literature review will shed light on the extent of the problem and, then, solutions will be explored for overcoming ballast water transfers' environmental impacts. Ultimately, more research is needed to define the problem and derive the best solutions possible. The extent of the problem must be explored and, taking into consideration the many primary and secondary stakeholders, a plan should be created to overcome the issue.

Expected Outcomes to Improve the Problem

A set of new, best practices, guidelines, and protocols must be established to protect the natural environment from the negative consequence of ballast water transfer which compromise the integrity of the ecosystem. The research should help to establish a framework for which to better manage offshore and inshore exchanges. The research is needed to explore the extent of the issue, understand the options to fix (or at least improve it), and establish best practices, guidelines, and protocols for the maritime community and all its stakeholders to follow. The International Maritime Organization (IMO) has slowly been addressing these issues and hopefully will continue to do so.

Fortunately, there are already cutting edge technological and biological solutions to reduce the impact that transferring ballast waters may have on the environment. The research indicates that there are many ways to overcome at least some of the negative consequences of ballast water transfer. Dobbs (2005) explains, "However, the bacterial and viral diversity in ballast water is absolutely unknown. Our understanding of the microbial diversity found in ballast tanks depends on new, sophisticated molecular biological techniques and certainly will increase with more advanced studies." These solutions are all feasible, but before they are implemented the problem must be clearly defined and all of the options available should be assessed. Moreover, the options must be explored with regard to how they impact a diversity of primary and secondary stakeholders.

Once this understanding is reached, the proper solutions for the environment and the global shipping community as a whole may be implemented. Researching not just the environmental impact that ballast water has on oceans but the overall engineering and machinations behind the solution will be a critical component to the future. Maritime industries will provide a valuable contribution to current literature and a path to solutions. Ballast exchanges and transfers are often overlooked in importance and this is precisely the problem.

Stakeholders

There are numerous stakeholders either directly or indirectly involved in managing the ballast water transfer issue. Major stakeholder are vessel owners who rely on the transfer and exchange of ballast water to not only facilitate the movement of cargo but to also keep their vessels afloat. Ballast water exchange and transfer is a necessity and if denied the right to transfer water, the entire global economy will suffer. Other primary stakeholders are local economies and ecosystems that are negatively impacted when foreign species invade and compromise not only livelihoods of those who rely on local waters but also the safety of the natural environment.

Secondary stakeholders include the scientific communities and political-legal organizations and committees such as the IMO's Ballast Water Management Convention, The Global Marine Environment Protection (GMEP), and the Environmental Protection Agency (EPA), the National Ballast Information Clearinghouse (NBIC), The United States Coast Guard (USCG), classification societies such as the American Bureau of Shipping (ABS), International

Maritime Organization (IMO), and Lloyd's Registry (LR). Additionally, international shipping organizations such as the World Shipping Council, and countless others all have stakes in ensuring that the ballast water transfer issue is managed, mitigated and enforced. They will be vital for controlling the problem and implementing the best practices for managing the issue of water being transferred from one environment to the next.

Tertiary stakeholders will be affected by the solutions of the ballast water and exchange issue, as they will be responsible for the execution and implementation of the approved best practices. The primary stakeholders of the BWTS market consist of the BWTS manufacturers, shipyards, merchant ship owners, testing laboratories, coastal maritime administrations, and recognized industry agencies (Hasanspahic & Zec, 2017). Vessel crews, marine architects (designers), ship builders, and ballast water treatment systems (BWTS) manufactures will be where the rubber meets the road.

Vessel Officers, both bridge and engine, are responsible for the proper use and maintenance of equipment, data recording of exchanges and transfers and recording of the procedures and associated reports required for enforcement. Marine architects are held accountable for new designs, allowing for treatment systems along with ship builders who will be responsible for the proper placement and instillation of the approved systems. Lastly, BWTS manufactures will be tasked with developing new systems that meet the next set of requirements while maintaining high flow rates demanded by the global fleet.

Research Aims and Objectives

The proposed research aims and objectives are as follows:

- Examine the scope of the Ballast Water Management Convention.
- Identify inherent challenges associated with hot to cold temperature shifts.

- Investigate the elucidation of viable solutions for ballast water transfers.
- Increase overall awareness and understanding of the ballast water transfers.

Research Questions

The research questions that will be answered by the proposed research are as follows:

R_1: What are the most pressing issues concerning the ballast water transfer problem?

R_2: What are the most viable solutions to the ballast water transfer problem?

R_3: What role does the Ballast Water Management Convention play in ballast water transfer solutions?

R_4: What are the most prominent future trends in ballast water management?

Problem Statement

There is a significant transfer of ballast water between different continents and oceans which is detrimental to the preservation of aquatic life, the environment, and public health. Moreover, the increased speed of global maritime traffic and larger ballast water volume capacities of 21st century marine vessels contribute significantly to the harmful transfers of aquatic organisms (Hasanspahic and Zec, 2017). Evidence-based solutions to the global ballast water transfer crisis are needful.

Significance of the Problem

The problem of ballast water transfer and its impacts on marine life is not a new phenomenon. Miller (2004) found that “Biological invasions by non-native, invasive species are having significant ecological and economic impacts on the waters of the United States. The rate of new invasions is increasing.” Werschkun et al. (2014) point out that around 66% of globally traded goods are transported by merchant ships, which are the primary contributor to ballast water transfer and exchanges. Further, Ghosh and Rubly (2017) estimate that over 10 billion tons of ballast water are moved by vessels in the facilitation of global trade, each year, with the effect of risk to human health and natural habitats for a diversity of aquatic species due to the transfer of none native species and pathogens. Therefore, the problem is quite far-reaching and significant. Literally, billions of tons of water are being displaced and transferred each year, leading to major issues with the countless marine ecosystems.

Ballast water transfers and exchanges are a daily process aboard vessels. Each transfer is unique and is executed for a multitude of reasons ranging from stability to trim and list required for a load or discharge. Additional transfers are also executed as required to compensate for fuel burn off during transit or taking on bunkers. As this is a daily process, and these vessels transit globally, a major issue arises when these vessels are in warmer climates and destined for colder ones. Gollasch and Leppäkoski (2007) found that:

> Vertical gradients strongly influence not only the native biotic communities, but also provide a broad range of temperature and salinity conditions inhabitable by alien species of different biogeographical origins. Since both established and potential aquatic invasive species originate primarily from warmer areas, changes in the temperature and salinity conditions may influence the invasion pattern and population dynamics of AIS.

This data provides a valuable starting point to increase understanding of the effect of transferring ballast waters; particularly when ships travel from hot to cold waters.

Significance of the Study

An increase in knowledge of how ballast water transfers effect the natural environment, ecosystems, and public health will contribute significantly to future environmental sustainability practices and the establishment of more effective standards for the maintenance of global public health. Prior studies of the human environmental footprint have focused upon the impact of industrialism in the context of manufacturing and the management of waste. In-depth **r**esearch of aquatic species and the mechanisms of the merchant ship heightens awareness of the adverse effect of human activity on the environment. The enhancement of awareness and understanding of the ballast water transfers based upon changes in temperature will contribute to discoveries and the development of evidence-based solutions to the problem.

Literature Review

The impact of ballast water uptakes and discharges on the natural environment, public health, the global economy, ecosystem services, and the stakeholders of marine vessels has drawn the interest of national government leaders, environmental scientists, and researchers. Environmentalists have proven theories that ballast water that has not been treated properly will invoke the introduction of alien species, as well as environmental pollution from the discharge (Ndlovu, 2016). Several studies have been published attesting to the sequential ballast water exchange problem, with proposed solutions for the prevention of aquatic species and pathogen relocation by transoceanic ships (Chen et al. 2013; Batista et al. 2017; Ndlovu, 2016; Werschkun et al. 2014; David, Gollasch & Pavliha, 2013; Hasanspahic & Zec, 2017; Painter et al. 2016; Brown, Dobroski, Nedelcheva, Scianni & Thompson, 2017; Whittle et al 2017; De Baere et al. 2014; Ghosh & Rubly, 2017; Cvetkovic, Kompare and Klemencic, 2015; Sandrom et al 2014). A number of such studies have been published by the agencies such as the International Maritime Organization (IMO) and the Baltic and International Maritime Council (BIMCO).

The articles for this review were gathered from global databases which feature peer-reviewed articles for scientific, environmental, marine biology, and macroeconomics disciplines. The primary search terms used to locate articles for the review include “ballast”, “oxidative”, “water management”, “double hull”, “disinfection”, “vessel biofouling”, “aquatic invasive species”, “invasive organism”, “non-indigenous”, “BWM”, “ballast water management”, “IMO ballast water guidance”, “electro-chlorination”, “in port ballast discharge and uptake”, “sacrificial anode”, “coastal indicator taxa”, “ultraviolet irradiation” and “vessel ballast regulation”.

Defining Ballast

Cvetkovic, Kompare and Klemencic (2015) defined ballast as “any materials which are used to weight and balance; the additional, necessary weight to bring the marine vessel to suitable draft; required weights to trim and reduce stress; and additions to improve the vessel stability” (p. 7422). Painter et al. (2016) described the temperate coastal oceans as “significant sinks for atmospheric CO_2 which are at future risk due fluctuating environmental conditions” (p. 4522). Chen et al. (2013) described the offshore exchange method as “a substitution of fresh water from the open ocean with ballast water to remove pathogens and harmful aquatic species offshore”. Hasanspahic and Zec (2017) supported that the increased speed of global maritime traffic and larger ballast water volume capacities of 21st century marine technology and vessels also significantly contribute to the harmful transfers of aquatic organisms.

Cvetkovic, Kompare and Klemencic (2015) asserted that “ballast water, aquaculture, and hull fouling” represent “the most significant factor in global transfers of non-indigenous, invasive organisms to aquatic ecosystems” (p. 7422). Invasive aquatic species may be characterized by population dynamics which are unstable, collapsed, or prone to heavy fluctuation in the initial phases of growth (Sandstrom et al. 2014). Non-indigenous species, indicator microbes, and human pathogens found in the ballast water discharge have the capacity to survive for long periods of time (David, Gollasch & Pavliha, 2013). Moreover, Werschkun et al. (2014) pointed out that species invasion is irreversible and potentially grows worse over time.

Vessel biofouling organisms are found on wetted and submerged surfaces of the marine vessel (Brown et al. 2017). Biofouling organisms transfer by detachment from host structures and the release of large volumes of larvae. Sandstrom et al (2014) asserted that climate variability, density dependence, and fisheries, along with the underlying mechanisms that contribute to the variability, are critical factors in the survival of specific species after instances of population collapse.

Current Methods of Ballast Water Exchange

Disinfection methods for ballast water must comply with industry regulations, with a minimized environmental footprint. Electrochemical disinfection encompasses microorganism eradication with adequate electrodes (Batista et al. 2017). UV irradiation is an anti-bacterial filtration treatment for aquatic species in the ballast water uptake. Batista et al. (2017) described ultraviolet irradiation and electrolytic disinfection as the most common types of ballast water treatment strategies, which cause conflict in the context of how they are used.

The UV treatment approach is generally regarded as an environmentally friendly, low maintenance treatment approach for pathogens and bacteria. Electrolytic disinfection or electro-chlorination is achieved by the generation of ($CI_{2(g)}$) reactions with water to produce an (HOCl) oxidant. Cha, Seo, Lee and Choi (2015) investigated outcomes from the use of ballast water CO_2 injections on electrochlorination in processes of bacteria and plankton disinfection. The CO_2 was found to promote a significant improvement in ballast water treatment efficiency. Brown et al. (2017) argued that vector management approaches are the most suitable for prevention of invasive species introductions by ballast from marine vessels.

Quilez-Badia et al (2008) applied a brief, high temperature treatment to a marine vessel used to transport automobiles between Egypt and Belgium. Ballast water was exposed to temperatures between 55°C and 80°C. The increase in temperature was found to cause bacteria, zooplankton, and phytoplankton mortality. Moreover, the kill rate increased; however, the researchers could not confirm an improvement to the efficacy of the heat.

Bioinvasions and subsequent changes in biodiversity have been the focus of the development of monitoring tools and disinfectants to aid in effective ballast water treatment management (Werschkun et al. 2014). The principal modes of disinfection center upon the environmental impact upon discharge, efficiency, and practicality. Moreover, the same electrochemical disinfection methods used in drinking water and industry have been tested as potential disinfectants in seawater and wastewater.

Marine vessel exchanges.

Werschkun et al. (2014) supported that approximately 66% of globally traded goods are transported by merchant ships. Ghosh and Rubly (2017) projected that over 10 billion tons of ballast water are moved by vessels in the facilitation of global trade, each year, with the effect of risk to human health and natural habitats for a diversity of aquatic species due to the transfer of none native species and pathogens. Whittle et al. (2013) contributed that the need for biosecurity through heightened regulation and surveillance has increased dramatically since the open of the new millennium, as industrial and maritime capabilities advance and increased production and transport negatively impacts the environment.

Brown et al. (2017) supported that retention is the optimal strategy for ballast water management. Whittle et al. (2017) presented surveillance as a risk management strategy for ballast water management onboard the vessels. Carney et al. (2017) investigated the effects of trade dynamics and ballast water management on the unintentional transfer of marine organisms by ship. Zooplankton concentrations in ballast waters sampled between 1993 and 2000 were recorded as pre-management; while samples from 2012 to 2013 were recorded as post-management. The data regarding uptake, ballast water management, and discharge were compared for the two eras. The outcomes confirmed that the ballast water propagule pressure in a specific geographic region is driven by a diversity of factors which fluctuate over time with the capacity to undermine the BWM strategy.

Ballast water treatment systems

Chlorine dioxide has been deemed the best approach to turbidity treatment in ballast water systems. Ozone has also been highly regarded as an oxidizing biocide for micro-organisms and as a gas with an ozone generator. Ultraviolet light is used as a direct producer of ozone in the ballast water to produce bromates. UV irradiation and electrolytic disinfection treatment strategies have also been generally regarded as low maintenance and ecofriendly (Batista et al 2017). Discharge rates for ballast water is typically proportionate to the tank size; however, ballast water exchanges are not feasible for vessels limited to on-shore activities (Albert et al. 2010). Ballast water management in steel hulled vessels achieve a reduction of stress and stabilizes transverse; improves maneuverability and propulsion; and compensates for weight changes at different loads due to the consumption of water and fuel (Koncept Analytics, 2017).

The United States Environmental Protection Agency (EPA) has advocated for international ballast management laws in regard to dumping ballast water. Whittle et al. (2013) supported that surveillance and detection mechanisms for rare events in the oceanic environments are critical risk management tools in support of the biosecurity of the natural environment, human health, and agricultural interests. Truncated seismic and construction surveillance mechanism designs may meet the maritime stakeholders' demands for efficiency, effectiveness, regulatory compliance, and corporate objectives.

Baltic and International Maritime Council (BIMCO) President Denholm highlighted the urgency of the expedient implementation of the most appropriate ballast water laws and the associated costs based upon the current global economic climate (Ndlovu, 2016). The BWM Convention Regulation B-6 requires the seafarer to become proficient in the responsibilities outlined for every vessel assignment (Ghosh & Rubly, 2017). The ballast water management system (BWMS) typically conforms to the BWM Convention, regulation D-2 discharge standards for a diversity of organism classes and sizes (Batista et al. 2017). Regulation D-1 requires the exchange of no less than 95% of the ballast water volumes a minimum of 50 nautical miles from shore and at 200 m or more in water depth.

Onboard BWM Solutions

Batista et al. (2017) proposed that the onboard ballast water plans and management system (BWMS) may be a solution to the marine ballast water problem when properly utilized. In the same context, Coldharbour Marine CEO Marshall (2018) asserted that a significant percentage of marine vessel operators are deficient in the required understanding of the technologies associated with ballast water treatment in real-life applications, which has been reflected as a lack of due diligence (Marex, 2018). Werschkun et al. (2014) supported that mechanical-physical and chemical methods of onboard ballast water treatment are typically executed with an initializing hydrocyclone constitutes or the use of particle filters. The mechanical-physical onboard method is characterized by particle separations, cavitation and ultrasound destruction of particles, and molecular level destruction by UV radiation, electric pulse, or heat. The chemical onboard methods utilize halogen-free oxidative processes; denaturing with aldehydes and pH shift; surface active quaternary ammonium salts; and coagulation. UV irradiation filtration methods minimize the environmental footprint caused by the release of chemicals and byproducts into the waters (Batista et al. 2017).

Successful aquatic species invasions are followed by phases of reproduction, proliferation, and dispersions which create new alterations to the natural food chain (Sandstrom et al. 2014). A percentage of the transferred organisms and pathogens significantly damage or destroy aspects of the host ecosystem due to incompatibilities across populations, climate, and local environmental factors. Vessel Crews have expressed that the testing data and certifications issued under the ballast water management system operations do not match the environmental conditions faced on the vessel each day (Marex, 2018). Moreover, De Baere et al. (2014) supported that in addition to the ballast water exchange problem, the ballast tanks must also be protected from corrosion; and particularly corrosion of the sacrificial nodes.

Whittle et al. (2013) proposed a method for the manufacture of risk-based surveillance equipment for observation of non-indigenous plants, vertebrates and invertebrates which may potentially be introduced to natural areas by industrial projects in the interests of biosecurity. Painter et al. (2016) proved the particulate organic carbon downslope flux from the Hebrides Shelf to be three to five folds larger than the global mean per unit length/area. Particulate and carbon fraction offshore transport was achieved by Ekman Drain and compared to simultaneous fluxes. The total offshore particulate organic carbon flux measured 0.007 Tg C d^{-1}; while the air-sea CO_2 flux measured 0.0021 Tg C d^{-1}. Cha et al. (2015) performed chlorination to measure the outcomes of CO2 injections on plankton in a ballast water simulation. The total residual oxidant concentrations declined faster in brackish and marine waters treated with electro-chlorination as opposed to waters with chlorine + CO_2 treatments.

Bakalar (2016) compared the functionalities and malfunctions of five ballast water treatment system and operator experiences aboard maritime vessels with consideration for environmental sustainability issues. A sample of 68 Officers and vessel Masters who work aboard ships with ballast water treatment systems were surveyed. The most recurring challenges were system efficacy, maintenance, and consistency issues and tracking for the ballast operations from the shore. The highest ranking ballast treatment system was the deoxygenation process for both port and at sea. Approximately 7% of the sample asserted that all of the ballast water treatment methods were problematic. The participants also asserted approximately 9% of the total operating time was consumed with system maintenance and repairs. Bakalar (2016) concluded that inefficient ballast water system functioning increases costs and the negative impact on the environment.

Knowledge of the impact of undesirable ballast water transfers on the natural environment, ecosystems, and public health is critical to future environmental sustainability and acceptable standards of global public health. Cvetkovic, Kompare and Klemencic (2015) presented that a gap exists in the literature in regard to hydrodynamic cavitation applications as a potential ballast water treatment solution. Sandstrom et al. (2014) presented that future studies of ballast water treatment strategies on aquatic populations should investigate the impact of harvesting and mortality in the context of population collapses.

Ballast Water Management

Ghuge (2018) described the dynamics of the ballast water management market as a demand for ballast treatment systems due to a need to conserve the marine ecosystem as well as public health and projected future growth of the market at a rapid pace. Optimarin CEO Anderson reported record breaking performance in 2017, to include 550 system sales and 440 systems delivered around the world (ShipInsight, 2018). Systems testing has risen to the top of the global agenda for regulators and private industry as ballast water systems revenue continues to grow at an exponential pace (Laursen, 2018). Drivers of the growth rate include the massive requirements for ballast water management by the United States Coast Guard and the United States Environmental Protection Agency; the increase in demand for cargo ships; and the updating standards of the IMO. Koncept Analytics (2017) asserts that future trends in the ballast water treatment market will encompass an increase in adoptions of the IMO requirements; critical technological advancements; and new conventions for ballast water. Desales (2018) recognizes increases in population centers as an additional driver of future market growth in ballast water treatment systems over the next eight years.

Mouawad Consulting CEO Maouaway describes the administrative and regulatory actions of the ballast water treatment industry leaders and national regulators as equivalent to fumbling in the dark (Laursen, 2018). The *2018 ShipInsight Ballast Water Guide* is a pioneering publication in support of future solution systems to meet the maritime regulatory, technical, and research. It requires of the United States marine pollution authorities; compliance guidance for ship owners; and examinations of future ballast water treatment system market; how the market changes will affect the installation system manufacturers; and what the changes mean for the ship owners. Several announcements in the context of maritime regulation changes and projected impacts beyond 2018 have contained (Latarche, 2018):

- The United States Coast Guard stated that ships which face compliance by January 2021 will likely not be granted any extension of time (Latarche, 2018).

- Differentiations between the United States maritime regulations and approval processes and those of the IMO may translate to future conflicts and an eventual conversion back to prior standards. Type approval differentiations have translated to fewer system approvals.
- A Same Risk Area (SRA), where vessels operate in regions of shared species, has not been established despite national negotiations by South East Asian and Baltic states.

The Guide also presents potential solutions to eliminate shore-based treatment system installations; alternative designs for hulls; and SRAs.

Training of vessel crews is an integral part of the implementation of the most recent IMO standards and United States Coast Guard requirements. In order to minimize the number of complex conditions which escalate to become problematic, the vessel crew and more specifically the vessel crew's responsible parties must be knowledgeable of all aspects of the Convention and the requirements for Ballast Water management certification. In essence, the competency of the vessel crew and responsible parties have a significant effect on outcomes in the contexts of environmental sustainability, public health, and natural resource management.

No ballast system concepts

Albert et al. (2010) addressed the hindrances to future sampling protocols for the quantification of ballast water treatment system efficacy in shipboard and land-based testing. A harmonization of ballast water testing methods is needful. The space requirements are considerably reduced in proposed designs, as the ballast water treatment system requires large amounts of space in the vessels' machinery areas. The Japan Ship Technology Research Association proposed tankers which would not require ballast water when empty by a design that features V-shaped hulls and wider beams (ShipInsight, 2018). Namura Shipbuilding proposed a minimal ballast water ship (MIBS) VLCC design which was approved by the Japanese

Classification Society ClassNK. Further, compliance with the new rules set forth in the ballast water treatment plan require systems, procedure, and processes training.

Ballast Water Treatment Market Segmentation

Ghuge (2018) described the ballast water treatment market segmentation by vessel type, technology types, capacity, and by the vessel category. The market may be further segmented on the basis of technologies by solid-liquid separation, chemical dechlorination, and disinfection. On the basis of vessel types, the market segmentation may be divided into:

- container ships
- break, dry bulk
- multi-purpose / OSV, and
- tankers

By capacity, the market may be segmented as:

- $\leq$ 1500 cubic meters;
- 1500 to 5000 cubic meters; and
- $\geq$ 5000 cubic meters.

Vessel types include low and high ballast types. Desales (2018) described the new age equipment segmentation of the ballast water management market in terms of construction and demolition, manufacturing products, engineering equipment, and heavy industry. Capital intensive ancillary industries are characterized by low transportability and high barriers to market entry.

Retrofit installations will also produce big business in the global market, as vessel owners pursue compliance and increased efficiency (ShipInsight, 2018). Retrofit options for in-service vessels provide flexibility; optimizes time management; quality assurance; contingency and the ease of commissioning (Harris Pye, 2016). The retrofit shipyard issues include inflexibility, access restrictions, Critical Path risk, commissioning pressure, and lack of contingency. The retrofitting process for ballast water treatment systems begins with a preliminary design, followed by engineering isometrics, prefabrication, commissioning and training (Harris Pye, 2016). The process can take approximately six months based upon the efficiency of the required operations. Retrofit movement in the market has been slow due to shipowners shying away from the additional costs.

Ballast Water Exchange Regulation

The 33 CFR § 401.30 (e)(2) supports that "every vessel that enters the seaway or the Great Lakes must comply with the 2001 Voluntary Management Practices to Reduce the Transfer of Aquatic Nuisance Species Within the Great Lakes by United States and Canadian Domestic Shipping" (USCG, 2004). However, the National Invasive Species Act of 1996 (NISA) includes exemptions for certain instances of coastwise ballast water discharges from passenger ships. Sec. 1101(c)(2)(K) provides discharge exemptions for passenger vessels with ballast water treatment systems except cases in which the ballast water exchange would provide a more effective approach to species transfer risk reduction (Verna & Harris, 2016). Moreover, Sec. 1101(c)(2)(L) provides discharge exemptions for crude oil tankers which engage solely in coastwise trade.

The United States Coast Guard Alternate Management System (AMS) provides for five years of admission for non-US IMO systems, until the U.S. compliance is met (World Shipping Council, 2018). In the event that the compliance is not met within five years from the compliance date, retrofitting with a U.S. Type approval will be required for continued operation. However, the AMS is projected to drive market growth in the North American region (ShipInsight, 2018).

The INO D-2 Ballast Water Performance Standard for discharged ballasts also requires 1 CFU per 100 ml for *Vibrio cholera*; 250 CFU per 100 ml for *Escherichia coli*; and 100 CFU per

100 ml for *Intestinal Enterococci* (Harris Pye, 2016). The ultraviolet system is heralded for a small environmental footprint, high energy efficiency, and chemical-free approaches toward consistency in operations with minimal risks of corrosion (Alfa Laval, 2018). Shirshath (2018) investigated the point-of-use water treatment system market and the associated emerging commercial landscapes. Anti-fouling systems have evolved to correct hull fouling and niche fouling in the sea chest (World Shipping Council, 2018). Significant hull fouling amplifies the costs of operations in large vessels; therefore, niche fouling is not most effectively addressed by antifouling systems.

United States Coast Guard Alternate Management System (AMS)

Old habits die hard, as old ship owners and crews struggle to adjust to the new management conditions and rapid changes in maritime equipment technologies. The crews are plagued with old attitudes in a new era, and struggle with new demands without new training (World Shipping Council, 2018). The role of ballast water treatment systems manufacturers, beyond sale and delivery of the advanced systems, remains undefined. The United States Type Approval does not accept the IMO standard as the minimum requirement; but instead provided a more aggressive schedule for shipboard and land-based testing (World Shipping Council, 2018). Discrepancies between standards have been resolved temporarily with arbitrary agreements. Further, the ballast treatment system manufacturers cannot guarantee full efficiency of the systems after installation, and does not guard against unforeseeable or unique complexities; particularly the technical issues that arise at sea and in port.

Industry Leaders

Optimarin was the first ballast water management system manufacturer to offer a five-year warranty on the product; and the Optimarin Blast System (OBS) was the first system to obtain full approval from the United States Coast Guard in 2016. However, Latrache (2018) questioned the necessity of fitting legacy vessels with ballast water systems based upon exemptions from the IMO, United States regulation and technical alternative solutions which have yet to be perfected. *PureBallast 3.1* by Alfa Laval has been highly regarded for large flow ballast water treatment as the trend toward UV methods over electrochlorination continues (Alfa Laval, 2018). PureBallast, with an enhanced ultraviolet reactor, was the first ballast water treatment solution to be offered on the commercial market for ballast, oil and gas industry, and power plants. Further, *FutureProof* ballast water technology by Coldharbour has been highly regard for the design, which is optimized for large product tankers, bulk tankers, bulk carriers and LNG vessels.

Ship owners must be educated and vessel crews must be trained to maintain the ballast water treatment systems (World Shipping Council, 2018). Disruptive ballast water treatment models and due diligence generate new streams of revenue for testing centers and treatment center manufacturers. Approximately 51 nations signed the Ballast Water Management Convention through 2016, which represents approximately 34.87% of the Gross World Tonnage (Harris Pye, 2016). As of 2016, the United States Coast Guard has required the installation of Type Approved systems at the closest docking appointment. Moreover, the Alfa Laval, DESMI, Hyde, and the Trojan have passed the testing with Most Probable Number; however, the United States Coast Guard was reluctant to accept it (Harris Pye, 2016). A Ballast Water Treatment Technology Conference scheduled for April 2018 in the Netherlands is expected to produce updates in technology and strategies for ballast water treatment management strategies, as well as regulation updates in regard to compliance and costs. A second Denmark conference is also scheduled in the same week to resolve ballast water exchange issues.

Future Trends and Conventions in Ballast Water Treatment

Researchers have explored ballast water testing (Albert et al. 2010; Laursen, 2018); marketing and future market trends (Ghuge, 2018; Desales, 2018); treatment, and storage for military and merchant maritime vessels (Koncept Analytics, 2017; Latarche, 2018; Balakar, 2016); and uptake and discharge avoidance (Olsen et al. 2016). However, inadequacies in the United States Coast Guard Independent laboratory certification testing and the IMO G8 Guidelines have been attributed for the water testing outcome being unreliability and compromised in quality. Laursen (2018) conjects that the closure of the DHI Singapore and Maritime Environment Resource Center (MERC) testing facilities is an indicator of the future of the industry. GlobalTestNet has also been confronted with making improvements to its international platform for ballast water treatment research. Moreover, the costs of the testing remain exploitive at more than $1 million to conduct 15 tests.

Koncept Analytics (2017) projected that the global market for ballast water treatment systems will realize favorable growth due to factors of increases in sea borne trade; an increase in merchant ships; an acceleration of economic development in developing nations; and an increase in platforms for public health and environmental sustainability. Latarche (2018) supported that:

> Although marine vessels have used sea water for ballast for more than 100 years, ballast water treatments for organism removal is a new phenomenon in the shipping industry despite pioneering steps toward filtration schemes to reduce the build up of sediment in the ballast tank of a specific ship (p. 17).

Mouawad Consulting CEO Maouaway argued that five global testing centers are responsible for the world demand for ballast water testing in the same water conditions while international interpretations of the IMO G8 are different (Laursen, 2018).

Natural connectivity by waterways between Russia, Japan, Taiwan, China and South Korea is significant to cargo vessel traffic and will contribute to future market growth (Ghuge, 2018). Point-of-use water treatment models that have emerged in the global market such as Denmark's DESMI Ocean Guard who has contracted with the Turkish MISHA Shipping for a full supply of CompactClean Ballast Water Management Systems from 340 cu.m/h to 750 cu.m/h (MISHA, 2017). MISHA's decision to use the DESMI CompactClean system due to suitability to 50 m^3/h to 3,000 m^3/h flow rates. Moreover, the CompactClean was selected due to the brand reliability; ease of operations, Capex and Opex; and the size of the environmental footprint.

Creative Project

The scope of the creative project is a quantitative assessment of the impact of contrasting temperatures on ballast water exchanges in coastside and overseas maritime activities. The sample data used to conduct the assessment will be extracted from the United States National Ballast Information Clearinghouse, Ballast Water Delivery and Management Database.

The rationale for the creative project method is based upon prior studies which identify temperature as a critical factor in marine ecosystems and maritime vessel activity. Hunt et al (2005, 324A) included water temperature as a challenge condition for assessments of ocean water quality, tests for species, and estimations of hydraulic loading. More specifically, water temperature, dissolved organic matter, and solids were cited as "problematic" for the ballast water treatment system. Gollasch & Leppäkoski (2007) upheld that potential aquatic invasive species originate more often from warmer regions; therefore, it may be theorized that changes in temperature and salinity may influence invasion patterns and population dynamics.

Planning

The planning for the project is divided into 4 phases: (1) research; (2) statement of the scope or objective; (3) scheduling; and (4) implementation. Phase one of the plan encompasses further research of ballast water exchanges, currently available technological systems, and the free zone maritime traffic along the east coast of the United States. Phase two encompasses an evaluation of the project aim and method based upon the outcomes of the research. Phase three will produce a more concrete timeline and outlook for the completion of the project. Phase four will document the initiation of activities toward the implementation of the project.

Participants

The participants for this project will consist of the researcher; the United States National Ballast Information Clearinghouse; ballast water management system manufacturers; and Miami and Boston port personnel.

Method

A quantitative examination of maritime data from Miami, Florida and Boston, and Massachusetts ports has been selected as the method for this research. The effect of the ballast water transfer based upon temperature changes from warm to cold will be investigated by multi-criteria analysis of a data series based upon criteria associated with different temperature regimes during travel and corresponding transfers in diverse temperatures. Differences in ballast water exchanges between vessels which travel outside the free zone will also be identified.

The National Ballast Information Clearinghouse Online Database reports provide logs for discharges of ballast water overseas, coastside, and areas marked as “unknown” according to the requirements of 33 CFR §151.2041 (NBIC, 2018). Tables 1 and 2 show a small sample of the data that will be extracted from the United States National Ballast Information Clearinghouse, Ballast Water Delivery and Management Database for the project:

Boston, Massachusetts Port	
Vessel	*Cs Jenna*
Departure Port	Port Puerto Plata, Doo
Discharge Volume [MT]	
Overseas	14335
Coastwise	0
Unknown	672

Table 1. *Cs Jenna* (Author created, 2018)

The *Cs Jenna* uses an ID AMS-2013-PANASIA-GloEn-Patrol-001 ballast water exchange treatment system. A sample of the Miami Port data is presented in Table 2:

Miami, Florida Port	
Vessel	*Seaboard Patriot*
Departure Port	Puerto Cortes, Honduras
Discharge Volume [MT]	
Overseas	810
Coastwise	1307
Unknown	0

Table 2. *Seaboard Patriot* (Author created, 2018)

The *Seaboard Patriot* uses an ID AMS-2013-Hyde-Guardian-001 ballast water exchange treatment system. The Ballast Water Management System addresses three types of salinity regime and temperatures between 4°C and 35°C. Figures 1 and 2 show the average sea water temperatures for the Boston and Miami ports:

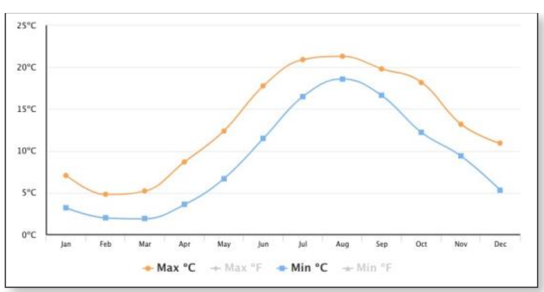

Figure 1. Boston Port Average Temperatures for 1 Year (Sea Temperature, 2018)

Figure 2. Miami Port Average Temperatures for 1 Year (Sea Temperature, 2018)

The average annual temperatures for the Boston seawater ranged from a minimum of approximately 3°C and a maximum of approximately 21°C. The average annual temperatures for the Miami seawater range from a minimum of approximately 22°C and a maximum of approximately 31°C. The Miami port temperatures are significantly higher than the temperatures in Boston consistently over the course of the year. The temperature differences for the two ports were noted from an annual perspective to match the period from the vessel data collection.

Materials

The materials required for project implementation are the data sheets for the maritime vessels at the Boston and Miami Ports. The data assessment of the ballast water exchanges between the two ports will be analyzed using StatPlus and IBM SPSS software. The materials for the research will also include commercial publications of ballast water treatment systems and the operational processes associated with the systems for a multi-criteria analysis.

Data for the project will be extracted from the United States National Ballast Information Clearinghouse, Ballast Water Delivery and Management Database for a Boston, Massachusetts port and a Miami, Florida port. The ballast water exchange information for marine vessels provide arrivals and departures for the Boston and Miami ports, to include the highest records of ballast water exchanges coastside and overseas. The marine vessels from the Boston and Miami ports which executed a minimum of five overseas trips within the same period will highlighted.

Ballast Water Treatment Systems

Ballast water treatment systems used in the maritime vessels used in the creative project sample have certification in ballast water discharge standards according to the requirements of the United States Coast Guard, the IMO, or both. Some manufacturers have appealed to the Environmental Protection Agency (EPA) 2013 Vessel General Permit (VGP). The disinfection technologies used across the sample of commercial vessels for this study include UV, UV combination, chlorination, oxidation, disinfection, electrolytic, and deoxygenation.

Ultraviolet irradiation and electrolytic disinfection are the predominating types of ballast water treatment systems used in different combinations of fresh, salt, and brackish waters. Differentiations between systems also include flow rates, ultraviolet intensity, and differential pressures across the filters.

The most commonly used Ballast Water System Treatments for the sample were AMS-Hyde-Guardian-001; and Swedish AMS-Alfa Laval-Pure Ballast-002 and -003. The Ballast Water Treatment systems which were less common across the data were STEP Vessel; AMS-Techcross Electro-Cleen; and AMS-GEA Westfalia BallastMaster-001; AMS-2016-BSKY BWTS-001; AMS-2013-JFE BallastAce-001; and AMS-PANASIA-GloEn-Patrol-001.

AMS-Hyde-Guardian-001.

The Hyde Water Ballast Water Treatment System is used by more than 400 owners of marine vessels, approved by the IMO and the United States Coast Guard types, and is considered by many to be one of the most used system (Hyde Marine, 2018). Vessel types include RoRo, drill ships, carriers, container and container feeder ships, general cargo, LNG and LPG carriers, and river liners. The Hyde-Guardian utilizes the high intensity, ultraviolet treatment system of disinfection. The UV dosage is derived from an integration of lamp power flow paths and exposure times.

BWMS ID (AMS) - Alfa Laval-Pure Ballast-002

The AMS-Alfa Laval-Pure Ballast is approved by the IMO and the United States Coast Guard types and may be used for new installations, commissioning, and retrofits (Alfa Laval, 2018). Approximately 1600 of the biological disinfection systems have been purchased worldwide. Vessel types for Pure Ballast include carriers, container and container feeder ships, naval, shuttle tankers, RORO, general cargo, LNG and LPG carriers, and river liners. The Alfa Laval-Pure Ballast is ideal for marine, fresh, and brackish waters.

BWMS ID (AMS) - STEP Vessel

Shipboard Technology Evaluation Program (STEP) marine vessels are approved for use according to the requirements of 33 CFR §151.1510 to §151.2025. The STEP is often used for research & development, and prototyping for ballast water treatment systems and the pursuit of USCG type approvals.

BWMS ID AMS - Techcross Electro-Cleen

The Korean De Nora Balpure Techcross Electro-Cleen was presented to the USCG for approval in brackish and marine waters in 2015 as the first Korean BWMS manufacturer to complete the testing requirements of the Coast Guard. The Techcross Electro-Cleen system utilizes electrolysis technologies and $CI_{2(g)}$ reactions with water to produce HOCl oxidants to treat ballast water invasive treatments.

BWMS ID - GEA Westfalia BallastMaster-001

The GEA Westfalia BallastMaster was submitted to the IMO according to the IMO D2 standards for ballast discharge for approval by manufacturer GEA. The electrolysis method is used in the BallastMaster ecoP model; while the UV radiation is offered in the BallastMaster ultraV model. The BallastMaster ultraV achieves disinfection by monochromatic, 254 nm ultraviolet-C radiation. Both models are used in new international trade maritime fleets, as well as retrofitted into older marine vessels from 2012.

BWMS ID (AMS) - 2016-BSKY BWTS-001

The 2016-BSKY BWTS-001 was submitted to the USCG for approval in brackish and marine waters by the Chinese Wuxi Brightsky Electronic Company in 2013. Since then, the original model has been revised and extended.

BWMS ID (AMS) - 2013-JFE BallastAce-001

The 2013-JFE BallastAce-001 was submitted to the USCG for approval by the JFE Engineering Corporation according to the requirements of 33 CFR §151.2026 (a)(5). The ballast water treatment system was preset to increase flow rates for flushing automatically when differential pressures across the filters reach 0.5 bar. When the differential pressure exceeds 0.7 bar, an alarm sounds. The 2013-JFE BallastAce-001 was designed for all types of water salinity. The ballast water system was accepted by the United States Coast Guard in 2014.

BWMS ID (AMS) - PANASIA-GloEn-Patrol-001

The PANASIA-GloEn-Patrol-001 was submitted as a BWTS in brackish and marine waters to the USCG according to the requirements of 33 CFR §151.2026 (a)(5), and to the Republic of Korea Ministry of Land, Transport and Maritime Affairs for review by Panasia Co. Ltd. The differential pressure limit across filters is 0.5 bar. The ballast water system was preset to increase flow rates for flushing automatically when differential pressures across the filters reach 0.45 bar beyond 3 seconds. Several models of the GloEn-Patrol ballast water system have been accepted from 2013.

The 33 CFR §151.2041 provides that ballast water reporting requirements apply for each type of vessel that is bound for United States ports and places, irrespective of whether the vessel operates outside the EEZ unless the vessel is exempted by §151.2010 or §151.2015 (USCG, 2004). A vast number of commercial marine vessel types, with a diversity of mission types operate on the open seas each year, to include training vessels. Vessel types that will be included in the sample data for the project include General Cargo, Bulker, Container, Passenger, RoRo, Tankers, and 'Other'. Although the marine vessels in the sample use ballast water treatment systems from many of the same manufacturers, the model numbers and methods differ across manufacturers.

Timeline

The research will be conducted during a period of 3.5 years. The proposed timeline for the study is presented in Fig. 3:

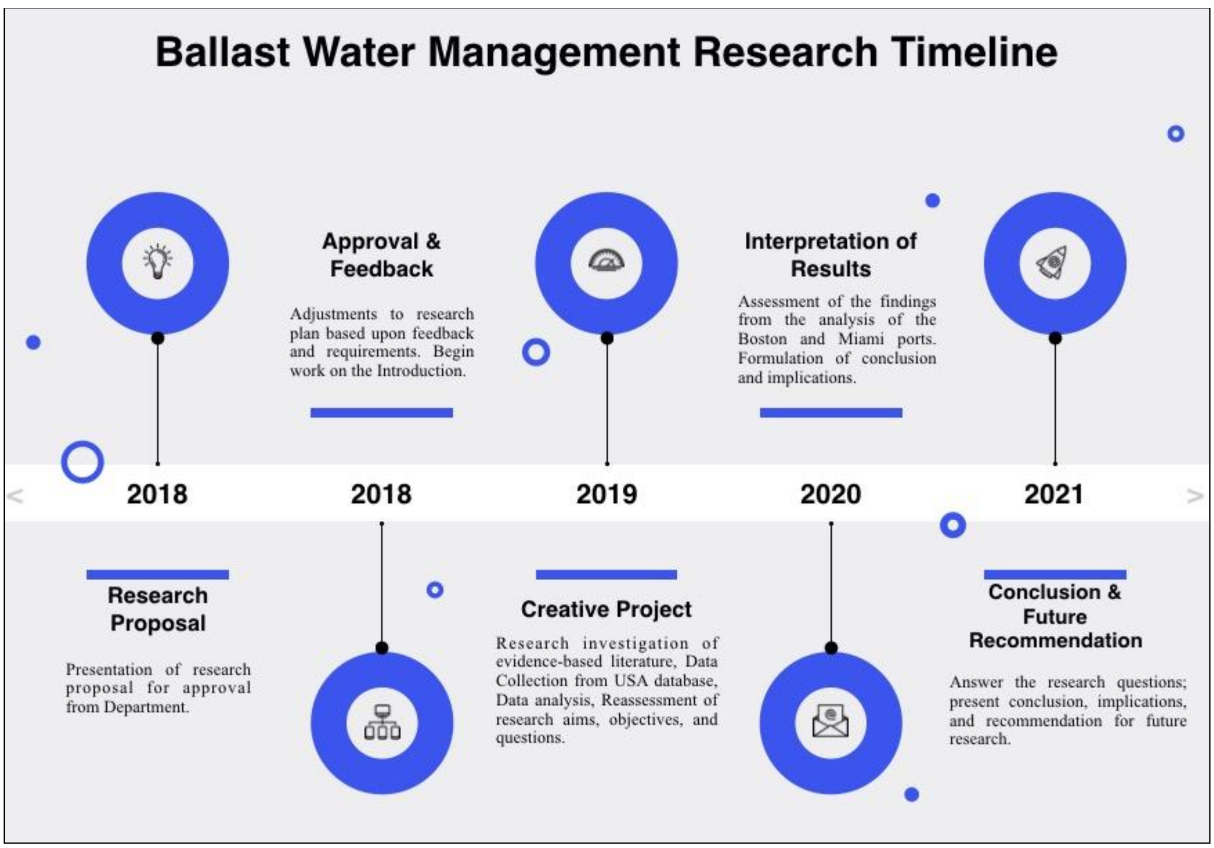

Figure 3. Proposed Timeline for Research (Author Created, 2018)

Implementation

The implementation phase of the project will consist of all of the deliverables necessary to answer the research questions, after the research has been conducted from the database and categorized as .CVS files for analysis. The outcomes of the data analysis will be presented and the research questions will be answered according to the outcomes.

Assessment

Temperature dynamics are the primary focus of the project; however, other factors which may be assessed with the same data will also be considered. The E/R, empty/refill exchange defines the emptying of the ballasted tank by pumping and gravitation. The FT, flow-through exchange defines the mid-ocean pumping method into full tanks or hold from below with water volumes 300% larger than the capacity of the ballast tank (NCIB, 2018). The type of vessel, and more specifically, whether the vessel carries passengers or cargo must also have a significant impact on the reported ballast water discharges. The project hypothesis supports that whether the maritime vessel operates solely along the coastline or across the open seas also influenced trends in the ballast water discharge reports.

Summary and Conclusion

A preliminary investigation of ballast water exchanges and the impact of temperature on the maritime vessel performance in the context of biosecurity has been examined. Aquatic species invasions are followed by phases of reproduction, proliferation, and dispersions which create new disruptions to the natural food chain (Sandstrom et al. 2014). Biofouling organisms detach from the host structures and release of large volumes of larvae. In the interest of biosecurity, the market for the manufacture of ballast water treatment systems has grown. Most maritime vessel operators use UV irradiation filtration methods to treat ballast water exchanges

(Batista et al 2017). The outcomes of the ballast water treatment systems have varied as some operators have been successful in making a complete transition; while others have not achieved compliance.

The research, thus far, supports that the current regulation and certification programs for maritime vessels to mitigate the debilitating effect of ballast water exchanges are deficient. Global and national regulations for retrofitting older vessels with Ballast water treatment systems have been enacted; however, compliance to the industry standards has lagged. It may be concluded that a lack of knowledge and understanding of the new ballast water treatment systems are significant challenges to the full implementation of improvements to ballast water management regimes (Marshall, 2018; Batista et al 2017). A number of maritime vessel operators are unaware of all of the stipulations for ballast water exchanges. Moreover, Cvetkovic, Kompare and Klemencic (2015) identified a gap in the literature in regard to hydrodynamic cavitation applications as a potential ballast water treatment solution.

Marcx (2018) highlighted the challenge of vessel crews who argue that the testing data and certifications issued under the ballast water management system operations do not match the daily environmental conditions to which the vessels are exposed (Marex, 2018). The discharge standard established under the USCG and the IMO were originally developed to apply to all ballast water treatment strategies. Hunt et al (2005, 325A) confirmed that “ballast water treatments may transpire in a diversity of scenarios, based upon a simple cycle ballasting, transit, and deballasting”. Beyond the EEZs, the maritime vessel remains subject to the 33 CFR 401.30 Ballast water and trim (e)(1) and (e)(2). The 33 § CFR 401.30 (e)(1) supports that “every vessel that enters the seaway beyond the EEZ must comply with the 2000 Code of Best Practices for Ballast Water Management” (USCG, 2004). However, Hunt et al (2005) argued that the capacities and limitations of ballast water treatment systems that are most used around the world, during typical ballasting operations, and within the ballast tanks remains poorly understood.

Ballast water treatment technology over the global market has been met with compatibility issues following the IMO Convention. Moreover, the extensive, ongoing costs of new installations and training workshops have repelled some industry participants, who have not been convinced by the IMO that the ballast water systems are needful, although retention of IMO class is dependent upon adaptation to the policies. Future research based upon a quantitative method to test correlations between water temperature and aquatic invasive species transfers may also identify a more complex rationale for the differences in ballast water discharge reports between the northern and southern port.

The creative project will present a comparison of data collected from ports in contrasting temperature demographics. Established and potential aquatic invasive species typically originate from warmer regions; therefore, it may be theorized that changes in the temperature and salinity may influence the invasion pattern and population dynamics of the invasive species (Gollasch &Leppäkoski 2007). It is hypothesized that the outcomes of the Creative Project will support that temperature factors significantly influence the annual statistics for maritime vessel ballast water discharges in addition to other geological demographics. The outcomes of this project will provide a more detailed profile of the impact of temperature on ballast water exchanges and invasive species invasions if the quantitative study is based upon a regression analysis of a series of temperatures for a larger sample of data.

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