



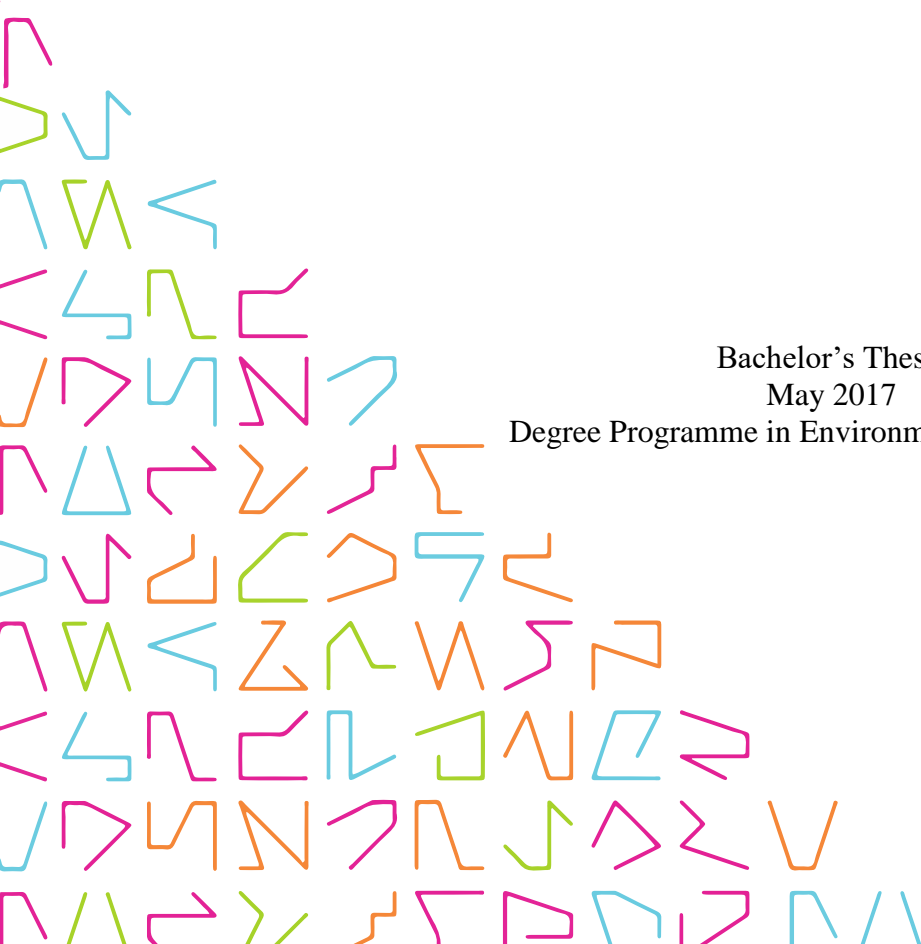
TAMPEREEN
AMMATTIKORKEAKOULU

BALLAST WATER MONITORING

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Bachelor's Thesis
May 2017

Degree Programme in Environmental Engineering



TIIVISTELMÄ

Tampereen ammattikorkeakoulu
Ympäristöinsinööri

KARJALAINEN TIMO:
Ballast Water Monitoring

Opinnäytetyö 40 sivua, joista liitteitä 2 sivua
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Opinnäytetyö toteutettiin kirjallisena tutkimuksena. Työn tavoitteena oli tutkia laivojen painovesilastin mukana leviäviä vieraslajeja ja niiden vaikutuksia ympäristöön, talouteen sekä terveyteen. Tutkimuksen tarkoituksena oli selvittää ja verrata keskenään kansainvälisen merenkulkujärjestön laatiman D-2-regulaation sekä Yhdysvaltojen rannikkovartioston sääntöjen eroavaisuuksia. Niiden lisäksi, työn kuvaan kuului painolastiveden laadunmittauslaitteiden ja menetelmien etsiminen ja analysointi.

Kansainvälinen merenkulku on ensisijainen akvaattisten vieraslajien leviämisen aiheuttaja. Suuria määriä vieraslajeja kulkeutuu uusille elinalueille laivojen painolastiveden mukana. Vieraslajit aiheuttavat haittoja ympäristölle, taloudelle sekä terveydelle. Kansainvälinen merenkulkujärjestö on laatinut regulaatiot tämän estämiseksi. Kansainvälisen merenkulkujärjestön D-2-regulaatiot astuvat voimaan 8.9.2017, velvoittaen laivanomistajat asentamaan viiden vuoden sisällä painolastiveden puhdistusjärjestelmän laivoihinsa, joka suodattaa ja tuhoaa eliöitä matkalla painolastitankkiin. Painolastiveden laatua täytyy tarkkailla puhdistusjärjestelmän toiminnan takaamiseksi. Mikäli painolastivesi ei saavuta tarvittavia kriteereitä, siitä saattaa saada sakkoja.

Monenlaisia mittauslaitteita on tällä hetkellä markkinoilla. Osa laitteista antaa suuntaanäyttäviä tuloksia ja on edullisia, kun taas toiset mittauslaitteista on hyvin tarkkoja mutta maksavat enemmän. Tarkoissa laitteissa on myös ominaisuuksia, joilla mittaustulokset tallennetaan automaattisesti tietokoneelle, eikä tuloksia voi muuttaa jälkikäteen. Tämä varmistaa mittaustulosten luotettavuuden.

Laivanomistajien ja painolastiveden puhdistusjärjestelmävalmistajien tulee päättää, haluavatko he sijoittaa epäluotettaviin vai luotettaviin menetelmiin. Luotettavat menetelmät ehkäisevät mahdollisten sakkujen saamista paremmin ja saattavat olla kokonaisuudessa edullisempi ratkaisu.

Asiasanat: : kansainvälinen merenkulkujärjestö, vieraslaji, painolastivesi, monitorointi, mittauslaite

ABSTRACT

Tampereen ammattikorkeakoulu
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KARJALAINEN TIMO:
Ballast Water Monitoring

Bachelor's thesis 40 pages, appendices 2 pages
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This Bachelor's Thesis was conducted as a literary research. Aim of the work was to research the spread of invasive species in ballast water tanks of ships as well as the impacts of invasive species on the environment, economy and human health. Another purpose of the work was to research, analyze and compare the similarities and differences of the International Maritime Organization D-2 regulation with regulations set by the United States Coast Guard. Final target of the project was to research and analyze ballast water monitoring instruments and methods that are available in the market.

International maritime shipping is the primary cause for the spread of invasive aquatic species. Large numbers of invasive species are carried in the ballast water tanks of ships and introduced to new ecosystems. Invasive species can cause harm to the environment, economy and human health. International Maritime Organization has developed regulations to stop this. In September 8, 2017, International Maritime Organization D-2 regulations will come to force, obligating ship owners to install a ballast water management system in their vessels within five years to filter out and inactivate organisms entering the ballast water tank. Accurate ballast water monitoring systems have been developed to ensure that the ballast quality meets or exceeds the D-2 regulations. Ballast water must be monitored to ensure that the ballast water management system is operating properly. If the ballast water is not up to standard, penalty fees may be given.

There are many different measuring equipment in the market today. Some of them give indicative result and are inexpensive, whereas others are accurate but are expensive. The more accurate devices come with properties where measurement data is stored automatically on a computer and the data cannot be tampered with. This ensures the reliability of the measurement data.

It is up to the ship-owners and ballast water management system provider to decide if they want unreliable or reliable measuring systems. Investing in the more reliable equipment can prevent possible penalty fees and can be a less expensive in the long run.

Key words: international maritime organization, invasive species, ballast water, monitoring, measuring device

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ERITYISSANASTO tai LYHENTEET JA TERMIT (valitse jompikumpi)

ATP	adenosine triphosphate
BWMS	Ballast water monitoring system
BWC	Ballast Water Convention
CFA	chlorophyll fluorescence activity
EPA	Environmental Protection Agency
FDA	fluorescein diacetate
FPSO	floating production, storage, and offloading vessel
FSU	floating storage unit
gt	gross tonnage
IL	independent laboratory
IMO	International Maritime Organization
MARPOL	The International Convention for the Prevention of Pollution from Ships
MEPC	Marine Environment Protection Committee
NZ	New Zealand
UN	United Nations
US	United States USCG United States Coast Guard
UV	ultraviolet

1 INTRODUCTION

90% of all globally traded goods are carried out by international maritime shipping, due to its low cost, and is therefore irreplaceable as a means of transporting goods. Without it, we would not be able to have the access to products and services we enjoy today, nor enough energy to meet the global need. (International Maritime Organization, 2012)

Merchant ships have increased dramatically in their number, average size and speed since the 1950s. The sector is currently estimated to grow at 8% per year until 2020, in response to widening world trade. Routes of shipping have expanded and diversified, leading to much greater quantities of ballast water being relocated more frequently, quickly, to and from an increasing number of new destinations. (WWF, 2002)

Ships use ballast, which can be solid or liquid brought into a ship as weight, to maintain proper trim, depth, structural integrity as well as keep stability in rough seas. In the past rocks and sand were used as ballast. They had to be carried into and out of the ship by hand. Solid ballast was prone to movement in high seas if not properly secured to the ship. (Transport Canada, 2017)

As vessels transitioned from wood to steel and pump technology was developed, water as ballast became the norm. Ballast water can be pumped into and out of the ballast water tanks effortlessly and requires little or no use of manual labor. Ships can have more than one ballast water tanks spread around the ship close to the hull. This allows the ships to fill the separate ballast water tank full of water. This eliminates the movement of ballast water during voyage. (Transport Canada, 2017)

Ballasting is used usually when cargo is being removed from a ship, keeps the ship level and balanced at all times. It can also be used when passing under bridges or in stormy conditions to make the ship sit lower in the water. Deballasting is mainly used when cargo is brought on board a ship. (Transport Canada, 2017)

Vessels coming into port can cause a stir in the sediment of the sea floor. The organic concentration of the water is at its highest during this time. When a ship takes in ballast water, organisms make their way into the ballasts water tanks as well. Ballast water tanks in commercial ships can carry large amounts of ballast water, varying anywhere from 100

to 100000 tons. This means that a large number of aquatic organisms can be taken up at the same time. Ships often take up ballast water in one port and discharge it in another. This makes way to the possibility of non-native species and possible pathogens being introduced to a new environment. When an introduced organism begins to have a negative impact on the environment, economy or human health it is called an invasive species. Ballast water usage has been widely accepted as being the main reason for the spread of invasive aquatic species. (Molnar, Gamboa, Revenga, & Spalding, 2008)

Introduction of aquatic invasive species can have negative impacts on the environment, economy and human health. The effects of the introduction of invasive species are different from oil or chemical spills in that contrary to them, the problem often becomes worse over time.(WWF, 2002)

Steps have been taken to stop the spread of invasive species. on 8th of September 2016, International Maritime Organization (IMO) Ballast Water Convention (BWC) was ratified and will enter force on 8th of September 2017. The BWC demands ships to equipped with ballast water management system to rid invasive organisms and gave specific parameters for the quality of ballast water discharge. The BWC regulations go by the name D-2 regulations. These regulations are implemented all over the world, giving every country and ship-owner a level playing field. (IMO, 2017)

In response to IMO's BWC, industries have developed ballast water management systems (BWMS) to eradicate invasive species from ballasts water. There are currently over 160 separate BWMS that have been type approved by IMO. (IMO, 2016)

To make sure that a ships ballast water complies to D-2 regulations, ballast water monitoring systems have been developed. These sampling and monitoring systems can and should be used to determine the efficiency of the BWMS fitted within a ship to avoid possible penalty fees. (Bradie et al., 2017)

2 AIM

Aim of this research was to research the various negative impacts caused by using ballast water and get familiar with the ballast water standards and requirements set by IMO and United State Coast Guard (USCG), analyze and make a comparison of the two in detail. After comparing the regulations, research was conducted to find sampling and methods of analyzing ballast water that comply with set regulations. Then research was directed at finding existing sampling, testing and monitoring equipment and methods currently available in the market and study the possibility of potential productization of monitoring equipment for ship-owners' ballast water self-testing.

3 INVASIVE AQUATIC ORGANISMS

3.1 Extent

It is estimated that, at any given time, 10000 species are being transported around the world in ballast water tanks. Most species die during long voyages in the ballast water tanks due to the dark and often dirty condition of the tanks. As environmental management of marine port has become better and cleaner, it has become easier for invasive species to establish themselves in new areas. As ballast water tanks have become cleaner, destinations are more varied and the voyage durations have gotten smaller, more and more species survive the trip. Due to these factors and the increase of marine shipping, the rate of foreign species getting established in foreign ports has increased dramatically. In U.S Australia and New Zealand (NZ), a new species establishes itself every 32-85 weeks, and that number is expected to increase. Scientists have now discovered 252 invasives in Australia, 215 in NZ, 212 in California, and 91 in Hawaii. (Bax, Williamson, Aguero, Gonzalez, & Geeves, 2003)

Invasive non-native aquatic organisms have in the past and are continuing to transform habitats around the globe. Unlike oil spills or other pollution, the problem with invasive species gets worse with time. Currently 84% of the 232 marine ecoregions have reported on having invasive species in their waters. Though a clear majority of marine species introduced to environments outside their native habitats cannot survive or thrive. The species that can, may be of concern. Most harmful of these species can and have displaced native species, disrupt the local food chain and food web and can change the entire nutrient and sedimentation cycle. Invasive species can cause major damage to environment, economy and human health. (Molnar, Gamboa, Revenga, & Spalding, 2008)

3.2 Categorization

The sheer number of non-native species found in a habitat does not directly indicate the potential harm they can cause to the native species. Scientists have developed a tool to identify between harmful and non-harmful non-native species. It is a scoring system that helps determine the impact of invasive species and to decide on their threat level. Each separate organism has been given a threat-level based in the categories: ecological impact,

geographical extent, potential of invasiveness, and, management difficulty. The number of every category is added together to determine overall value. The higher the number, the higher the potential risk. The scoring is directly as follows:

3.2.1 Ecological impact

4 – Disrupts entire ecosystem processes with wider abiotic influences

3 – Disrupts multiple species, some wider ecosystem function, and/or keystone species or species of high conservation value (eg threatened species)

2 – Disrupts single species with little or no wider ecosystem impact

1 – Little or no disruption

U – Unknown or not enough information to determine score (Molnar, Gamboa, Revenga, & Spalding, 2008)

3.2.2 Geographic extent

4 – Multi-ecoregion

3 – Ecoregion

2 – Local ecosystem/sub-ecoregion

1 – Single site

U – Unknown or not enough information to determine score Invasive potential (Molnar, Gamboa, Revenga, & Spalding, 2008)

3.2.3 Invasive potential

4 – Currently/recently spreading rapidly (doubling in < 10 years) and/or high potential for future rapid spread

3 – Currently/recently spreading less rapidly and/or potential for future less rapid spread

2 – Established/present, but not currently spreading and high potential for future spread

1 – Established/present, but not currently spreading and/or low potential for future spread

U – Unknown or not enough information to determine score (Molnar, Gamboa, Revenga, & Spalding, 2008)

3.2.4 Management difficulty

4 – Irreversible and/or cannot be contained or controlled

3 – Reversible with difficulty and/or can be controlled with significant ongoing management

2 – Reversible with some difficulty and/or can be controlled with periodic management

1 – Easily reversible, with no ongoing management necessary (eradication)

U – Unknown or not enough information to determine score (Molnar, Gamboa, Revenga, & Spalding, 2008)

3.3 Environment

Most of the non-native species blend into the background of their new habitats, some can become invasive and develop into having a dominant position over native species. Once an invasive organism settles in a new environment, most likely, it will remain there forever. It will interact with, and change the surrounding environment. This can occur through increased predation, smothering by overgrowth, or by altering the structure of the habitat. With the introduction of terraforming invasive organisms, the environment can then become more favorable for other invasive organisms. This synergistic invasion is now being referred to as “Invasional Meltdown”. (Bax, Williamson, Aguero, Gonzalez, & Geeves, 2003)

3.4 Predation

An example of predation as an environmental impact, we can look to the North American comb jellyfish. The jellyfish has had a huge impact in the native environment of the Caspian Sea. The Caspian Sea is the largest inland body of water in the world. It supports large populations of commercially important planktivorous fish, mainly anchovy. The invasive comb jellyfish feeds exclusively zooplankton. Since its discovery in the Caspian Sea in 1999, it had spread over the entire area in just one year. The comb jellyfish’s feeding habits has caused the populations of the native fish to crumble. Due to its large population, it keeps the zooplankton population at a very low concentration, causing phytoplankton species to overgrow to extension of eutrophication. (Kideys, Roohi, Eker-Develi, Mélin, & Beare, 2008)

3.4.1 Smothering

The green alga *Caulerpa taxifolia*, originating from the Indian Ocean, was introduced in the Mediterranean in 1984 and has been steadily spread across the entire region ever since. The introduction most likely was due to an accidental release, not by ballast water. The alga grows on the bottom of the seabed in tight colonies, preventing native plants from growing. In 2000, 103 independent sites of *Caulerpa taxifolia* have been found. Together those areas amount to 131 km² and span across 191 km of the coast of Spain, France, Italy, Croatia and Tunis. Areas nearby offer similar growing conditions, which suggests that the alga will continue to spread. (Meinesz et al., 2001)

3.5 Terraforming

The New Zealand screw shell (*Maoricolpu roseus*) has terraformed coastal lagoons in the east coast of Australia. The gastropod changes the usually sandy seabed into a vast collection of live and dead shells, reaching from shore to depths of 80 meters. The impact on the native wildlife is not substantial, however the economic impact can be large due to the lessening of recreational use. (Nicastro, Bishop, Kelaher, & Benedetti-Cecchi, 2009)

3.6 Health

The Chinese mitten crab has come to Europe and American coasts most likely through untreated ballast water. The crab not only causes erosion of riverbeds due to its burrowing habit but can also be a carrier of *Clonorchis sinensis* (liver fluke). Liver fluke eggs are digested by aquatic snails. The larvae surface from the snails and connect to the under scales and flesh of fish and crab. If the crab or fish are consumed raw or only partially cooked, the parasite can reach the liver, causing illness including: diarrhea, fever and liver cirrhosis. (“WHO | Trematodosis,” 2010)

In 1991, Peru was overwhelmed with an outbreak of *Vibrio cholerae*. One million people were reported to have been infected and ten thousand of them died. This was the result of a ballast water released from cargo ships’. The released ballast water entered the public

water system and due to the lack of proper drinking water treatment, the bacteria was not eradicated. (Takahashi, Lourenço, Lopes, Rall, & Lopes, 2008)

3.7 Economy

Economic impacts of invasive species can be extremely vast. One of the most troublesome species has been the Black Sea zebra mussel (*Dreissena polymorpha*). The mussel is a filter feeder and lives in very tight colonies. Due to the constant flow of nutrient rich water at industrial water intake pipes, it makes for a perfect living area for the mussel. The mussel colonies can block or disrupt the inflow water significantly and they need to be removed regularly. The zebra mussel has spread across the Great Lakes as well as the coast of California costing U.S. an estimated 1 billion USD annually.

All the fore mentioned impacts of invasive species and pathogens have an economic impact when trying to eradicating or minimizing the problem. In 2004, global losses for battling invasive aquatic species was an estimated 7- 10 billion USD per year. By the date of 14th of September 2017, the estimated costs can run over 100 billion USD. (WWF, 2002)

All the estimated costs are for losses made in fisheries, aquacultures, water supply, industrial infrastructure harbors. They do not include the cost of sicknesses of humans causing loss of revenue. The costs from the loss of native species and biodiversity are extremely difficult to calculate, but can make the surrounding environment more susceptible to outside stress in the forms of global climate change, pollution and over fishing. (WWF, 2002)

4 INTERNATIONAL SHIPPING REGULATIONS

4.1 International Maritime Organization

IMO, created in 1948, is a specialized agency of the United Nations (UN). Its main responsibilities are to set standards in international shipping industry in the areas of safety, security and environmental performance that are fair, effective and are globally accepted and implemented. It was established to create an equal and level playing field within the shipping industry. This prohibits countries from cutting corners in safety, security and environmental issues in order to increase their financial gains. (IMO, 2017)

To become a member of IMO, a country must ratify the IMO's Convention. At the current time members include 171 countries of the UN and the Cook Islands. Most of the 22 UN countries that are not IMO members are landlocked countries in Africa, Central Asia and Europe. Associate members include Faroe Island, Hong Kong and Macao. (IMO, 2017)

4.2 MARPOL 73/78

In 1973, The International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted at IMO. The purpose of the MARPOL Convention was to prevent and minimize marine pollution from accidental spills as well as from the regular operations of international shipping. The initial Convention was altered in 1978 in response to the large amounts of marine oil spills that occurred between 1976 and 1977. The Convention entered force in 1983, giving ship-owners 5 years to make changes to their fleets to meet the requirement of the Convention, including the implementation of double hulls on oil tankers. (IMO, 2017.)

Since the entering force, the Convention has been updated several times due to new discoveries and sources of pollution. Currently, the Convention has six Annexes, each regulating a specific area of shipping. The Annexes include oil pollution, pollution from liquid substances, harmful substances packaged in cargo, sewage, garbage and air pollution as seen in APENDIX 1.

4.3 Ballast Water Convention

IMO started to pay attention to the spread of non-native invasive aquatic species in the 1980s, when information was brought to the attention of Marine Environment Protection Committee (MEPC), that member states around the world were experiencing problems caused by the invasives. In 1991, MEPC adopted the International Guidelines to stop and prevent the invasion of harmful spread of non-indigenes aquatic species and pathogens from the discharge of ballast water. In 2004, after 14 years of negotiations between the IMO member states, the first Ballast Water Convention (BWC) was adopted by IMO and its members. The Convention requires all the members to have a ballast water management (BWM) plan as well as to keep a record of locations and amounts of ballast water uptake and discharge. Further alterations to Annex 4, was the addition of D-1 regulations, which included the 95% content exchange of the ballast water tanks 200 nautical miles from shore with minimum depth of 200 meters during international shipping. At these distances and depths, the number of organisms per m³ is vastly less than closer to the shores, ensuring the least amount of spreading of harmful non-indigenes aquatic organisms. In practice, this meant exchanging three times the volumetric amount of each ballast water tank. (IMO, 2017)

4.4 Ballast Water Management Convention

Ballast Water Management Convention was in development since 1991 by IMO and was adopted in 2004. The Convention would come into force only if it were ratified 30 member states, representing 35% of world merchant shipping tonnage. (IMO, 2016)

On 8th of September 2016, Finland ratified the Ballast Water Convention. By doing so, the total amount of member countries having ratified the Convention rose to 52, with 35.1441% of the world merchant shipping tonnage. The Ballast Water Management Convention will enter force a year after the signing of Finland. From 8th of September 2017 till 8th of September 2022, ship-owners are required to fit and retrofit their fleets with an IMO type approved ballast water management system. (IMO, 2016)

4.4.1 IMO D-2 Regulations

IMO's Ballast Water Convention states that all ships with a carrying capacity of over 400 gross tonnage (gt) must have: an onboard ballast water management plan that indicates what measures have been taken to ensure ballast water quality, a ballast water record keeping system that indicates amount and locations of ballast water intake and discharge, and a IMO type approved ballast management treatment unit. These include submersibles, floating craft, floating platforms, FPSOs (floating production, storage, and offloading vessel) and FSUs (floating storage unit). Marine vessels excluded from complying with IMO's Ballast Water Convention are: ships not designed to carry ballast water, ships operating in native waters, warships, naval auxiliary ships or other ships owned or operated by a state, exclusively non-commercial ships, or ships with permanent ballast water in sealed tanks. (Lloyds Register Maritime, 2015)

According to IMO D-2 regulations, ships that have a ballast water management system installed prior to 8th of September 2017, will not require to be retrofitted with a new ballast water management system, even if the ballast water requirements of the D-2 regulations are not met. This exemption is designed not to penalize early movers. (International Maritime Organization, 2008)

Only type approved treatment units are eligible to be fitted into vessels. IMO requires that all the BWMS are to be tested on-land laboratories as well as on board laboratories to receive type approval. In both testing methods, the ballast water is tested in triplicates from three separate locations: before entering the treatment unit, from the ballast water tank(s), and before ballast water discharge point(s). Some BWMSs use active substances to render organisms unviable. These active substances can cause further harm to human health as well as to the environment and therefore must be rendered inactive by a neutralizing substance, before discharging ballast water. (International Maritime Organization, 2008)

4.4.2 IMO D-2 Regulation

Regulation D-2 of IMO's Ballast Water Convention, stipulates that ships meeting the requirements of the Convention by meeting the ballast water performance standard must discharge:

- 1) *Less than 10 viable organisms per cubic meters greater than or equal to 50 micrometers in minimum dimension.*
- 2) *Less than 10 viable organisms per milliliter less than 50 micrometers in minimum dimension and greater than or equal to 10 micrometers in minimum dimension.*
- 3) *Less than the following concentrations of indicator microbes, as a human health standard:*
 - a) *Toxicogenic Vibrio cholerae (serotypes O1 and O139) with less than 1 Colony Forming Unit (cfu) per 100 milliliters or less than 1 cfu per 1 gram (wet weight) of zooplankton samples*
 - b) *Escherichia coli less than 250 cfu per 100 milliliters*

Intestinal Enterococci less than 100 cfu per 100 milliliters (International Maritime Organization, 2008) (International Maritime Organization, 2008)

Ships that do not comply with these regulations may endure a penalty fee. (International Maritime Organization, 2008)

4.5 USCG Regulations

USCG regulations are mostly similar with IMO D-2 regulations with exceptions in ship gross tonnage and implementation schedule. In United States of America (U.S.), the USCG and Environmental Protection Agency (EPA) control and enforce IMO's D-2 standards. All non-recreational vessels over 300gt and/or having a capacity to discharge 8m³ of ballast water, fall under the USCG BWMS regulations. BWMS must be installed during the first regular dry docking; on ships with a ballast water capacity of less than 1500m³ from 2016, between 1500m³ and 5000m³ from 2014, and over 5000m³ from 2016. ("Code of Federal Regulations," 2016)

USCG was proposing tighter ballast water discharge regulations during the ballast water convention negotiations (United States Environmental Protection Agency Office of Wastewater Management Washington, 2011). Though U.S. is a full member of IMO since 1950 (IMO, 2017), USCG requires a ship discharging ballast water in United States water must have a type approval from the USCG. IMO type approved ballast water management systems will not outright meet U.S requirements. USCG will use more rigorous verification measures to ensure that the ballast water management systems will in fact meet the D-2 requirements as seen in TABLE 1. Key difference between the USCG and IMO protocols is that USCG demands the testing is done by an independent, vetted, laboratory with no ties or affiliations to the manufacturer, who's ballast water management system is being tested. All test performed by the laboratories will be reported with a pass or fail grade. All results must be reported to USCG along with the exact procedures used by the laboratory. (World Shipping Council, 2017)

TABLE 1. IMO and USCG approval procedure. (World Shipping Council, 2017)

	IMO Approval Procedure	USCG Approval Procedure
Approval by:	Flag state	USCG
Testing done by	Manufacturer	Independent laboratory (IL)
Laboratory for testing	Any competent laboratory	Approved IL's only
Observer for lab testing	Self-observing by laboratory	IL
Reporting to	Manufacturer/Lab	USCG by IL

4.5.1 Exemption for BWMS

Exemption, granted by USCG, from complying with the D-2 regulation have been given to recreational vessels, military vessels, coastal oil tankers and ships travelling between similar ecological zone. ("Code of Federal Regulations," 2016)

Ship, operating with a IMO type approved ballast water management system can operate in U.S. waters for a period of five years after 2016. If the BWMS is not USCG type approved by then, the ship-owner is required to install a USCG type approved BWMS or it will not be permitted to enter the U.S. waters unless using alternative management systems listed below. (World Shipping Council, 2017)

If a marine vessel, operating in waters of United States, does not meet the ballast water discharge requirements set by USCG and EPA, there are alternative methods of complying:

- 1) A ship can use water from a public water supply as ballast water
- 2) Use an alternative management system for 5 years, from the year 2016. Alternative management system is an IMO type approved treatment unit that has not received type approval from the USCG. If the treatment unit does not receive USCG type approval, then it needs to be replaced with a treatment unit with USCG type approval.
- 3) Ballast water can be discharged to a treatment facility
- 4) No ballast water discharge (“Code of Federal Regulations,” 2016)

4.6 State Regulations

Though USCG, along with EPA, regulates and enforces ballast water discharge requirements on a federal level, an individual state can implement even stricter regulations. An example of states enforcing stricter regulations are the states of California and New York.

4.6.1 California

As seen in TABLE 2, the state of California is enforcing much stricter regulations compared to the IMO’s D-2 regulations. California allows no organisms larger than 50 μm in ballast discharge and only one percent of the organisms are allowed over the size of 10 μm compared to the D-2 regulation. The amount of *Escherichia coli* allowed in California is half of that in D-2 regulation and Intestinal enterococci amount are a third. California is planning on enforcing even stricter rules on ballast water quality after 2020. The planned regulation values are zero detectable living organisms. This would mean that the discharged ballast water would be, in effect, completely sterile. (United States Environmental Protection Agency Office of Wastewater Management Washington, 2011)

4.6.2 New York

The state of New York is also tightening their regulation on ballast water discharge levels. Only 1 living organism in 10 m^3 of discharged ballast water is allowed, over the size of 50 μm . The amount of *Escherichia coli* is only half of D-2 regulations and Intestinal enterococci amount are only a third. Like California, New York is also toughening their regulations, although not quite as drastically. In the future New York, will allow no organisms sized over 50 μm and 1 organisms over or equal to the size 10 μm in 100 mL of

ballast discharge. (United States Environmental Protection Agency Office of Wastewater Management Washington, 2011)

4.6.3 Michigan

USCG has not type approved any BWMS to this day. The State of Michigan Department of Environmental Quality, however has determined that four BWMS are deemed to be an effective way in prevention of the spread of aquatic invasive species, while being environmentally safe. These BWMS are: Hypochlorite treatment, Chlorine Dioxide treatment, Ultraviolet Light Radiation treatment after filtration, and Deoxygenation treatment. This ruling was issued on 31.01.2017 and expires on 01.01.2022. After the expiration of the ruling, only USCG type approved BWMS are allowed to discharge ballast water in around the lake waters of Michigan. (Michigan DEQ, 2017)

5 BALLAST WATER MANAGEMENT SYSTEMS

Ballast water management systems are designed to reliably remove unwanted organisms from the ballast water. Water taken for ballast is usually filtered to remove larger organisms and debris. The size of the filter mesh is usually around 40-45 μm in diameter. Filter mesh of this width, can remove 90-95% of organisms sized over 50 μm in diameter. Filters could be used to remove all organisms from the ballast water. This would require the use of a semipermeable membrane, similarly used in reverse osmosis. In reverse osmosis, the water is pushed through a semipermeable membrane that allows water molecules and smaller molecules pass. This however, is not a financially viable way to remove or inactivate organisms from ballast water due to the large amounts of energy consumed in forcing water through the membrane. Therefore, it is economically more viable to inactivate organisms in ballast water using a treatment unit. In 2016 there were 69 IMO type approved BWMS' s and that number is growing as more companies are entering the market (IMO, 2016). (Wärtsilä, 2017)

Currently, there are various methods of ballast water treatment and more are on their way. Typically, treatment methods fall under two categories, physical treatment and chemical treatment. Physical treatment uses heat, pressure or the combination to eliminate viable organisms. Chemical treatment uses chemicals to turn ballast water inhabitable for living organisms. (Wärtsilä, 2017)

Two, commonly used treatment methods are ultraviolet (UV) radiation treatment and electro-chlorination (EC) treatment. When using UV treatment, uptake water is first filtered to remove larger organisms and debris, then moved through a chamber with high energy UV lights placed inside. High amount of UV-radiation is extremely hazardous to small organisms and it essentially burns the organisms, rendering them unviable. Ballast water can be redirected through the UV treatment unit before it is discharged, ensuring organism inactivation. Other physical treatment methods include: ultra sound, cavitation, de-oxygenation and heat treatment. (Wärtsilä, 2017)

When using EC treatment method to treat uptake water, it is again filtered to remove larger organisms and debris. Sodium hypochlorite (NaClO) is dosed and mixed into the

water before it enters the ballast water tank, raising the water's pH. When sodium hypochlorite is introduced to water, it reacts with it producing hypochlorous acid and sodium hydroxide. Sodium hydroxide dissolves in water hydroxide ions that can cause hydrolysis of proteins in bacteria and plankton. This eliminates or inactivates organisms in ballast water. (Wärtsilä, 2017)

IMO D-2 regulations state that active ballast water treatment chemicals must be neutralized before discharge. If sodium hypochlorite is used as a treatment chemical, it can be neutralized using sodium sulfite, sodium bisulfate (sodium metabisulfate), sodium thiosulfate, hydrogen peroxide and ascorbic acid. Sodium hypochlorite is neutralized and the pH of the water is returned to neutral and can be safely discharged. Other chemical ballast water treatment methods include: ozone, chlorination, and chlorine dioxide treatment. (Wärtsilä, 2017)

6 BALLAST WATER QUALITY MONITORING

6.1 Compliance Testing

BWMSs are designed to remove and inactivate harmful aquatic species from ballast water. To verify the efficiency of the BWMS, ballast water must be tested on a regular basis. The ballast water for testing must be collected from three sampling locations onboard a vessel, as stated in the D-2 requirements. These sampling points are in the following locations: ballast water intake before entering BWMS, from the ballast water tank, and ballast water discharge point. The water can then be tested and the results compared to the D-2 regulations. The measurement results from the sample locations can be compared with each other. The comparison will indicate the actual performance level of the BWMS. (International Maritime Organization, 2008)

Per IMO, ballast water sample size must be at least one cubic meter of water for the determination of organisms over 50 μm in size and at least one liter for organism under 50 μm but over 10 μm in size. 500 mL of ballast water should be collected for the determination of bacterial concentration. (International Maritime Organization, 2008)

To receive reliable ballast water quality data, according to EPA, at least 6 m^3 of ballast water samples need to be collected and tested to determine the number of organisms over 50 μm in diameter and 32 m^3 for organisms under 50 μm but over 10 μm . (United States Environmental Protection Agency Office of Wastewater Management Washington, 2011) The question becomes how often and with what methods should be used to determine the quality of the ballast water. EPA suggests that vessels entering U.S. waters with a USCG type approved BWMS should undergo compliance testing 2 times per year and vessels running a BWMS not type approved by USCG should undergo compliance testing 4 times per year. Compliance being the official testing provided by an independent USCG approved laboratory that would relay the results straight to USCG. (United States Environmental Protection Agency Office of Wastewater Management Washington, 2011)

IMO and EPA recognize that self-monitoring can be both costly and difficult to manage by a third party. Having several tons of ballast water tested on a regular basis for self-monitoring purposes can be expensive and finding scientists and laboratories capable of handling large quantities of samples can be difficult, due to the large number of vessels

operating in international waters. (United States Environmental Protection Agency Office of Wastewater Management Washington, 2011)

6.2 Self-monitoring

EPA and IMO encourage ship-owner to self-monitor the efficiency of their BWMS's. IMO suggested and EPA promoted self-monitoring protocol does not require such large amounts of ballast water to be tested. Self-monitoring would be focused mainly on the search for possible indicators organisms for ballast water discharge quality. To self-monitor the efficiency of a vessels BWMS, EPA demand that certain biological indicators of the ballast water should be measured including: *E. coli*, enterococci, *V. cholera*, and live organisms sized 10-50 μm . Self-monitoring, for the time being, would not replace official compliance testing, at least in U.S. (United States Environmental Protection Agency Office of Wastewater Management Washington, 2011)

TABLE 3. IMO suggested ballast water analytical methods. (United States Environmental Protection Agency Office of Wastewater Management Washington, 2011)

Analyte	Measurement	Instrument
Biomass	Adenosine triphosphate (ATP)	ATP (luciferinluciferase)
	Chlorophyll fluorescence	Chlorophyll fluorometer
Live Organisms, 10-50 μm	Chlorophyll fluorescence	Chlorophyll fluorometer
Bacteria	<i>E. coli</i>	Selective substrate
	Enterococci	Selective substrate
	<i>V. cholerae</i>	Colorimetric immunoassay kits

6.3 Self-monitoring Methods

Ship-owners need to monitor the efficiency of their BWMS. With proper ballast water monitoring instruments, ship operator can regulate either the dosage of chemicals or the intensity of UV radiation used to treat their ballast water. This can create saves in operational costs of a BWMS as well as help to avoid possible penalization fees that come with ship's ballast water not complying with quality regulations.

When it comes to monitoring devices, the more accurate results you want, the more you must invest in monitoring devices. IMO suggests the use of indicative methods that are quick and would be expected to show clear over exceeding amounts of species 10 X or 100 X over D-2 regulations. The tools could use other metrics from the official measurements. In aquatic organisms $<50\ \mu\text{m}$ to $>10\ \mu\text{m}$, instead of using number of organisms, a concentration of chlorophyll would be sufficient. The bacterial count could be shown as mg/L instead of colony forming units per 100 mL. These measurements would be enough to estimate the quality of a vessel's ballast water quality and would show if ballast water quality is clearly not in compliance with the D-2 regulations. (Drake, Tamburri, First, Smith, & Johengen, 2014)

USCG funded study in 2012, developed a procedure to test the compatibility of instruments used to monitor ballast water quality in-situ. The study was conducted U.S. Naval Research Laboratory, Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, Moss Landing Marine Laboratories, U.S., and Cooperative Institute for Limnology and Ecosystems Research, University of Michigan. The study was broken into three areas: proof of concept, validation and verification, and feasibility and selection. (Drake, Tamburri, First, Smith, & Johengen, 2014)

Proof of concept in this study means that the method of the sample measurements and the instrumentations used are proven ways to collect data. Validation and verification criteria focused on the accuracy, precision, range, stability and reliability of the instrument in question. Feasibility and selection of the measurement devices data quality requirements, physical and performance characteristics, safety factors, cost, ease of use, maintenance and technical. From a ship-owners perspective, these characteristics are paramount. These characteristics can affect the entire operation of a vessel. In short, ballast water testing methods must produce reliable data regardless of the changing conditions of temperature,

pH, salinity, or possible chemical compounds used to treat ballast water and testing instruments must not require a high degree of expertise to operate. (Drake, Tamburri, First, Smith, & Johengen, 2014)

In 2015, a parallel comparison study was conducted of the analytical methods of ballast water compliance monitoring. This study used equipment and testing methods approved by the protocol mentioned earlier. The results of quick and easy in-situ testing methods were compared against real laboratory test results (microscopy). In total, this meant the collection of 40 samples for 20 paired trials. The sampling location around the globe included open seas, where biological life of the sea water was at or below D-2 regulation, the English Channel and the North Sea, where the biological life concentrations of the sea water were between 1000 and 800000 individuals/m³ for organisms under 50 µm and 0.6-69.7 individuals/mL for organisms under 50 µm and over 10 µm. (Bradie et al., 2017)

The measurement methods were based on measuring chlorophyll fluorescence activity (CFA), adenosine triphosphate (ATP), fluorescein diacetate (FDA), flow cytometry and microscopy (as the laboratory method). Microscopy turned out to be the most time consuming, with a running time of 20-60 minutes per sample, and required a high level of expertise. CFA handheld devices gave results in around 2 minutes and required minimal training to use. The ATP measuring system required minimal training and required 50 minutes for results. (Bradie et al., 2017)

When testing for organisms over 50 µm, all the ballast water testing methods showed positive correlation when compared to the values of the highly accurate laboratory microscopy results, although there was less variation between the microscopy replicate samples. (Bradie et al., 2017)

When testing for organisms under 50 µm and over 10 µm, most of the measuring equipment showed good correlation with laboratory microscopy. The closest correlation was achieved with CFA, with a correlation of 0.82–0.94. (Bradie et al., 2017)

The experiment concluded that all the measurement methods were providing significantly accurate results when compared to laboratory microscopy. The largest correlation differences occurred when the number of individual organisms in the samples reached extremely high. According to the authors, this can be neglected due to most instruments

were purpose built to count the number or concentration of individual organisms at lower concentrations. (Bradie et al., 2017)

As a side note, while conducting sampling and measurements, the scientists discovered that 85% of the organisms over 50 μm in diameter, were from the class of dinoflagellates. Dinoflagellates consist mainly of phytoplankton but a large amount are mixotrophs, consuming organic as well as inorganic carbon. Organisms under 50 μm and over 10 μm were dominated by phytoplankton with a few rotifers. It stands to reason that when measuring biomass or the number of viable organisms, estimations can be made on calculating phytoplankton alone. (Bradie et al., 2017)

6.3.1 CFA

In recent years, CFA measurements have become more and more popular amongst scientists studying plant life. In fact, it is challenging to find a recent scientific plant life study without CFA data. Because CFA data is crucial data in many studies, manufacturers have developed many easy to use hand held devices for CFA measurement, further fueling CFA measurement popularity. (Maxwell & Johnson, 2000)

CFA measures the amount of natural photosynthetic activity of chlorophyll molecules in a plant cell. Energy in the form of light is directed at the plant cell. The initial light energy in modern modular equipment is produced by the device itself and different emitted wavelengths can be defined. The energy of the light can be absorbed by the plant in photosynthesis, it can be dissipated as heat or it can be re-emitted as light in the form of chlorophyll fluorescence. Chlorophyll fluorescence re-emitted by the plant life makes up for only 1-2% of the original light energy directed at the specimen. The fluorescence wavelength re-emitted is much longer than the wavelength of initially directed at a plant. The amount of fluorescence can be calculated by the difference in light energies of the initial emitted light and re-emitted light. (Maxwell & Johnson, 2000)

CFA measurement devices have developed to test the plant tolerance of environmental stress. This means that the devices are able measure the differences between the inactive and active fluorescence re-emitted by the plant life shown in Equation 1 (Maxwell & Johnson, 2000). This means that CFA measurement devices can be used in ballast water quality monitoring to determine the viability of phytoplankton.

$$F_v = F_m - F_o \quad 1.$$

F_v is the variable fluorescence

F_m is the maximal fluorescence when a high amount of light energy has been applied on the specimen

F_o is the amount of fluorescence there is no photosynthetic light (Maxwell & Johnson, 2000)

An example of an inexpensive approach for ballast water monitoring, is a hand-held device like the AquaFlash™ Handheld Active Fluorometer by Turner Desings, for measuring the concentration of chlorophyll in the ballast water. The fluorometer weights 400 grams and is capable of distinguishing between live and dead plankton cells with a measuring accuracy of 0.3 µg/L and range of 0.3-100 µg/L. The test time of the instrument is 15 seconds and has storage capacity for 1000 measurement records which can be downloaded into a computer. The device can operate in temperatures between 5 and 40 °C and costs around 4000 euros.(Turner Designs, 2017)

An example of a high-end measuring system is the bbe 10cells by Moldaenke. This device was conceptualized by request of USCG for ballast water compliance measurements and is specifically designed for that purpose. The device requires minimal training to operate, eliminating the need for expertize. It has a detection limit of 1 cell/mL for organisms between 10 and 50 µm in diameter and the measurement time is less than a minute. It is built into a carrying case, making it robust and easy to carry. The 10 cells has a touchscreen interface and monitoring data can be uploaded to a computer. Cost of this system is 16000 euros.(Moldaenke, 2016)

6.3.2 ATP

The amounts of microbial-life in a water supply can be quickly assessed by measuring the amount of Adenosine triphosphate (ATP). ATP is a molecule responsible for the chemical energy transfer within all living cells, that is why, in the scientific community, measuring the amount of ATP has long been considered to be a viable method of estimating viable organism biomass. (Hammes, Goldschmidt, Vital, Wang, & Egli, 2010)

ATP is commonly measured using a chemical, chemical enzymatic or enzymatic method. This method removes ATP molecules from bacterial cells. When mixed with naturally-

occurring firefly enzyme Luciferase, the combination produces light. The amount of light produced can be measured using a Luminometer. The intensity of the light produced by ATP and Luciferase indicates the amount of ATP in the solution, and the amount of ATP indicates an estimation the number of viable organisms in set solution. The method is fast, easy and usually very inexpensive to perform. (Hammes, Goldschmidt, Vital, Wang, & Egli, 2010)

To perform a bacterial test on ballast water using ATP, the water sample must be filtrated to remove organisms larger than bacterial cells. The ATP test measures does not distinguish between different bacteria, instead gives a total bacterial concentration. The results may not necessarily correlate with number/concentration of *E. coli* or Enterococci in the sample water. For ATP to give accurate results on *E. coli* and Enterococci, immunomagnetic separation should be used. This method, however, requires a degree of expertise and laboratory equipment. (Vang, 2013)

An example of an ATP measurement device is the AquaSnap by Hygiena. This device is specifically designed to test for bacteria suspended in water. The measurement collector, automatically collects the correct amount of water needed for the test and results indicative results are ready within seconds. The device gives measurement results in $\mu\text{g/L}$. The device is easy to use and is priced at 4000-5000 euros.

6.3.3 Quick Bacteria Tests

Quick bacteria tests fall under two categories: strip testing methods and over-night incubation tests. With the strip testing methods, a testing measurement strip is dipped into filtered ballast water and placed inside a sterile vessel. The strip is left there for the duration recommended by the manufacturer which is usually between 15-30 minutes. The strip is then taken out and results can be determined by comparing the strips color change to a reference chart. This method is highly inaccurate and only gives an indication large amounts of bacteria being tested. An example of this type of testing system is the Quick Bacteria Test (15 minutes) from Industrial Test Systems Inc. (Industrial Test Systems, 2017)

With the over-night testing method, unfiltered ballast water sample is placed into a sample vessel. The vessel is placed into an incubator unit that allows bacteria to grow. The incubator unit measures the conditions in the vessel and can give highly accurate bacterial

counts. Some over-night testing units will automatically record the results onto an electronic recording system. The recording system records the ship information, Ballast water measurements as well as location information.(SpeedyBreedy, 2017)

An example of this type of device is Speedy Breedy SeaSure®.This ballasts monitoring device is an integrated measuring system that can test for microbial and chemical contamination. It requires no expertize nor laboratory to operate. It comes with robust carrying cases for storage Microbial tests can be performed overnight and are designed specifically to test for bacteria mentioned in D-2 regulation with an accuracy of 1 cfu/50 mL. The samples are automatically pasteurized after results.(SpeedyBreedy, 2017)

The measurement data is uploaded into a data log and cannot be tampered with at any time. This data can be sent to the manufacturer of the ballast water system or port authorities. The system saves unique data automatically for auditing purposes and marks the data with the serial number of the test device. The databank is compatible with partnered measuring devices like the bbe 10 cells, to include other measurements needed. The device costs a little over 10000 euros.(SpeedyBreedy, 2017)

6.3.4 FDA and Cytometry

Fluorescein diacetate is introduced into the ballast water sample. FDA can permeate the cell wall and come into contact with enzyme esterase. When FDA meets esterase, a reaction will occur, causing fluorescence in living cells. The water sample is then placed into a flow cytometer. (MacIntyre, Cullen, & Collier, 2016)

The FDA treated cells are suspended in a stream of fluid and the cytometer uses laser based detection system for cell calculation. The flow cytometer calculates the number of living cells based on the fluorescence of the FDA treated cells, producing highly accurate results. This method calculates the total biomass/number of live cells in the medium. (MacIntyre et al., 2016).

An example of this type of device is CytoSense by CytoBuoy. This device is able to classify organisms going through the system up to 1.3 mm in diameter. This can be achieved by changing light emission equipment in the machine. The cost of this machine is over 15000 euros.(CytoBuoy, 2016)

7 SAMPLING METHODS

It stands to reason, that without proper sampling methods and equipment, results by analytical methods are subject to scrutiny. Therefore, investing in proper sampling equipment can enhance the reliability of analytical methods drastically. When using highly sensitive measuring equipment, the pre-filtering of ballast water may not be necessary.

When collecting data on water quality based on plankton numbers and/or concentration, plankton nets have been the tool for the job. Plankton nets come in a variety of mesh sizes depending on size of the organism a sampler is trying to catch, so to capture different sized organisms require either separate sampling or the plankton nets can be placed linearly to collect multiple sized samples at the same time. The net captures the organisms in a cup at the bottom of the net, allowing water and smaller organisms to flow through. If sampling large amounts of ballast water, this method requires a ballast water feed going into the plankton net and into a large container. Amount of sample water filtered can be measured using a flow meter or having volumetric reception container. The plankton net must be washed and dried between sampling to avoid contamination of samples to come. This requires a significant amount of space for the barrel and a significant amount of time for washing and drying of the nets. (Bradie et al., 2017)

Passing of D-2 regulation, has given rise for industries to develop easy to use methods for sampling ballast water. Sampling skids have been recently developed to improve ballast water sampling. They are compact, reliable, easy to use and able to filter large quantities of ballast water in a short period. The skids can simultaneously collect samples at many different sizes, organisms over 50 μm , organisms between 10 and 50 μm and bacteria. Sampling skids can use a closed loop system, where ballast water runs through the filtration system and is returned into the ballast water pipe. (Bradie et al., 2017)

Water flow pressure is a crucial factor when collecting samples with a sampling skid. Organisms can be destroyed if the pressure is too high. This would lead to inaccurate measurements. (Bradie et al., 2017)

Ballast water sampling skid could aid with sampling for compliance measuring by authorities. They would not have to bring large number of sampling equipment onboard, making the collection faster and easier. (Bradie et al., 2017)

8 CONCLUSION

Ballast water monitoring devices come in many different shapes, sizes and accuracies. It is up to the ship-owners and BWMS manufacturers to decide how much capital they are willing to invest to ensure that their BWMS is operating accordingly. The initial cost of investing on accurate measuring devices can be costly, however it may help prevent ship-owners from receiving penalty fees that could amount to higher costs.

Study of the ballast water monitoring systems were conducted between 2013 and 2015, and since then, techniques and technologies of monitoring systems have continued to be developed. Companies are now producing analytical equipment designed especially for ballast water monitoring. A few monitoring systems have developed software that automatically records measurement data that cannot be altered, only accessed and sent to proper authorities. This eliminates the possibility of tampering with measurement, giving result a higher degree of trust. Ship-owners investing in more accurate and expensive monitoring systems have a lower probability of receiving possible penalty fees. This can save money in the long run.

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APENDIX

Appendix 1. IMO Annex regulations

Annex I Regulations for the Prevention of Pollution by Oil (entered into force 2 October 1983)

Covers prevention of pollution by oil from operational measures as well as from accidental discharges; the 1992 amendments to Annex I made it mandatory for new oil tankers to have double hulls and brought in a phase-in schedule for existing tankers to fit double hulls, which was subsequently revised in 2001 and 2003.

Annex II Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk (entered into force 2 October 1983)

Details the discharge criteria and measures for the control of pollution by noxious liquid substances carried in bulk; some 250 substances were evaluated and included in the list appended to the Convention; the discharge of their residues is allowed only to reception facilities until certain concentrations and conditions (which vary with the category of substances) are complied with.

In any case, no discharge of residues containing noxious substances is permitted within 12 miles of the nearest land.

Annex III Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form (entered into force 1 July 1992)

Contains general requirements for the issuing of detailed standards on packing, marking, labelling, documentation, stowage, quantity limitations, exceptions and notifications.

For the purpose of this Annex, “harmful substances” are those substances which are identified as marine pollutants in the International Maritime Dangerous Goods Code (IMDG Code) or which meet the criteria in the Appendix of Annex III.

Annex IV Prevention of Pollution by Sewage from Ships (entered into force 27 September 2003)

Contains requirements to control pollution of the sea by sewage; the discharge of sewage into the sea is prohibited, except when the ship has in operation an approved sewage treatment plant or when the ship is discharging comminuted and disinfected sewage using an approved system at a distance of more than three nautical miles from the nearest land; sewage which is not comminuted or disinfected has to be discharged at a distance of more than 12 nautical miles from the nearest land.

Annex V Prevention of Pollution by Garbage from Ships (entered into force 31 December 1988)

Deals with different types of garbage and specifies the distances from land and the manner in which they may be disposed of; the most important feature of the Annex is the complete ban imposed on the disposal into the sea of all forms of plastics.

Annex VI Prevention of Air Pollution from Ships (entered into force 19 May 2005)

Sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances; designated emission control areas set more stringent standards for SO_x, NO_x and particulate matter. A chapter adopted in 2011 covers mandatory technical and operational energy efficiency measures aimed at reducing greenhouse gas emissions from ships. (IMO, 2017)

