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CONSIDERATION OF DISINFECTION BY-PRODUCTS FOR USCG TYPE APPROVAL OF BALLAST WATER MANAGEMENT SYSTEMS

Authors: Rachel Campbell, Demi Davis, and Jadon Thomas

Advisors:

Professor Adrienne Hall-Phillips

Professor Lauren Mathews

Sponsor: United States Coast Guard

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Abstract

The goal of this project was to determine to what degree the concentrations of different disinfection by-products created by ballast water management systems exceed EPA recommendations and suggest where ballast water management regulations should be implemented. We first gathered information about disinfection by-products and compiled and organized testing results from Coast Guard data. We then analyzed the data in reference to EPA recommendations alongside opinions of subject matter experts. Finally, we determined societal implications of disinfection by-product regulations. Recommendations include development of concentration limit regulations, as well as further research to gather a more comprehensive understanding of health and environmental implications of disinfection by-products.

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Authorship

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Executive Summary

The goal of this project was to determine to what degree the concentrations of different disinfection by-products (DBP) created by ballast water management systems (BWMS) exceed Environmental Protection Agency (EPA) recommendations and suggest where ballast water management regulations should be implemented.

Ballast water is necessary to ensure the stability, buoyancy, maneuverability, and overall safety of a vessel. This water sits inside the ship's hull during its voyage and is drained and replaced with each cargo exchange (Kim et al., 2022). However, as vessels take in water from one port and discharge it at the next, they can inadvertently transport organisms in the ballast water from one location to another, thereby introducing invasive organisms to oceanic ecosystems (Kim et al., 2022). To avoid this, ballast water management systems (BWMS) are necessary to remove or neutralize the organisms in the ballast water before it is reintroduced into the ocean.

Common BWMS utilize chemical disinfectants to neutralize these organisms before they are released back into the ocean. As a result of this process, DBPs formed from reactions between disinfectant chemicals and organic oceanic matter can lead to significant health and environmental issues. Incidental discharges from vessels can have negative effects on aquatic environments and can lead to adverse effects on human health through our drinking water and consumption of seafood. Water tested for high concentrations of DBPs was found to cause a higher risk of diseases such as bladder cancer in humans with extended consumption of contaminated water (Beene Freeman et al., 2017). The combination of chemicals used in the BWMS and the condition of the surrounding water determines the severity of the DBP created (Shah et al., 2015). Because disinfection and discharge of ballast water occurs when ships are near port, DBPs tend to have higher concentrations in shallow, coastal waters, which are highly ecologically sensitive areas.

To mitigate this issue, the United States Coast Guard (USCG), a branch of the United States military dedicated to the nation’s maritime safety, security, and stewardship, is creating DBP regulations for the Vessel Incidental Discharge Act (VIDA). In December 2018 VIDA was passed by the United States Congress, which put into effect the "Uniform National Standards for Discharges Incidental to Normal Operation of Vessels" section of the Clean Water Act (CWA) (US EPA, 2019). This section would affect about 82000 commercial vessels, and it requires the USCG and the EPA to develop nationwide standards for pollutant control. Vessel owners must already display best management practices by using the most updated and effective equipment for pollution control that they can reasonably implement (US EPA, 2019). In addition to this subjective best practice standard, the USCG is required to develop a standard for the limit of acceptable concentrations of DBPs created from ballast water management systems.

Our goal was to determine to what degree the concentrations of different disinfection by-products (DBP) created by ballast water management systems (BWMS) exceed EPA recommendations and suggest where ballast water management regulations should be implemented. We worked to achieve this goal by gathering information about the health implications of DBPs from archival research and compiling and organizing USCG BWMS testing results. The USCG has collected land-based testing results from independent labs testing the DBP production of BWMS in different water salinities. This data was given to us in the form of 18 PDF documents with tables displaying the testing results for each BWMS manufacturer and the chemicals the systems produced. We then analyzed the organized USCG data in reference to EPA standards and recommendations alongside opinions of subject matter experts.

Our conversion of the 18 USCG given PDFs of BWMS lab testing to Excel sheets was essential in retrieving the data points for our statistical analyses. Organizing the data into categories based on DBP and the water salinity of the testing results allowed us to notice which DBPs seemed to have outstanding concentrations. We found that trihalomethanes (THMs) and haloacetic acids (HAAs) had data points in almost every data set and had high testing result concentrations.

Through statistical analysis with t-tests at a 95% confidence level, we have concluded that the concentrations of three out of the four THMs, as well as the sum of the nine haloacetic acids (HAA9), to be significantly over an acceptable limit based on EPA recommendations. Bromoform, chlorodibromomethane, dichlorobromomethane, and HAA9 had significantly higher concentrations than what is deemed safe by the EPA. Chloroform did not show to be significantly higher in concentration than its EPA limit. Our results of DBPs with concentrations significantly higher than EPA recommendations are summarized in Figure 1.

Figure 1

Visualization of DBP Results From Statistical Analysis

	Water Quality		
Chemical name	Fresh	Brackish	Marine
Bromoform	○	●	●
Chlorodibromomethane	●	●	●
Chloroform	○	○	○
Dichlorobromomethane	●	○	○
HAA9	○	●	●

○ = BWMS data chemical concentration **is not** significantly greater than EPA limit

● = BWMS data chemical concentration **is** significantly greater than EPA limit

Note: This figure shows the 3 salinities for which 5 chemicals were analyzed. The provided key shows that an open circle represents a chemical and salinity for which the chemical concentration from the BWMS testing results was not significantly higher than the EPA limit. A closed circle shows the chemicals and salinities for which the chemical concentrations from the BWMS testing results were significantly higher than the EPA limit. Authors own work.

We recommend increased testing and development of regulations for the three significantly high THMs as well as HAA9s for BWMS type approval. This limit should be determined based on continuous testing and analysis conducted by the EPA and USCG. These standards in accordance with VIDA would reduce harmful effects of THMs and HAAs on the environment and human life, without placing undue burden onto vessel operators.

Through conducting an analysis on the political, economic, societal, technological, environmental, and legal aspects of changes in BWMS type approval regulation, the strengths, weaknesses, opportunities, and threats surrounding the process become apparent. We determined the potential external influences of DBP regulation through PESTEL and SWOT analysis, using both archival research and findings to develop a holistic view of the environment in which DBP regulation exists. From these analyses, we learned that the current market for shipping has been steadily increasing however, this growth has been restrained as companies are not meeting demand as it would require ship construction without an understanding of new regulations in BWMS.

1 Introduction

Ballast water is necessary to ensure the stability, buoyancy, maneuverability, and overall safety of a vessel. This water sits inside the ship's hull during voyage and is drained and replaced with each cargo exchange (Kim et al., 2022). However, as vessels take in water from one port and discharge it at the next, they consequentially transport organisms in the ballast water from one location to another, thereby introducing invasive organisms to oceanic ecosystems (Kim et al., 2022). Because of this side effect, ballast water management systems (BWMS) are necessary to remove or neutralize the organisms in the ballast water before it is reintroduced into the ocean.

Common BWMS utilize chemical disinfectants to neutralize these organisms before they are released back into the ocean. As a result of this process, disinfection by-products (DBPs), formed from reactions between disinfectant chemicals and organic oceanic matter, can lead to significant health and environmental issues. Incidental discharges from vessels can have negative effects on aquatic environments, which then has adverse effects on human health through our drinking water and consumption of food. Water tested for high concentrations of DBPs was found to cause a higher risk of diseases such as bladder cancer in humans with extended consumption of contaminated water (Beene Freeman et al., 2017).

Commercial shipping companies have hundreds of vessels each, that all follow many routes and visit hundreds of ports, contributing greatly to DBP production in high-density shipping areas through various ballast water management systems. These DBPs are currently not regulated in the United States. The Environmental Protection Agency (EPA) has suggestions for acceptable DBP concentrations in water, but there is no current regulation or enforcement through the United States Coast Guard (USCG) on DBPs. This is a concern of the USCG as they work to create standards for Vessel Incidental Discharge Act (VIDA). The goal of VIDA is to set standards for commercial vessels to follow concerning incidental discharges, including ballast water management. With regulations and standards set in place for ballast water management, there is an opportunity to reduce the amount of DBPs forming in the water, and therefore reduce the harmful effects.

There is currently a need for a more comprehensive understanding of how different DBPs created from BWMS are measuring up to EPA recommendations for acceptable DBP concentrations in water. Through analyzing DBP concentration from varying ballast water management systems and vessels' current compliance with EPA standards, in addition to a more thorough understanding of the current effect the DBPs have on humans, marine life, and the environment, the USCG will be able to set new standards for ballast water management systems in VIDA for commercial vessel compliance.

The goal of this project was to determine to what degree the concentrations of different DBPs created by ballast water management systems exceed EPA recommendations and suggest where ballast water management regulations should be implemented. We accomplished this goal by first compiling and organizing data provided by the USCG on different BWMS and the DBPs they create, as well as developing a thorough understanding of their associated harmful health implications. We then analyzed the organized data in reference to EPA standards and recommendations. Finally, we determined if and to what degree the USCG should be regulating the production of DBPs.

2 Background

In this chapter, we begin with an overview of the impact that disinfection by-products (DBPs) have on human health, marine life, and the environment. Next, we evaluate current ballast water management systems (BWMS) used by commercial vessels, as well as the creation processes of DBPs. We also give an overview of the Environmental Protection Agency (EPA) and United States Coast Guard (USCG) standards for different DBPs. We conclude the chapter with an overview of where high concentrations of DBPs are most prevalent, as well as the USCG's role as the sponsor of this project.

2.1 Local Impact of Disinfection By-Products

DBPs are created when excess BWMS chemicals react with organic matter in the water. These reactions form toxic by-products that are detrimental to both human and oceanic animal health. The combination of chemicals used in the BWMS and the condition of the surrounding water determines the severity of the DBP created (Shah et al., 2015). Because disinfection and discharge of ballast water occurs when ships are near port, DBPs tend to have higher concentrations in shallow, coastal waters, which are highly ecologically sensitive areas.

Disinfection-by products form in water treatment plants from the disinfection chemicals interacting with organic matter. As disinfection chemicals are naturally volatile to neutralize organisms, they also readily react with excess organic matter (Villanueva et al., 2015). This leaves people exposed to DBPs constantly through tap water. Because of the various exposure pathways DBPs can take to enter the body, it is difficult for studies to pin specific human symptoms to a specific DBP (Villanueva et al., 2015). By-products can enter the body not just though water consumption, but also inhalation and skin exposure. People are exposed to disinfection by-products through everyday tasks such as hand-washing dishes, or showering. This makes it very difficult to create a controlled study surrounding DBP effects in humans because a variety of DBPs enter the human body daily. There are, however, certain correlations that are strong enough to attribute some human effects to DBPs in general. Because of the prevalent usage of chlorinate disinfection chemicals in water management systems, there are more known symptoms of chlorinated DBPs in humans than other chemical by-products (Villanueva et al., 2015).

DBPs can cause bladder cancer and birth defects in humans. When consumed, water tested for higher DBPs and brominated trihalomethanes is found to have high associated risks for development of bladder cancer. Upon observation, subject pools jumped from the >95th percentile to the >25th percentile in reference to the development of bladder cancer (Beene Freeman et al., 2017). In addition, trihalomethane (THM), a DBP resulting from chlorinated disinfection, has been shown to have an over 9% increase in risk of still birth. There is an increased risk of spontaneous abortion among women who consumed 5 or more glasses of cold tap water containing a concentration of 75 microgram per liter or more of total THM (Villanueva et al., 2015).

2.2 The United States Coast Guard's Mission for Environmental Protection

The United States Coast Guard (USCG) is a branch of the United States military dedicated to the nation's maritime safety, security, and stewardship. They are heavily involved in managing borders and migrant interdiction, maritime environmental protection and law enforcement, maintaining aids to navigation, as well as search and rescue. The Marine Safety Center (MSC) is an independent Headquarters established in 1986, focused on supporting marine safety and environmental protection. (Marine Safety Center (CG-MSC), n.d.). The MSC's primary goal is to review and approve standards and plans for design, construction, and repair to any commercial vessels subject to United States regulations and International Standards. The MSC also reviews and issues type approval certificates for environmental compliance equipment used on commercial vessels, including ballast water management systems.

The Office of Operating and Environmental Standards (OES) is an office of the USCG dedicated to the development and maintenance of operational and environmental standards in commercial maritime industry. OES consists of two divisions. OES-2 is the Vessel and Facility Operating Standards Division, which dictates regulations and standards around vessels, facilities, and offshore platforms alongside oversight and facilitation duties alongside the IMO. OES-3 is the Environmental Standards Division, which operates alongside OES-2 with a focus on standards and policies that pertain less to operational guidelines, but environmental benchmarks and regulations. OES-3 aims to reduce environmental hazards and harm within the maritime industry while maintaining a level of integrity which aligns with the most economical practices available. (Office of Operating and Environmental Standards (CG-OES), n.d).

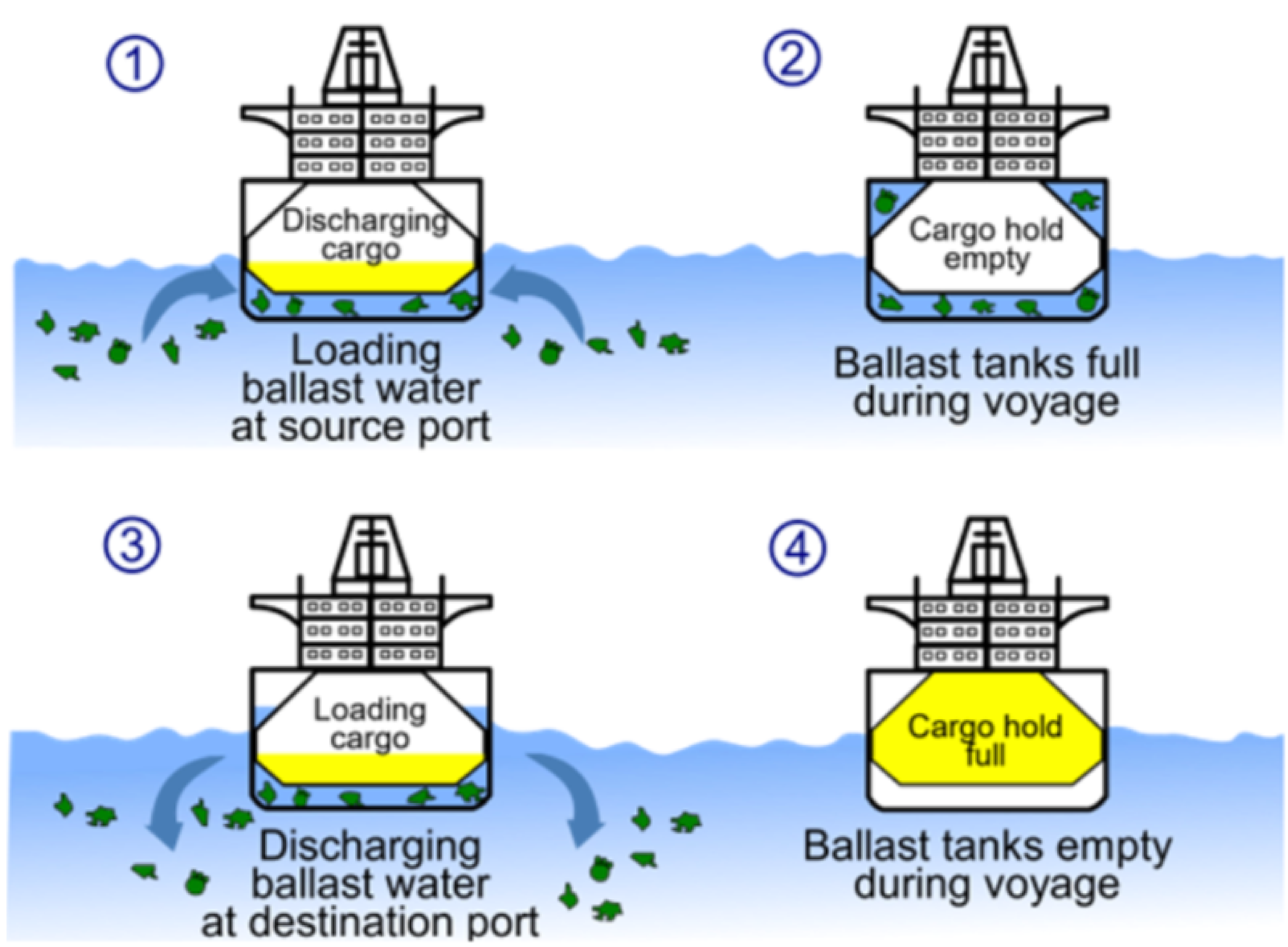
As a part of this project, we seek to support USCG OES-3 in analyzing ballast water testing data submitted to MSC for type approval to determine how commercial vessels are currently adhering to the EPA's recommendations pertaining to BWMS and DBPs. Our findings will be reported to the USCG to aid their goals in policy making for VIDA to minimize the DBPs produced that stem from Ballast Water Management Systems.

2.3 How Ballast Water Management System Technology Works

Ballast water has been used since the 1800s due to its convenience, economic advantages, and adjustability (Kim et al., 2022). Vessel operators are able to compensate for shifts in the weight distribution of their vessel from cargo movement and fuel consumption by taking specific amounts of water into the ship's ballast water tanks. This creates an extremely accessible and infinitely adjustable counterbalance to the weight shifts. Using ocean water means that ballast water is a convenient and cost-effective option for maintaining vessel stability, however this means that oceanic organisms will inevitably be transported with the ballast water. To address the issue of organism invasion, a variety of innovative ballast water management companies have developed different technologies to clean ballast water before it is deballasted (released from the vessel's hull back into the ocean). Shown in Figure 2 is a diagram of how ballast water is transported and released. This section will highlight the methods that BWMSs implement to treat ballast water and several varieties of ballast water management technologies available.

Figure 2

Cross Section of Vessel Showing Ballast Water Cycle



Note: The top left diagram (1) shows the ballast water, including microorganisms (green specks), entering the vessel's ballast tanks as the cargo is being emptied at a port. The vessel then travels to its next destination with full ballast tanks (2). Upon arrival at the next port the ballast water tanks are emptied as cargo is loaded onto the vessel (3). The microorganisms are also discharged back into the ocean. The ballast water tanks have effectively taken microorganisms from one oceanic ecosystem and inserted them into another. This image is in the public domain.

2.3.1 Ballast Water Management System Pre-Treatment

Most BWMS use two or three stages to remove organisms. The first stage is called pre-treatment and most commonly involves physical separation where the ballast water flows through a filter to remove the larger organisms and particles. The second stage is the introduction of chemicals, UV radiation, or other non-physical cleaning methods (Ballast Water Treatment Systems (BWTS), n.d.). Having an effective filtration system is essential in meeting BWMS standards. Using an optimal physical separation system to remove as many organisms as possible in stage 1 creates less of a need for large amounts of radiation or chemicals in stage 2 (Ballast Water Treatment Systems (BWTS), n.d.). Additionally, filtration reduces the amount of mechanical wear on the system (Duan et al., 2023).

2.3.2 Ballast Water Management System Primary Treatment

The second stage of ballast water disinfection is the primary treatment. This is where most of the organisms are neutralized as filtration only removes the larger organisms. Some of the primary treatment methods include UV radiation, electrolysis, chemical injection, heat, ozone, and deoxygenation. Only electrolysis and chemical injection use disinfection chemicals so they are the only systems to produce DBPs.

2.3.2.1 Electrolysis Primary Treatment

Following filtration, an additional method is needed to neutralize the organisms that were not caught in the filter. A common second process is electrolysis, which works by running an electrical current through the seawater to create chemical disinfectants. These disinfectants are then introduced to the ballast water, which damages the cell membranes of organisms and neutralizes them. This system has the advantage of not requiring chemicals to be stored aboard the vessel as electrolysis creates its own disinfection chemicals. However, this system does require salt water to function, so it is not as effective in fresh or brackish water applications (Ballast Water Management, n.d.).

Some electrolysis-based systems omit the filtration step because the system can introduce a high enough concentration of the disinfectants to kill the additional organisms that would have been removed by the filter (Ballast Water Management, n.d.). Due to the tendency of filters to clog, electrolysis-only BWMS are becoming more appealing. Omitting the filter has the advantage of creating a more reliable, fast system. The cost of the system is also significantly reduced by not having to purchase or install a filter which can account for up to 30% of the total BWMS cost (Duan et al., 2023). Although the option of omitting filtration seems beneficial, the need to create higher concentrations of disinfectants in the water means that discharged water could contain significantly higher total residual oxidant (TRO) than a filtered system. TRO is a measurement of remaining chlorine in the water during discharge. The higher TRO content means that there are more opportunities for DBPs to be created upon discharge (Duan et al., 2023). For more detailed information about DBPs created by electrolysis, please reference Appendix A.

2.3.2.2 Chemical Injection Primary Treatment

Another typical process to follow filtration is chemical injection which works by infusing the incoming ballast water with chemicals formulated to kill the organisms, then neutralizing the chemicals. These systems are common due to their effectiveness in varying water qualities and against most organisms. Because the system requires chemicals to be stored on the vessel, it is a more viable option for vessels that make frequent stops so that the chemicals can be easily resupplied.

The specific chemicals used in chemical systems change with varying water conditions such as salinity, temperature, and dissolved organic matter (DOM) (Shah et al., 2015). These chemical adjustments are necessary not only to increase the effectiveness of BWMS organism removal, but also to decrease the quantity and toxicity of the DBPs created from this process. For more detailed information about DBPs created by chemical injection, please reference Appendix A.

2.3.3 Ballast Water Management System Post-Treatment

For BWMS that use chemicals there will inevitably be excess disinfection chemicals in the treated water. Before it can be deballasted the concentration of these chemicals must be at an acceptable limit, defined by the EPA to be 100 µg/L. The TRO concentration is used to determine if additional treatment to the water is necessary before discharging due to excess chlorine concentrations. A neutralizer might be used for chlorinated systems to discharge water within the allowable TRO. (Bailey et al., 2022). Some BWMS will simply use time to meet discharge requirements. Although neutralization can be used to speed up the process of meeting discharge requirements, it is an inconvenient final step for BWMS that use chemical disinfectants because the vessel now must transport neutralizing chemicals in addition to disinfection chemicals.

2.4 Understanding Disinfection By-Product Standards

With the growing maritime transport industry, it is becoming increasingly important to regulate what vessels are releasing into the waterways. This comes in the form of applying more stringent pollution standards as water management technology gets better.

2.4.1 Increased Standards

In 2004, the International Maritime Organization (IMO) created the Regulation D-1 Ballast Water Exchange Standard, with the understanding that as technology advances a D-2 standard will be put into effect. The IMO is “a specialized agency of the United Nations which is responsible for measures to improve the safety and security of international shipping and to prevent pollution from ships” (Frequently Asked Questions, n.d.). The IMO currently has 175 member states, with an additional 88 nongovernmental organizations working in consultative positions. The United States does not currently adhere to IMO standards, but standards can be observed in reference to formulation of US standards. The IMO D-1 standard required at least 95% of all ballast water to be exchanged at a distance of 200 nautical miles from any shoreline.

There is now an updated D-2 standard that applies to vessels constructed in 2017 and later. This standard creates limits on the concentration of organisms that can be released into ocean waters after ballast water cleaning. Ballast water management systems (BWMS) have been implemented on commercial vessels to comply with D-2 standards. (Feng et al., 2023).

In December 2018 the Vessel Incidental Discharge Act (VIDA) was passed by the United States Congress, which put into effect the "Uniform National Standards for Discharges Incidental to Normal Operation of Vessels" section of the Clean Water Act (CWA) (Vessel Incidental Discharge National Standards of Performance, 2020). This section would affect about 82000 commercial vessels, and it requires the USCG and the EPA to develop nationwide standards for pollutant control. Vessel owners must already display best management practices by using the most updated and effective equipment for pollution control that they can reasonably implement (Vessel Incidental Discharge National Standards of Performance, 2020). In addition to this subjective best practice standard, the USCG is required to develop a way to enforce the EPA’s discharge standard for quantity of organisms.

2.4.2 USCG Type Approval for Ballast Water Management Systems

Ballast water management systems receive type approval (TA) by the USCG which allows vessel owners to choose a system that complies with domestic or foreign operation standards. The TA certificate lists the specifications of the BWMS including the water salinity and temperature ranges that the system can tolerate, whether a holding period for the water withing the system is required, the approval limitations, along with any other operational limitations the BWMS may have (Orthmann, 2020). There are currently 53 USCG type approved BWMS. As a part of the TA process, the manufacturer must provide details about any active substances used for the BWMS, as well as any discharges or hazardous materials that are produced. This information is collected, but there are no current regulations on those discharges. There is a need for regulation on the discharges produced to ensure that the USCG does not type approve any BWMS that produce by-products in a higher concentration than deemed safe for human health, aquatic life, and the environment.

3 Methodology

Our goal was to determine to what degree the concentrations of different disinfection by-products (DBP) created by ballast water management systems (BWMS) exceed EPA recommendations and suggest where ballast water management regulations should be implemented.

We worked to achieve this goal with three objectives resulting in a final deliverable:

1. Gather information about the health implications of DBPs from archival research and compile and organize USCG BWMS testing results.
2. Analyze organized USCG data in reference to EPA standards and recommendations alongside opinions of subject matter experts.
3. Determine the societal implications of DBP regulation through PESTEL and SWOT analysis.

After completing these objectives, we created a report compiling DBP and BWMS research to highlight where the BWMSs meet and fall short of EPA standards and provided the USCG with their complied BWMS data in excel for future analysis.

3.1 Objective 1: Compile and Organize USCG Data

We compiled and organized the data we received from the USCG on different BWMS testing and the DBPs created as a result. During this process we also examined and organized EPA recommendations for concentrations of DBPs and performed additional archival research to gather a thorough understanding of the history and future of BWMS and DBP standards, as well as the health implications of DBPs.

The USCG has been collecting BWMS testing data since 2015 (Ann Kimrey, personal communication). This is a part of the Type Approval (TA) process. To receive TA for a BWMS, the system manufacturer must submit lab test results which include results for the concentrations of DBPs in the deballasted water of the BWMS. The Coast Guard compiled the testing results for BWMS using electrolysis and chemical injection. The compiled testing resulted in data containing basic information about the BWMS system tested, the salinities for which the test was run, and the DBP concentrations that were found in the stimulated deballasted water in testing. This data was given to us in the form of 18 PDFs containing test results. The original PDF data was gathered from BWMS undergoing whole effluent toxicity (WET) testing which is a form of land-based testing. Land based testing involves replicating a BWMS on a small scale in a land-based laboratory. This simulates the operation of a BWMS on a vessel and gives an estimation of the by-products remaining in the deballasted water. Although WET testing is land based, it is representative of the typical operation of an on board BWMS (Ann Kimrey, personal communication).

Once we received 18 documents containing tabulated test results from a variety of BWMS manufacturers and models, we converted from PDF to Microsoft Excel format by using Excel's 'data from picture' functions to pull information from the tabulated data in the PDFs. After using this function, we checked to make sure the data was imported correctly and fixed any minor formatting mistakes. We assigned each document a number 1-18 and labeled each data set we converted with its corresponding document number to easily see the original source of each data point in Excel.

To proceed with the BWMS testing data analysis, we reformatted and compiled the results from the BWMS testing into a more organized set of spreadsheets. We organized the results by the salinity of the water used in the testing, the BWMS model tested, and the document from which we transferred the information. This included categories for fresh, brackish, and marine water salinities as well as filtration and electrolysis, filtration, and chemical injection, and solely electrolysis management systems.

This allowed us to loosely estimate which DBPs are being produced in significantly higher concentrations than others and in what water salinity the effects are most severe. It is important to analyze the different chemicals in the three varying salinities as vessels discharge ballast water in marine, brackish, and freshwater environments. The salinity levels can affect the type and concentration of the DBP produced, as detailed more specifically in Appendix A.

After gathering a general estimation of which DBPs are being produced in high concentrations, we performed additional archival research to gather insight into the human and environmental health impacts of these chemicals. We also chose to focus on groups of chemicals that were included in at least 8 data sets to ensure that we would have enough data points to perform an appropriate statistical analysis. As the majority of DBPs from the testing results were not present in many of the data sets, this limitation greatly restricted the amount of chemicals we had to choose from to analyze. This helped us determine which chemicals we should focus our statistical analysis on.

3.2 Objective 2: Analyze USCG Data and Cross Reference with EPA Standards

We analyzed BWMS data provided by the USCG and cross-referenced our analysis of DBP concentration from the data with EPA standards concerning safe levels of DBPs produced from BWMS. The EPA has a list of recommended chemical concentration limits for a water body that suggests concentration limits of DBPs below which exposure is not expected to be harmful to human and marine life (Kimrey, personal communication). In the absence of ballast water specific EPA recommendations, we used these standards to give a baseline for the limit of concentrations of DBPs in discharged water. The analysis of the EPA standards helped to understand the quantity and severity DBPs created by specific BWMS.

Using the trends we observed in the data compilation phase alongside our preliminary research, we came to conclusions as to if BWMS are producing dangerous or highly concentrated DBPs. We compared these concentrations of DBPs to what the EPA deems safe for human and aquatic life. We then used statistical right-tailed one sample t-testing to analyze whether the difference in heightened concentrations for a variety of DBPs in different water salinities are statistically significant using alpha = 0.05. The null hypothesis for these tests was that the mean of the chemical concentrations would be less than or equal to the suggested EPA limit for that chemical.

Each mean was calculated by first finding each occurrence of those specific chemicals in each of the three salinities from the 18 samples provided to us by the USCG. The data points for the concentrations of each chemical in each salinity were then averaged to find the three means for concentration of each DBP, one for each salinity. Each mean reflects testing done on several different BWMS. Since we ensured we only analyzed chemicals which appeared in at least 8 data sets, we had at least 8 data points making up the averages of the chemicals for each salinity. This was done in accordance with guidance from a subject matter expert (Kimrey, personal communication).

Using alpha=0.05 allows for a 5% chance that we falsely claim that the DBP concentration from the data is significantly higher than the EPA recommendations. This is referred to as a Type 1 error. When many t-tests are run the likelihood of making a Type 1 error increases as the 5% allowance for each test compounds over multiple comparisons. We accounted for this by using the Benjamini-Hochberg adjustment method (Chen et al., 2017). This adjustment creates a more stringent threshold for determining the statistical significance of a p-value, effectively reducing the number DBP concentrations we claimed to be higher than EPA standards. Adjusting the p-values in this manner ensured that the chance of Type 1 errors was minimized.

As part of our data collection process, we interviewed subject matter experts on ballast water management systems and disinfection by-products. These subject matter experts were from both the USCG as well as the independent contractors. From the USCG, we interviewed an environmental engineer from the Marine Safety Center. We also interviewed an independent contractor from Tetra Tech specializing in marine ecology and DBPs. We followed a semi-structured, recorded, interview format to inquire about different systems, the chemicals used, and the disinfection by-products that they create. The goal of these interviews was to aid our gathering of information on the pre-existing standards and practices that relate to BWMS and DBP's, as well as goals for the future regulation of DBPs. Please see Table 2 for the information of the specialists we interviewed, Appendix B for our consent statement, and Appendices C-E for our planned interview guides.

Table 1

Interviewees' Name, title, Organizational affiliation, and date interviewed

Interviewee Name	Interviewee Title	Interviewee Organizational Affiliation	Date of Interview
Ann Kimery	General Engineer	U.S. Coast Guard	10/31/2023
June Mire	Director of Ecological Services	Tetra Tech	11/08/2023

Note: Author's own work.

After we conducted the interviews with the subject matter experts, we analyzed and organized the information from transcripts based on relevancy of information given to the project goal. We highlighted important statements from our interviewees to support our assessment of the dangers of DBPs as well as BWMS regulations that could be beneficial in reducing harm to the environment.

3.3 Objective 3: Analyzation of Social Implications of DBP Regulations

Data was pulled from USCG and EPA sources referencing the risks of DBPs, as well as information gained from interviews with DBP subject matter experts. We took into consideration not only the statistical conclusions from our data analysis, but the harmful health implications of DBPs in high concentrations, as well as archival research and findings on market and societal trends which affects DBP regulation. This archival data conveys the historical behavioral patterns of markets, political decisions, social, environmental, and economic actions and reactions.

Additionally, we incorporated research regarding the extent to which the USCG can exert authority over commercial entities as well as the rights granted to those entities under US law. This provided perspective to understand potential obstacles and opportunities for the USCG in their future endeavors surrounding DBP management. This research formed a short list of aspects which we have deemed worthy of note for attention. To accomplish this, we analyzed political, economic, social, environmental, and legal factors (PESTEL) surrounding our data, to understand the external environment in which our project resides. Using this analysis, we also conducted an analysis of strengths, opportunities, weaknesses and threats (SWOT) within the USCG, to understand the internal operations and processes needed for large policy adjustments or additions.

4 Results

This section highlights our results. This will include the findings from interviews and archival research, as well as statistical results.

4.1 Objective 1: Archival Research and Compiled USCG Data

Our conversion of the 18 USCG given PDFs of BWMS lab testing to Excel sheets was essential in retrieving the data points for our statistical analyses. Organizing the data into categories based on DBP and the water salinity of the WET test allowed us to notice which DBPs seemed to have significant concentrations. We found that trihalomethanes (THM) and haloacetic acids (HAA) had data points in almost every data set and had high testing result concentrations.

Archival research concerning the effects of DBPs on human and marine health pointed to THMs as having significant human health effects, and HAAs having detrimental marine environment impacts (ATSDR, 2015). After finding that THMs can cause damage to the human nervous system, liver, and kidneys, we proceeded to pull data points for the four THMs from our Excel sheets. This gave us 13-15 data points for each chemical in each of the three water salinities allowing us to run 12 tests in Objective 2. Specific human health impacts of THMs can be found in the societal section of Objective 3. Our archival research included finding the EPA's recommended limit for each THM which is displayed in Table 2 in Appendix F.

In terms of environmental impacts, our archival research points to the nine HAA chemicals (HAA9) causing strain to organisms essential to the balance of oceanic ecosystems (Cui et al., 2021). Specific environmental health impacts of HAAs can be found in the environmental section of objective 3. Since the EPA sets HAA limits with the sum of specific HAA, we took the sum of the HAA9s from each data set in our Excel sheets and compiled 9-12 data points for each water salinity. To analyze the data in Objective 2, we needed a standard to compare the testing result DBP concentrations, but the EPA did not have one specifically for HAA9s. The Analysis for HAAs in Objective 2 details how we determined the scaled EPA HAA9 standard from our archival research.

4.2 Objective 2: Analyzed USCG in Reference to EPA Standards and SMEs

We analyzed USCG provided data on DBPs produced by BWMS, cross referencing with EPA recommended limits for chemicals. In addition to analyzing the data given to us, we also interviewed subject matter experts to determine the dangers of high concentrations of DBPs, and what can be done to minimize the potential harmful effects.

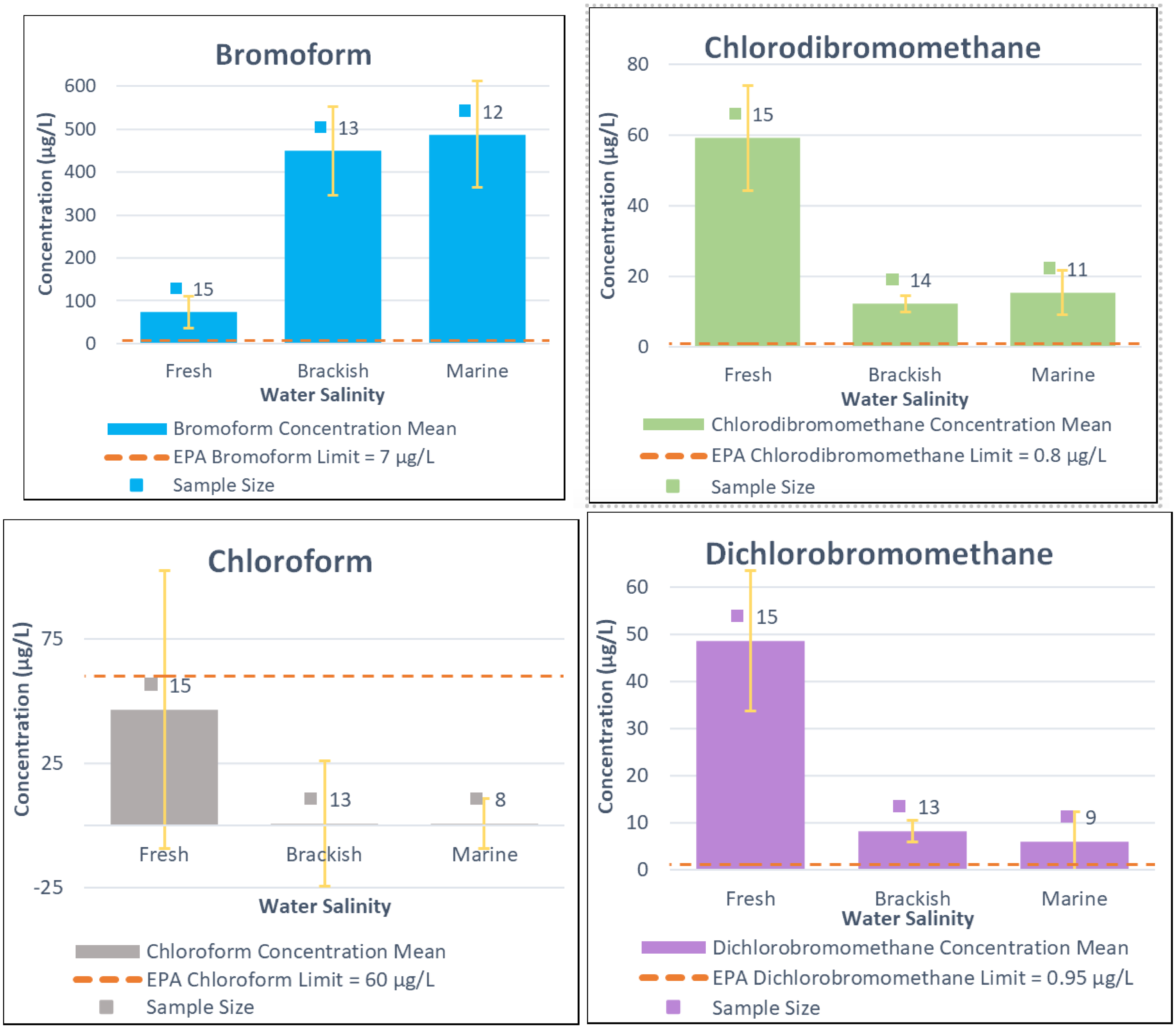
4.2.1 Analyzation of THMs

Concentrations of 4 different DBPs were separated by the water salinities used in WET testing: fresh, brackish, or marine. The DBPs that we focused on are the four primary THMs: bromoform, chloroform, chlorodibromomethane, and dichlorobromomethane. We chose to focus on these chemicals because of their ubiquity in the collected data, as 17 out of the 18 samples tested for all four primary THMs, as well as the high availability of information about the effects of these chemicals on human health from our archival research in objective 1.

Once separated by salinity, all four chemicals were evaluated at the three water salinities making for a total of 12 t-tests. Out of the 12 tests that were run, 7 initially resulted in a rejection of the null hypothesis. After Benjamini-Hochberg adjustment was conducted, this was reduced to 6 rejections out of 12. This shows that there is a significant difference in chemical concentrations in comparison to EPA recommendations. Figure 3 gives a visual representation of the difference between the THM concentrations and EPA recommendations in each salinity. Every THM, excluding chloroform, displays concentrations significantly higher than the EPA recommendations in each at least one water salinity. See Appendix F for the resulting means, standard deviations, and p-values from each t-test that was run.

Figure 3

Bar Charts Visualizing Results from T-tests for THMs in Different Water Salinities



Note: The yellow line represents the error bar for each test and the orange dotted line represents the EPA's suggested concentration limit for each THM. The error bars were created using the standard error of the data for each of our t-tests. The greater the separation of the yellow error bar and the orange dotted line, the more significant the difference between the concentration of the THM found in BWMS testing and the EPA suggested concentration limit. Figures depict the author's own work.

4.2.2 Analysis of HAA9

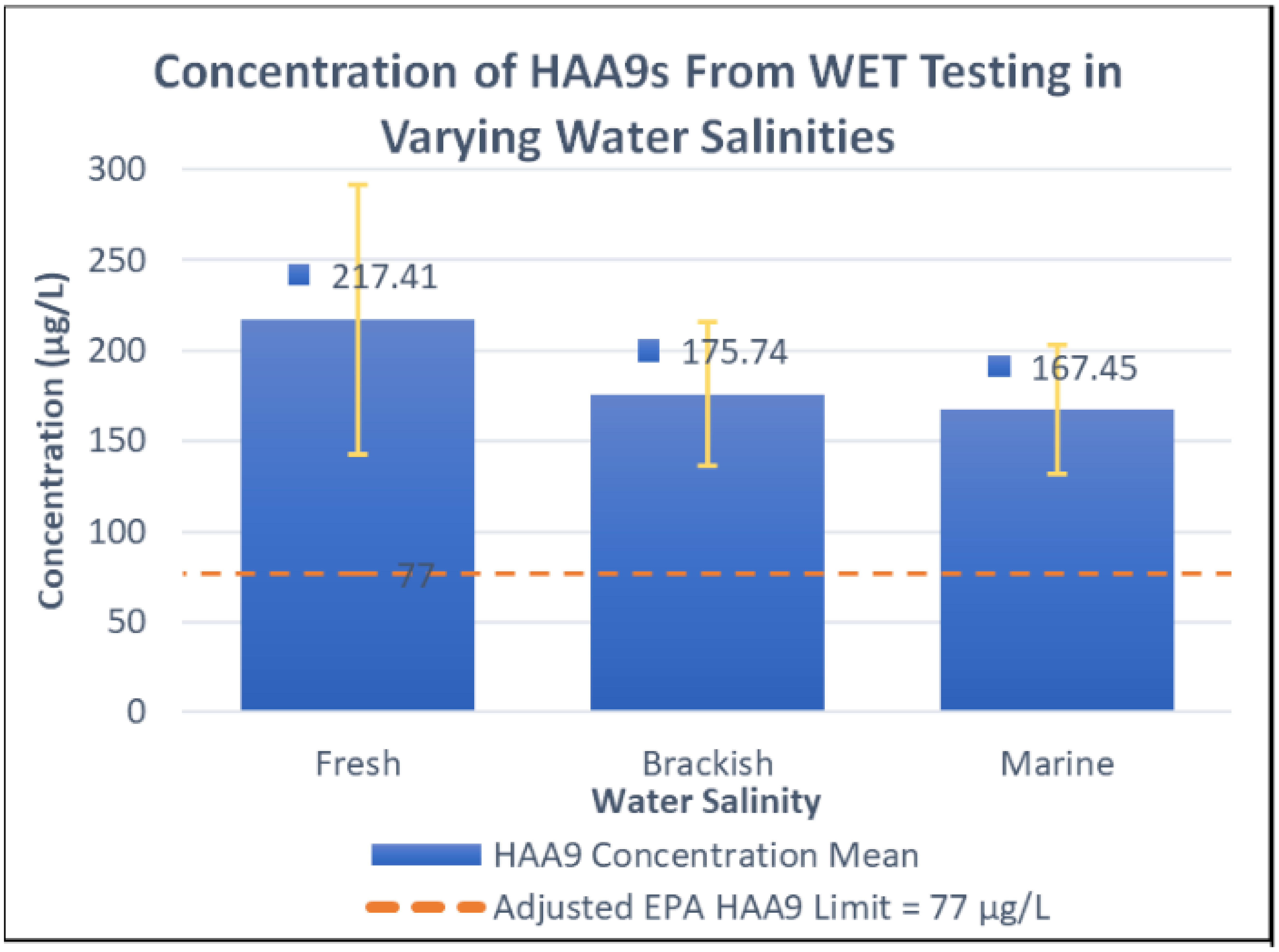
We chose to analyze HAA9 concentrations because of the availability of test results for all nine chemicals in most data sets as well as their profound ecological impacts (Cui et al., 2021). We took the nine HAA concentrations from each data set and organized them by water salinity. To account for the concentrations that were not detected in testing we took the EPA's suggested detection limits for each chemical and halved them to represent the undetected values. The detection limit represents the lowest concentration for which a chemical sensor should be able to measure a chemical concentration. 'Not detected' means that the chemical concentration is somewhere below the detection limit, but the exact concentration is not known (Ogden, 2010). We then removed individual chemical concentrations above 1000 micrograms per liter which we considered to be outliers. Two values were outliers, one from the marine water data set and one from the freshwater data set. Since concentrations over 1000 micrograms per liter were almost double any other concentration results across all chemicals and salinities in the USCG's data and those two values came from the same lab, we inferred that those values were due to a data recording or collection error. To get an HAA9 value we added the concentrations of the 9 HAAs together for each data set. We had 9 to 12 HAA9 sums for each water salinity, and we did not include data sets that only tested for HAA5 chemicals.

To find a suggested standard for comparison for HAA9 concentrations we looked to our archival research from Objective 1. The EPA has a suggested drinking water concentration standard for HAA5s which sits at 60 micrograms per liter for the sum of the five chemical concentrations (Fourth Unregulated Contaminant Monitoring Rule, 2022). However, this does not account for the four other harmful HAAs: tribromoacetic acid, bromochloroacetic acid, dibromochloroacetic acid and dichlorobromoacetic acid. A study funded by the American Water Works Association looked at how increasing drinking water standards to include an HAA9 regulation could unreasonably lower the efficiency of public water systems. The study concluded that a 72-77 microgram per liter concentration limit would be an appropriate increase in standards without placing excessive burden on public water systems (Samson & Seidel, 2022). Although we intended to compare the HAA9 concentration to EPA suggestions as we did for THMs, there are no current EPA HAA9 water standards. Due to the lack of research on HAA concentrations in ballast discharges we have chosen to proceed with HAA analysis using drinking water regulations and suggestions adapted by the American Water Works Association from the EPA's HAA5 drinking water standards. We performed the analysis with the understanding that drinking water standards are more stringent than ballast or wastewater standards and we discuss this limitation further in Section 5.

Knowing our standard of comparison, we then conducted the t-tests and analyzed statistical significance with a 95% level of confidence, meaning our p-values had to be below 0.05 for our BWMS data DBP concentrations to be considered statistically higher than our standard of comparison. Our p-values indicated that we could reject the null hypothesis for 2 of the 3 tests finding that the HAA9 concentrations are significantly higher than our suggested amount in marine and brackish water.

Figure 4

Bar Chart Visualizing Results from T-tests for HAA9s in Different Water Salinities



Note: The yellow line represents the error bar for each test and the orange dotted line represents the adjusted EPA suggested concentration limit for HAA9s. The error bars were created using the standard error of the data for each of our t-tests. The greater the separation of the yellow error bar and the orange dotted line, the more significant the difference between the concentration of the HAA9s found in BWMS testing and the EPA suggested concentration limit. Figures depict the author's own work.

Although the fresh water mean of measured HAA9 concentration is higher than that of marine and brackish water, the high variability of the freshwater data contributed to a high standard deviation making our p-value nonsignificant. Through statistical analysis with t-tests at a 95% confidence level, we found the concentration of HAA9 to be significantly over an acceptable limit based on adjusted EPA HAA5 drinking water standard.

4.2.3 Subject Matter Expert Interviews

From our interview with subject matter expert Ann Kimrey, we gained information on different existing standards regarding DBPs, as well as specific information about the Type Approval (TA) process for BWMS. We used this information to find our THM concentration standard from the EPA for our method 2 data analysis.

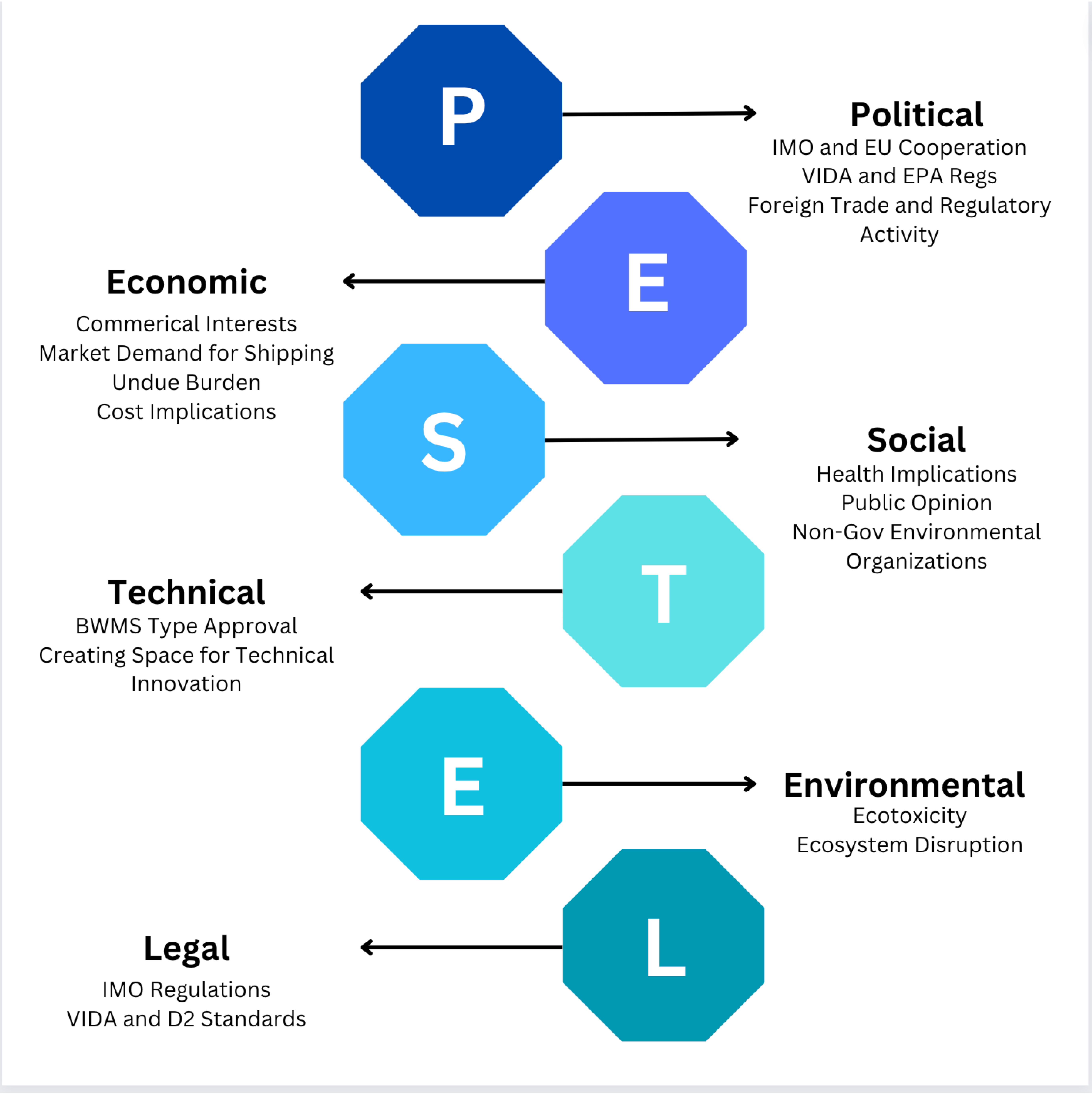
Our choice of chemicals to focus on came from expertise from our interview with Dr. June Mire. There are other lesser studied DBPs that were detected in some of the samples that potentially have negative health impacts. However, in choosing chemicals to target for analysis, we took into consideration that it is often more effective to target a well-researched chemical than many lesser-known chemicals (Mire, personal communication). As we learned in our interview with Dr. Mire, if production of the primary THMs is reduced, it is likely that other DBPs will follow a similar pattern.

4.3 Objective 3: Analyzation of Social Implications of DBP Regulations

To understand the external effects of DBPs and DBP regulation in relation to the USCG, EPA, and commercial entities, we conducted both a PESTEL (Political, Economic, Societal, Environmental, and Technical) and SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis. The following analyses describe the previously mentioned implications and interactions of imposing DBP regulations.

Figure 5

Visual Representation of PESTEL Analysis



4.3.1 Political Analysis

The politics of BWMS involve potential discrepancies in international regulations and standards between the Environmental Protection Agency (EPA) and International Maritime Organization (IMO). The IMO is the UN designated body which presides over the safety and security of international shipping while also regulating and reducing the pollution caused by the shipping industry (IMO, n.d). The EPA is the independent government agency which is responsible for the protection of human health and environment within the US (US EPA, n.d.). These two organizations have laid out their own requirements for BWMS. As US and EU economies interact, the IMO, EPA, and USCG must be sure to account for existing and potential differences in standards to prevent complications in foreign trade while also maintaining environmental awareness and using best business practices, meaning the most efficient, economical, and legally accepted way of operating.

Currently, the EPA regulations for BWMS are more stringent than the regulations put in place by IMO (Čampara et al., 2019). The easiest way for ships to fulfill the requirements set federally is by obtaining a USCG type-approved BWMS. Prior to D2 standards, which were enacted in 2017, foreign vessels were still required to adhere to EPA regulations. However, they were allowed to apply for an alternate management system (AMS) designation (33 CFR 151.2026., n.d.). This allows ships with IMO-approved systems to temporarily operate in US waters without a USCG type approved system. This is only a stopgap measure for some older ships, as the AMS will only remain valid for 5 years, after which the vessel is required to be outfitted with a type approved BWMS (33 CFR 151.2026, n.d.).

Climate change and environmental protection are divisive issues driven heavily by economic loss and gain (EPIC, 2022). Sustainability efforts from nonprofit organizations which are removed from monetary gain influence public awareness. As issues like climate change and renewable energy are addressed globally, the US will also feel pressure to keep a similar pace of implementation and innovation of new, more environmentally friendly, technology as they are partnered with the United Nations Framework Convention on Climate Change (UNFCCC) (Kuh, 2018). Considering this, EPA has been affected by the post-Trump era and discussions surrounding environmental improvement efforts such as the Green New Deal (Shear & New York Times, 2017). The Green New Deal refers to the government effort for economic stimulation through “green” construction and job creation, with the aim of reducing the effects of climate change through investment in renewable energy, clean manufacturing, removing greenhouse gas from farms, alongside many infrastructural projects and improvements (116th Congress, 2019-2020).

During the Trump administration, the EPA experienced significant changes, including rollbacks of environmental regulations and a shift in priorities to favor industry interests (Shear & New York Times, 2017). Since then, with the change in administration, there has been a renewed focus on environmental protection and sustainability. The Biden administration, which came into office in January 2021, expressed a commitment to re-establishing and strengthening environmental regulations, and addressing climate change. This included rejoining and supporting initiatives aligned with the goals of the Green New Deal (The United States Officially Rejoins the Paris Agreement - United States Department of State, 2021) which involved reaching net zero greenhouse gas emissions, providing clean air and water for future generations, creating zero emission energy grids, and a complete overhaul of public transportation (116th Congress, 2019-2020).

4.3.2 Economic Analysis

Economically, BWMS policy carries heavy implications in commercial spaces. Peripheral costs rising with policy changes present challenges for industry as market demand for shipping increases. The total world fleet has grown by an average of 3.18% per year since 2018, while the average age of fleets has been steadily increasing by 1.42 years from 2018 to 2022 (UNCTAD, 2023). From this data, we can see that companies are beginning to increase production of vessels to meet demand but may remain wary of policy changes which may require them to invest in retrofitting or purchasing entirely new systems for their vessels.

Figure 6

Cost comparison of potential cost changes in BWMS

Table 4. Cost components of IMO-BWTS[1].

Scenarios[5]	Total capital and installation cost ($)	Annual capital and installation cost[2] ($)	Annual operating cost[3] ($)	Unit treatment cost[4] ($/MT)
Lower bound	658,000	35,776	9,000	0.02
Average cost	**901,000**	**48,989**	**13,500**	**0.135**
Upper bound	1,144,000	62,201	18,000	0.25

Table 5. Cost components of Stricter-BWTS.

Scenarios[4]	Total capital and installation cost[1] ($)	Annual capital and installation cost ($)	Annual operating cost[2] ($)	Unit treatment cost[3] ($/MT)
Lower bound	4,600,000	250,108	326,000	0.27
Average cost	**7,000,000**	**380,599**	**502,000**	**0.48**
Upper bound	9,900,000	538,276	678,000	0.68

Note: From “Scenario-based cost-effectiveness analysis of ballast water treatment strategies” by Zhaojun Wang and James J. Corbett (2020)

According to Wang and Corbett (2020), the total cost of IMO BWMS installation averages at around $900,000 (Wang and Corbett, 2020). The upper and lower bounds of this data place larger ship installation costs at more than $1,000,000, with smaller ship installation costs around $650,000 (Wang and Corbett, 2020). More stringent regulations, like the interim regulations used by California before D2 standards took effect (Houlihan, 2023), would increase these costs close to $10,000,000 for larger ships, and around $7,000,000 on average (Wang and Corbett, 2020). Operating costs will also increase from an average of $13,500 to an average of $502,000 annually, an increase of 3618% (Wang and Corbett, 2020).

Economically, the shipping industry is in a precarious situation (Wang and Corbett, 2020). With demand still increasing, they are eager to recoup revenue lost during the Covid-19 pandemic. However, due to the amount of uncertainty in the political scope, doing so could be costly. By pushing forward without waiting for regulation, they could potentially be subject to penalties and system requirements which will both require much more time and cost when compared to waiting.

4.3.3 Societal Analysis

In high concentrations in water, trihalomethanes like bromoform and chlorodibromomethane can cause harm to the liver and kidneys (ATSDR, 2015). It has also been shown that bromoform and chloroform have the potential to change hematological count, which can be indicative of developing medical conditions (Lodhi, 2017). Trihalomethanes are also possibly carcinogenic in humans based on studies done on laboratory animals (Bureau of Water Resources Drinking Water Program, 2022). Further, long term exposure to THMs like chloroform can lead to harmful effects on the human nervous system, causing symptoms such as depression and irritability (ATSDR, 2015). Prolonged exposure to chlorodibromomethane has similar effects on the central nervous system, causing nausea, dizziness, headaches, and narcosis (National Center for Biotechnology Information, 2023).

DBPs can come into contact with humans in many ways, especially THMs. Most commonly, THMs are found within frozen or canned vegetables that are cleaned with disinfected water (Cardador et al., 2017). This is because the freezing/canning processes keep the compounds stable for longer, allowing DBPs to be present in food for longer periods of time. DBPs are also found in meat and fish, but on a lesser scale than in frozen vegetables, because meat and fish do not encounter as much disinfected water before packaging (Cardador et al., 2017). Although DBPs can come into contact with humans through food, it is still unknown how high the concentrations of these chemicals are by the time they have reached food that humans consume. Much further testing is needed to fully understand the effects of DBPs on human health through food.

Disinfection by-products can cause bladder cancer and birth defects in humans (Beene Freeman et al., 2017). When consumed, water tested for higher DBP's and brominated trihalomethanes was found to have high associated risks for development of bladder cancer (Beene Freeman et al., 2017). Upon observation, subject pools jumped from the >95th percentile to the >25th percentile in reference to the development of bladder cancer (Beene Freeman et al., 2017).

Lower income and nonwhite communities are affected more by all types of pollution, including water pollution (Trtanj et al., 2016). These communities have less access to clean or filtered water (Trtanj et al., 2016). Without access to clean or filtered water, there can be a higher number of people consuming higher concentrations of disinfection by-products, leading to higher rates of deaths and illnesses (Trtanj et al., 2016).

Several non-profit organizations are actively engaged in climate and marine activism, making significant contributions to environmental conservation. One notable organization is Greenpeace, which is renowned for its global campaigns advocating for climate action, protection of marine ecosystems, and the promotion of sustainable practices (Greenpeace USA, 2023). Other influential entities include Oceana, dedicated to preserving and restoring the world's oceans by campaigning against destructive fishing practices, pollution, and habitat degradation (Oceana, n.d.), The Ocean Conservancy, focused on finding science-based solutions to protect ocean health (The Ocean Conservancy, n.d.), and the World Wildlife Fund (WWF) which extends its efforts to marine conservation, working to safeguard marine species and habitats (World Wildlife, n.d.). These organizations, among others, exemplify the impactful work being done in the non-profit sector to address climate change and protect our oceans, highlighting the power of collective action for a more sustainable future.

As said previously, the total world fleet has grown by an average of 3.18% per year since 2018, with no signs of slowing down (UNCTAD, 2023). As more ships enter the global fleet, naturally the production of DBPs will also increase. This further emphasizes the need for DBP regulations which the USCG can enforce.

4.3.4 Technological Analysis

Imposing stringent DBP regulations for BWMS will further encourage development of existing and new non-chemical ballast water treatment methods (Sayinli et al., 2022). Chemical treatment methods such as electrolysis are inexpensive and effective against organisms, but if a DBP regulation is imposed then BWMS manufacturers could turn to developing more advanced non-chemical ballast water treatment methods to avoid DBP production all together. This push away from chemical BWMS could encourage innovation in treatment methods such as creating more advanced filters, or further development of secondary mechanical treatment methods such as ultrasonic treatment. Filters currently have the issue of becoming clogged from excess sediment and not removing enough organisms to be used as a standalone treatment, but they are very ecologically friendly since it is solely physical separation. Development to make filtration more effective and dependable could lessen the issue of DBP production and lessen the need for secondary treatment which would revolutionize BWMS. Additionally, the development of newer or existing treatment methods such as ultrasonic and ultraviolet treatment could result in more vessels using BWMS that do not produce DBPs thereby significantly lessening the issue of DBP concentrations in ballast water. The main drawbacks to such treatments are their extensive costs, high power consumption, and inefficiency in certain water conditions. These issues would possibly resolve with increased research prompted by the need to create BWMS with low DBP production (Sayinli et al., 2022).

4.3.5 Environmental Analysis

DBPs, specifically HAAs, affect marine environments by changing behaviors and biological operations of organisms. Phytoplankton, when exposed to HAAs, rapidly reproduces. This starves the rest of the local ecosystem of oxygen, while simultaneously producing more toxins which affect fish and other ocean life creating illness, fatalities, and reproductive issues. These toxins can also travel up the food chain to humans if they consume contaminated meat (Cui et al., 2022).

Haloacetic acids (HAA) are a group of nine chemicals formed from the interaction of chorine disinfectants with naturally occurring substances in water. The deballasted water from both electrolysis and chemical disinfection systems can produce HAAs as these BWMS use chlorinated disinfection as their primary form of water treatment. HAAs can be ecotoxic in aquatic environments where the treated water is discharged. Despite this, only 5 HAAs currently have EPA suggested limits, and none are officially regulated. These chemicals (HAA5) include monochloroacetic acid, monobromoacetic acid, dichloroacetic acid, dibromoacetic acid, and trichloroacetic acid. A study tested the toxicity of 8 HAA concentrations found in wastewater on three species of freshwater organisms (Cui et al., 2021). The tested chemicals were found to inhibit the growth and swimming ability of the organisms as well as induce abnormal development and mortality (Cui et al., 2021). Phytoplankton, an organism essential to maintaining both marine and freshwater ecosystems, was found to be the most impacted by HAAs (Cui et al., 2021). Because phytoplankton is the foundation of many aquatic food chains, when the organism is placed under stress from exotoxins the whole ecosystem is affected, as well as humans who rely on the fishing economy or eat seafood.

When placed under stress from low levels of HAAs, phytoplankton tends to bloom, or rapidly reproduce (Cui et al., 2022). This type of algae bloom can deplete oxygen from the surrounding waters and release toxins into the ecosystem causing increased mortality and illness in larger organisms such as fish. The effects of this are detrimental to aquatic life who rely on the balance of the food chain, as well as the humans who eat seafood. An increase in fish mortality is detrimental to the fishing industry, and humans can become sick from seafood that carries the toxins released by the algae blooms (Dai et al., 2023). A study done on the toxicity of different DBPs to aquatic organisms showed that while THMs were not found to have a large impact on organisms like phytoplankton, they are found in high concentrations in zooplankton, and have toxic effects on the zooplankton (Cai et al., 2021). It has also been shown that DBPs, including THMs, affect fish's swimming ability (Cai et al., 2021).

It is also unknown where concentrations of DBPs are safest to be released. IMO D1 Standards required 95% of ballast water to be released 200 nautical miles from any shoreline (Feng et al., 2023). Releasing at a significant distance from the port could be beneficial in limiting high concentrations of DBPs that come into contact with humans. Much further research is needed to understand how DBPs disperse once discharged into oceanic environments to ensure that ballast water is being discharged at a safe distance.

4.3.6 Legal Analysis

The legal environment of BWMS is dependent on the interactions of the IMO and EPA. Companies must adhere to the regulations laid out in the area between these two organizations to remain in proper legal standing and continue their business (Čampara et al., 2019b). The IMO and EPA have some major differences in standardization, with the US often requiring certain aspects outside of the IMO's concern (Čampara et al., 2019b). In these cases, it becomes difficult for foreign vessels to operate in US waters. Foreign vessels in these scenarios must apply for a type approval designation to hopefully be cleared for operation. Without it, the USCG will not allow any foreign commercial entities at port (Čampara et al., 2019b).

The Vessel Incidental Discharge Act (VIDA) was signed in 2018 (US EPA, 2019). VIDA requires the EPA to develop the standards for incidental discharges (US EPA, 2019). The goal of VIDA is to "reduce the environmental impact of discharges, such as ballast water, that are incidental to the normal operation of commercial vessels" (US EPA, 2019). Two years after the EPA publishes final discharge standards, the USCG is required to develop regulations for implementation, compliance, and enforcement of these standards (US EPA, 2019). This includes requirements for the design, construction, approval, and installation of any devices implemented to comply with EPA standards. VIDA will apply to any commercial vessels that are larger than 79 feet in length, and any other non-recreational or non-Armed Forces vessels (US EPA, 2019).

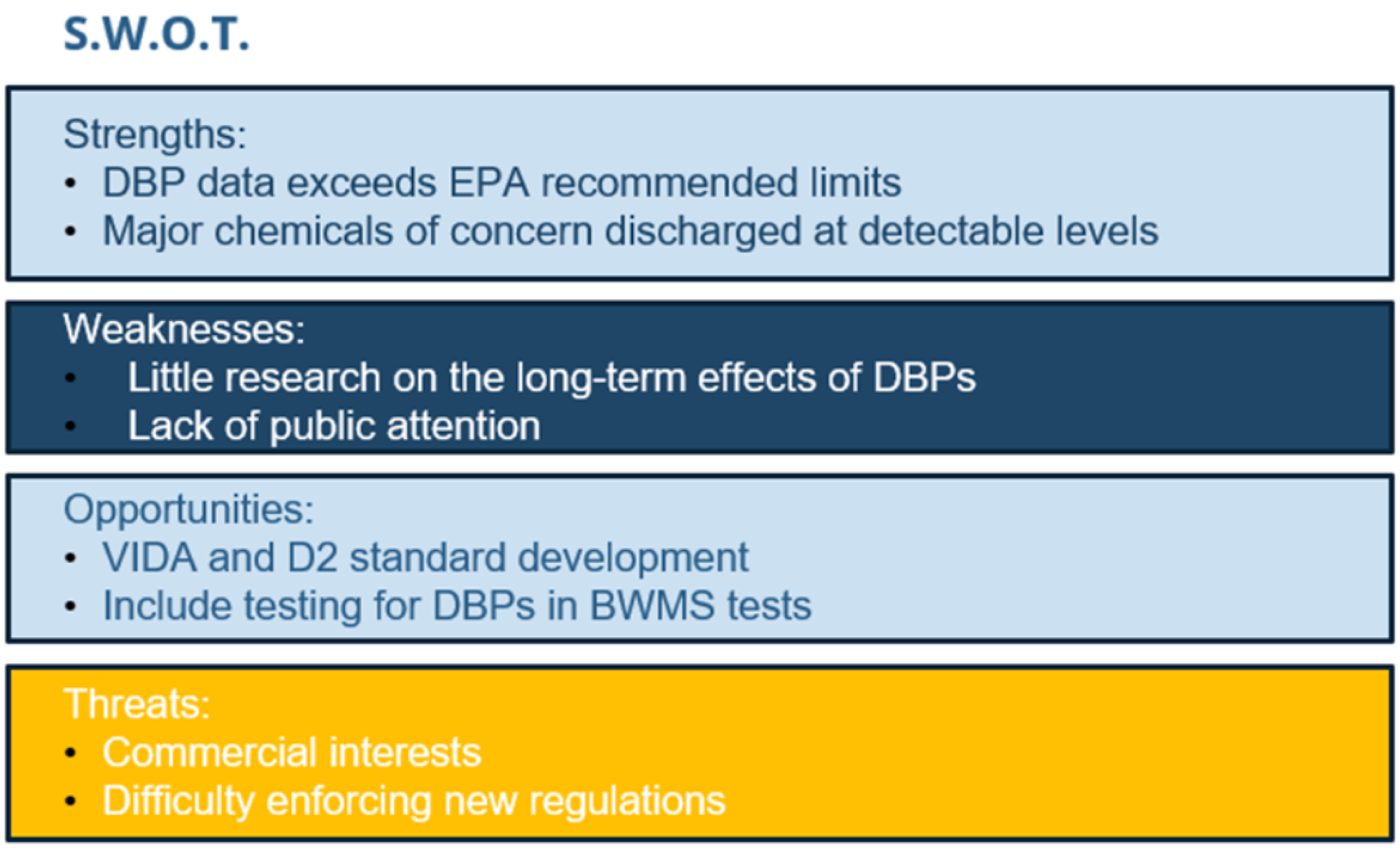
Regulations are checked and enforced by the USCG who also deals with complaints and points of contention companies may have. After designing, constructing, and testing the BWMS, companies must submit testing results to the USCG to be validated as a type approved BWMS (46 CFR 161.002-18, nd.). The USCG can reject the results however, and companies are able to file an appeal to attempt to circumvent the initial ruling. In special cases, companies can lobby congress in an attempt to change laws and regulations in order to better suit their needs (Kimrey, Personal Communication). While expensive, companies must keep up with regulations and testing as they are enacted, else they are at risk of paying a fine of up to $27,500 every day as per article 33 of the Code of Federal Regulations (33 CFR 151.1518, nd.). This also poses problems in conducting business, as it will become increasingly difficult to dock in ports monitored by the USCG.

4.3.7 SWOT Analysis

We are using a SWOT analysis to identify the strengths, weaknesses, opportunities, and threats of the possibility of the USCG implementing DPB regulations. This will provide a breakdown of the advantages and disadvantages the USCG have in proposing DBP standards, as well as the opportunities and threats they might encounter. We will be discussing the four sections of the SWOT in reference to the previously mentioned implications and interactions of imposing DBP regulations as seen in Figure 7.

Figure 7

SWOT Analysis Visual Representation



Note: This figure shows the strengths, weaknesses, opportunities, and threats that we will be discussing in this section. This analysis is to display the advantages and shortcomings of the USCG's case for considering creating DBP regulations. Authors own work.

Strengths

We identify a strength a advantage that the USCG have in suggesting that DBP regulations be implemented. It is not practical to implement regulations without solid evidence supporting why they are necessary. Our archival research and statistical analysis both show that the regulations could be necessary to protect the health of humans and wildlife and provides evidence that the potential DBP risks warrant further research. As discussed in our environmental impacts, HAAs can damage oceanic food chains which has effects on ocean animals as well as humans who depend on the fishing industry (Cai et al., 2021). Additionally, as discussed in the societal section of our PESTEL analysis, drinking water containing high levels of brominated THMs was found to have high associated risks for development of bladder cancer (Beene Freeman et al., 2017). Our statistical analysis from Method two shows that these DBPs are being discharged in concentrations that are higher than what the EPA suggests is safe. These examples of the negative effects of DBPs for both the environment and human life in addition to the statistical significance of our analyses would give support to our recommendation for consideration of DBP regulation and further research.

Weaknesses

We identify a weakness as disadvantages that the USCG have in suggesting that DBP regulations be implemented. One of these weaknesses is the lack of available information to support our claims of DBP health impacts. We lack definitive research to provide justification for implementing regulations that end up causing a significant increased cost for vessels owners with chemical BWMS. Information is needed to convince officials and companies that the concerns presented are legitimate. Additionally, more information is needed to create comprehensive regulations that will successfully decrease DBP production from BWMS while remaining scientifically uncontested. Currently, the potential negative impacts of DBP from ballast water remain relatively obscure which will likely make it difficult to create the widespread support that will be required for the USCG to implement and enforce new regulations. Opponents to such regulations would be able to use this fact to dismiss the severity of the issue of DBPs. Additionally, these types of chemical issues are also usually not brought to the attention of the public until there is a news story or lawsuit associated with the chemical side effects (June Mire, personal communication). This lack of publicity makes it difficult to garner support from the public which is needed to encourage government to provide funding for further research (June Mire, personal communication). The lack of funding for more DBP regulations and studies further perpetuates the issue of the lack of available DBP information.

Opportunities

The USCG is presented with the opportunity to improve BWMS regulations from the 2017 D2 standards. Since VIDA is under development, the USCG could use the need to create new BWMS standards to also garner support for BWMS type approval improvements. This could give the EPA an opportunity to put resources into studying ballast water health and environmental impacts, and specifically the impacts of DBPs produced by chemical BWMS. The need to research DBPs for regulation presents the additional opportunity to conduct longitudinal testing with specific focus on where and how DBPs are being released to ocean water to determine what specific chemical concentration limits the USCG can propose.

Threats

A major threat to the implementation of BWMS regulations would be the interests of corporate shipping entities and their partnerships. As demand rises for the goods and services provided by these entities, a desire to prevent further costs is reasonable. The costs incurred by updating or replacing the BWMS currently installed in company vessels would be large as discussed in the economic section of the PESTEL analysis. By maintaining current regulations or reducing the amount of change to them, companies could potentially retain their ships and equipment at no extra cost. Additionally, more stringent DBP regulations could be difficult for the USCG to enforce due to the potential for more BWMS type approval regulations initially getting rejected for not complying with a new DBP standard. With type approval applications getting rejected more frequently due to implementing DBP regulations, the USCG might have to spend more time addressing disputed from BWMS manufacturers (Ann Kimrey, personal communication). This drop in efficiency within the BWMS type approval process could dissuade the USCG from finding it practical to impose stringent DBP regulations.

5 Discussion and Recommendations

This section discusses the results from data analysis and provides recommendations for specific DBPs of concern to aid in future VIDA policy writing. These recommendations are supported by the findings collected from research, interviews, and statistical analysis. Per the USCG's request, we will not be making specific policy recommendations or suggesting a specific DBP concentration limit for future ballast water regulations. Rather, we will be suggesting specific DBPs to take into consideration when curating new regulation based on our statistical results and giving an idea of the scope of the issue using our PESTEL and SWOT analyses.

5.1 Discussion

From our archival research, we found that DBPs could pose a threat to human and aquatic life, as well as the environment. This is an important factor considered when curating our recommendations. We found that DBPs could have harmful effects on human health, aquatic life, and the environment, when chronically exposed to elevated levels. However, this does not take into account the dilution of ballast water when it enters a large body of water. We cannot claim that these findings are applicable to the lower concentrations of DBPs in the body of water after dilution. Much further research is needed to determine how DBPs interact with the environment to understand the full effect they could have on ecosystems and human health.

In analyzing the statistical significance of THMs and HAAs in the BWMS data, we have found chemicals from both categories to be significantly over suggested health limits in several water salinities, meaning the impacts of these chemicals are not limited to marine environments, they can also impact bodies of water such as rivers and lakes. Out of all the chemicals analyzed, only one, chloroform, showed to be not significantly higher than its recommended limit in all three water salinities. This leads us to believe chloroform is the only chemical analyzed that is not a concern according to this set of samples, as the concentrations in these studies are deemed safe by the EPA. None of the BWMS that were tested in the USCG provided data produced enough chloroform to be considered unsafe, but it is a possibility that other BWMS do produce enough chloroform to be considered dangerous.

Our interviews with BWMS data and environmental experts have also shown that there is possible concern from an environmental perspective about the concentrations of DBPs entering our waterways unregulated. Ms. Kimrey and Dr. Mire both emphasized in their respective interviews the toxicity of these chemicals to the environment, and the importance of further researching DBPs to determine if and how much they should be regulated. However, it is still relatively unknown how concentrated the chemicals are by the time they could interact with humans or aquatic life.

Through conducting a PESTEL and SWOT analysis, we have come to understand the micro- and macro- environmental factors which have the potential to affect the implementation of new BWMS type approval regulations. Conducting this analysis assists in finding a balance between the regulations that could be needed and the strain placed upon commercial entities. Many of the trends and relations revealed by the data are heavily contingent on the greater economic and political trends of the world. Data shows a growing market and growing concern in environmental conservation and protection, which will help propel the possibility of BWMS type approval regulation improvements in the government.

5.2 Recommendations

In the effort to mitigate water pollution from BWMS, ideally, concentrations of all DBPs entering the waterways would be limited. However, we anticipate that with the possible regulation of a few dangerous chemicals that are produced in high concentrations from ballast water disinfection, the production of other lesser researched but potentially more harmful DBPs will also be limited (Mire, personal communication). We also understand that it is unrealistic to propose regulation of all DBPs especially when there is so little information available about the impacts of these chemicals in diluted concentrations.

Through statistical analysis with t-tests at a 95% confidence level, we have concluded that the concentrations of three out of the four primary THMs, as well as HAA9, to be significantly over an acceptable limit in deballasted water based on EPA recommendations. Bromoform, chlorodibromomethane, dichlorobromomethane, and HAA9 had significantly higher concentrations than what we estimate is deemed safe by the EPA. Chloroform did not show to be significantly higher in concentration than its EPA limit.

We recommend increased testing for consideration of regulations for the three significantly high THMs as well as HAA9 for BWMS type approval. Any concentration limits should be determined based on continuous testing and analysis conducted by the EPA and USCG. These standards in accordance with VIDA would reduce potentially harmful effects of THMs on the environment and human life, while not placing undue burden onto vessel operators.

The limited information available about the human and ecological health impacts of THMs and HAAs indicated that more DBP research is necessary. Existing research already suggests significant human and wildlife health impacts with chronic DBP exposure at concentrations in the micrograms per liter range. However, we cannot justify through this research alone the immediate development of DBP regulation.

Because we ingest DBPs every day through our food and water sources it would be worth having a more comprehensive understanding of the health implications of those chemicals. As we had to use drinking and wastewater standards for our statistical analyses, chemical effects specific to ballast water should be better studied. Considering the few recent studies showing the detrimental aquatic effects of highly concentrated DBPs, further researching the pollutants entering ocean waters from vessels could keep aquatic ecosystems heathy and our fishing industry alive.

There is an opportunity for further research about the DBPs produced from BWMS to expand upon knowledge of how the BWMS are releasing chemicals into oceanic environments. We suggest significantly more testing be done on this topic to ensure that any standards set by the USCG can prevent high concentrations of DBPs going forward, while also not putting undue burden onto the shipping industry.

5.3 Limitations

In creating suggestions for the USCG concerning DBP regulations, it is important to discuss the limitations of our research and data analysis. We have found that there is a lack of research done on DBPs and their harmful effects. For chemicals that have proven to be dangerous, there is a lack of readily available public information on the specific effects of consumption of high concentrations in water, as well as limits to what is safe. Through analysis of what was available, we concluded that DBPs do warrant concern in high concentrations, and as research around ballast water pollution progresses, we expect to soon see more conclusive evidence about the health impacts of specific DBPs. As of right now, there is not enough research available about the effects of the DBPs from ballast water after they have been dispersed into the oceans to claim that concentrations of DBPs created by BWMS are detrimental to human or ecological health.

Concerning the data analysis, we were limited in that we did not have information on all Type Approved (TA) BWMS. In the data provided, only 16 out of the 24 TA BWMS using chemical treatments were represented in the data. Because there was not a large enough variety of BWMS, we could not analyze the data based on type of BWMS, only by the salinity of the water, and different models have to potential to produce differing DBP concentrations. We were also limited in that we only had 18 data sets, some of which did not include the chemicals we were analyzing. This led to our data analysis for each chemical having a low sample size meaning the statistical significance of our results has a higher potential to be inaccurate.

In using the statistical significance of our p-values to claim that the BWMSs produce significantly higher HAA9 concentrations than what the EPA would allow, there are a few factors we must take into consideration. The standard we chose for allowable HAA9 concentrations is based on calculations by the American Water Works Association to scale the EPA's HAA5 drinking water standard to determine a reasonable HAA9 drinking water standard. As drinking water standards are more stringent than general water standards for bodies of water, we understand that using such standards could create an overly critical analysis of BWMS DBP production. However, water standards increase in stringency over time and due to the emerging research of HAA health implications, it is reasonable to assume that DBP concentration limits will get quite low with future iterations of BWMS regulations. Technological advances would also allow for BWMS to be manufactured to mitigate DBP production making stringent DBP limits easier to meet, as discussed in the technology section of our PESTEL analysis. As technology advances and more HAA information is discovered we anticipate 77 µg/L to be a reasonable estimate for future HAA9 concentration limits for the purposes of our data analysis.

It is important to note these limitations to allow the USCG to understand where the shortcomings of this research and data analysis may lie so they can draw appropriate conclusions to aid in creating fair policy for BWMS type approval. We suggest that the Coast Guard take into account the limitations associated with the standards of comparison for appropriate DBP concentrations we used for the data analysis, and the implications of those limitations when writing specific DBP concentration limits.

6 Conclusion

It can be concluded from this project that DBPs created from BWMS could pose a considerable threat of harm to human health, marine life, and the environment. This is something to be taken into consideration when creating new BWMS Type Approval regulations to minimize potential harm from DBPs. Limitations of this project and the data provided did not allow us to curate specific limits for how concentrated DBPs should be allowed to be in deballasted water. We recommend the USCG and EPA conduct further research to determine such limits, and how they should be enforced for commercial vessels.

Future standards in place to limit the DBPs from deballasted water will provide the MSC with ample justification to reject Type Approvals for BWMS that produce too high concentrations of DBPs. These limits should also in turn provide industry the opportunity to innovate BWMS technology further to create new ways to treat ballast water that do not create such high concentrations of DBPs.

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8 Appendices

Appendix A: Understanding Disinfection By-Products

DBPs are an unfortunate side effect of the ballast water disinfection process. Very reactive chemical disinfectants are used with a goal of efficiently neutralizing microorganisms, but this consequentially allows disinfection chemicals in the cleaned water to readily react with organic matter upon being discharged from the management system. This reaction creates DBPs that can be very toxic to human health, marine life, and the environment. In this section, we will explore several different types of DBPs, how they are created, and how they interact with oceanic environments.

1. **Disinfection By-Products from Electrolysis**

During electrolysis the BWMS runs a strong electric current through salt water to create chlorine gas. The chlorine then dissolves in salt water to create sodium hypochlorite and bromide hypochlorite. These chlorites are then used as disinfectants to inactivate microorganisms in the challenge water. Electrolysis often generates more chemicals than are needed to neutralize the available microorganisms in the challenge water, so when the water is discharged from the BWMS it contains excess chlorine (Ballast Water Treatment with Chlorine-based Disinfectants, 2019). The leftover hypochlorite will react with organic matter in the ocean water it has entered and will rapidly form by products such as chloroform and bromoform. An example of this type of reaction is the warning not to mix bleach with ammonia. In a confined space mixing these cleaning agents creates high concentrations of chloramine gas which can be fatal with long exposure. Sodium hypochlorite is the active ingredient in household bleach, and ammonia is present in oceanic organic matter. Excess sodium hypochlorite in deballasted water creates a similar reaction on a smaller scale to produce compounds such as chloramine as DBPs (Sodium Hypochlorite (Bleach), n.d.).

Another commonly produced, particularly harmful by-product is brominated DBPs. Bromine is a very reactive element, and it is inherently in seawater. This means that with the chlorination of seawater comes the rapid production of brominated DBPs which are known to be genotoxic (Gonsior et al., 2015). This effect is less prevalent in freshwater due to the lower salinity and concentration of bromine in the water, but the severity of brominated DBPs must be taken into account when determining acceptable usages of chlorinated BWMS (Gonsior et al., 2015).

2. Disinfection By-Products from Chemical Injection

Since electrolysis requires salt water to run efficiently, fresh and brackish water BWMS will often use chemical injection of chlorinated disinfectants rather than attempting to produce them from sea water. Similarly to salt water, chlorinated disinfection chemicals can create some dangerous by-products in fresh and brackish water, one of which is trihalomethanes (THM). THMs are environmental pollutants and known carcinogens. Due to the varying compositions of dissolved organic matter in freshwater versus seawater, freshwater is more conducive to the formation of TMH (Shah et al., 2015). While the EPA is monitoring and limiting very harmful DBPs such as chlorinated and brominated DPBs, and THM, there are still unregulated DBPs that can be much more harmful to humans than other regulated DBPs as they contribute just as heavily to the cytotoxicity1 and genotoxicity2 of water but are less monitored (Allen et al., 2022) (Disinfectants and Disinfection Byproducts Rules (Stage 1 and Stage 2) What Do They Mean to You?, n.d.).

Appendix B: Informed Consent Agreement for Participation in a Research Study

Informed Consent Agreement for Participation in a Research Study
Investigator: Adrienne Hall-Phillips, PhD
Contact Information: ahphillips@wpi.edu (preferred); (508) 831-4934
Title of Research Study:
Consideration of Disinfection By-Products for USCG Type Approval of Ballast Water Management Systems
Sponsor: United States Coast Guard

Introduction:

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study:

The purpose of this study is to assess the different types of ballast water management systems and the variety of disinfection by-products they create, with the intent of recommending areas for potential improvement to the USCG for commercial vessel ballast water management system standards.

Procedures to be followed:

We will be interviewing subject matter experts to gain a more thorough understanding of ballast water management systems and disinfection by-products, as well as the standards that apply to them. As a participant, your participation will be limited to a recorded interview session, nothing will be expected of you past the interview session.

Risks to study participants:

There are no anticipated risks.

Benefits to research participants and others:

There are no direct benefits to you for participating in this research study.

Record keeping and confidentiality:

Only the research team will have access to your records. All data will be kept in a secure file that only the research team can access. All data reported in a research poster and manuscript will be aggregated. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you. The information that you give will be kept anonymous.

Compensation or treatment in the event of injury:

This research involves minimal risk of injury or harm. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact: The investigator (Dr. Adrienne Hall-Phillips, WPI School of Business, Tel. 508-831-4934, Email: ahphillips@wpi.edu), or the IRB Manager (Ruth McKeogh, Tel. 508 831- 6699, Email: irb@wpi.edu) and the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu).

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

______________________________ Date: _____________________

Study Participant Signature

____

Study Participant Name (Please print)

____ Date: _____________________

Signature of Person who explained this study

Appendix C: Interview Protocols for DBP and Data Collection Subject Matter Expert

DBPs Expert/ Data provider: Ann Kimery	
Questions	**Justification**
We recently sent you a proposal that we developed over A term. It is still a work in progress and was based on our preliminary knowledge of the scope of the project. What are your thoughts on our proposal?	Before we move forward in making progress to our final report, we want to ask for Ann's thoughts on the state of our proposal before coming into work at the Coast Guard.
What are your expectations for our delivery?	We want to clarify what is expected of us in terms of a final product to make sure we are on the correct trajectory.
What makes a DBP harmful to marine and human life?	Not all chemicals have the same toxicity levels. A high concentration of a semi-toxic chemical can be just as dangerous as a low concentration of a very toxic chemical. We would like to know what characteristics of chemicals make them harmful to understand what by-products will need stricter regulations.
What are the most concerning environmental consequences of DBPs?	We would like to understand how DBPs affect the environment and where the consequences of this are most prevalent to assist in further specifying and justifying regulations.
We know ballast water microorganisms have detrimental effects on marine ecosystems which is why we need disinfection. What are the consequences of DBPs on marine ecosystems?	We would like to know how disinfection affects oceanic ecosystems so that we can justify regulating DBPs.
Why is the testing that's been done predominantly land-based?	There is no data collected from systems currently in operation which is needed for us to understand a realistic view of DBP production
Is there a way we can scale the information from land-based testing to drinking water standards?	We need this information to be able to appropriately make suggestions that are applicable to on-ship applications of BWMS because land-based testing is not always representative of how vessels operate on water.

Appendix D: Interview Protocols for EPA Subject Matter Expert

EPA Contact: June Mire	
Questions	**Justification**
Why should DBP concentrations be regulated?	To determine main motivators in pursuit of improvements.
Are there specific DBPs that you feel we should be focusing on?	To narrow down the scope of chemicals we're researching.
How is the EPA determining which DBPs are regulated and the concentration limits? Would you change this process? If so, how?	To understand the process the EPA goes through to identify harmful DBPs
There is not much conclusive data about what specific DBPs have negative effects on human health. Why are they still considered to be dangerous? What are the theorized health implications of DBPs on human and marine life?	To understand the projected risks and concerns put forth by a lack of data.
Are there any additional DBP standards the EPA is working on that we could reference when determining safe levels of DBP concentrations for ballast water?	To see if there are any additional resources that we could use for EPA standards of comparison for DBPs.
Why should DBP concentrations be regulated?	To determine main motivators in pursuit of improvements.
Are there specific DBPs that you feel we should be focusing on?	To narrow down the scope of chemicals we're researching.

Appendix E: Interview Protocols for USCG Policy Expert

USCG Policy Expert: LT Justus Martin	
Questions	**Justification**
Why have DBPs remained unregulated?	To ascertain the existence of obstacles in the way of new policy and the steps required to promote it.
In what ways will the Coast Guard be able to assist entities in their responsibility to adhere to policy for DBPs?	This will allow us to understand the scope in which the Coast Guard is able to assist entities in the transition with new policy.

Appendix F: Data and Calculations

Calculations for P values:
Calculations were all done in Microsoft Excel.

Fresh Water (ug/L)			
Bromoform (P)	Chlorodibromomethane (P)	Chloroform (P)	Dichlorobromomethane (P)
57.8	142	105	104
12.6	54.4	108	69.8
7.4	40.4	109	55.3
19	91	100	84
3.1	19	16	20
1.17	2.04	20.3	5.48
52	110	19	42
3.4	15	15	19
77	160	51	87
103	151	107	206
1	10.05	31.42	17.62
1	10	1	0.1
547	68.9	1.69	9.27
225	8.82	1	1.31
0.85	5.2	13.7	7.54

BROMOFORM	
Sample Size	15
Sample Mean	74.088
Sample Stdev	144.0935076
Hypothesized Mean	7
Test Statistic T	1.803208978
Degrees of Freedom	14
P value	0.046456906
ID	S1

Samples were organized in a table by chemical.

One right tailed T-test was done for each chemical in each water salinity, resulting in 15 total tests, 12 for THMs and 3 for total HAA concentrations. The following formulas were used to calculate each step in the test.

Sample Size (N): =COUNT()
Sample Mean (SM): =AVERAGE()
Standard Deviation (STD): =STDEV()
Degrees of Freedom (DF): =N - 1
Test Statistic (T): =(SM – Hypothesized Mean)/(STD/SQRT(N))
P Value: =T.DIST.RT(T,DF)

The hypothesized mean for each sample is the EPA recommendation for acceptable concentration of that chemical in deballasted water.
Each test/P value was given an ID, to easier identify each sample when adjusting the p values for multiple comparisons.

Adjustment for Multiple Comparisons:
To adjust the P values for multiple comparisons to decrease likelihood of Type 1 Error, the Benjamini-Hochberg method was used.

ID	Pvalue	Rank	padjusted
S6	0.000135254	1	0.001623
S5	0.000501154	2	0.003007
S2	0.000772813	3	0.003091
S9	0.001293887	4	0.003882
S4	0.002578266	5	0.006188
S10	0.021361147	6	0.042722
S1	0.046456906	7	0.07964
S12	0.091332957	8	0.136999
S8	0.164250186	9	0.219
S3	0.865339164	10	1.038407
S7	1	11	1.090909
S11	1	12	1

P values for each test run for THMs were sorted in ascending order and given a rank 1-12. The following formula was used to adjust the P values:

= (P value * 12)/Rank

These P-adjusted values were the final P values used to reject or fail to reject the Null Hypothesis.

The Null Hypothesis for each test was:
H0 ≤ EPA recommendation for concentration of chemical

Since tests were done at a 95% confidence level, the null hypothesis was rejected if $P \leq 0.05$

If P value was below 0.05 and null hypothesis was rejected, it was concluded that the difference in heightened concentration of that DBP in specific water salinity was statistically significant.

Note: Initial P-values calculated for total HAA concentration in water salinities were not adjusted through Benjamini Hochberg method. Only 3 tests were run, which was not deemed a high enough number of tests to warrant adjustment for multiple comparisons. It is acknowledged that this could lead to a certain probability of Type 1 Error.

Testing Results

Results from T-tests for DBPs in Different Water Salinities

Chemical and Water Salinity Evaluated	EPA Suggested Standard (µg/L)	Mean of Measured Concentrations With Standard Deviation (µg/L)	Initial p-Value from t-Test	Adjusted p-Value from BH method
Bromoform Fresh Water	7	75.088 ±144.094	0.046	0.079
Bromoform Brackish Water	7	449.212 ±369.379	0.0005	0.003
Bromoform Marine Water	7	487.629 ±429.719	0.001	0.004
Chlorodibromomethane Fresh Water	0.8	59.187 ±57.715	0.0008	0.003
Chlorodibromomethane Brackish Water	0.8	12.26 ±8.681	0.0001	0.001
Chlorodibromomethane Marine Water	0.8	16.915 ±21.107	0.021	0.043
Chloroform Fresh Water	60	46.607 ±45.095	0.865	1.038
Chloroform Brackish Water	60	0.805 ±0.734	1	1.09
Chloroform Marine Water	60	0.770 ±0.979	1	1
Dichlorobromomethane Fresh Water	0.95	48.561 ±55.706	0.003	0.006
Dichlorobromomethane Brackish Water	0.95	8.047 ±25.122	0.164	0.219
Dichlorobromomethane Marine Water	0.95	5.858 ±10.091	0.091	0.137

Results from T-tests for HAA9 Concentrations in Different Water Salinities

Water Salinity	Suggested HAA9 Standard (µg/L)	Mean of Measured HAA9 Concentrations (µg/L)	Standard Deviation of HAA9 Concentrations (µg/L)	p-Value from t-Tests
Marine	77	167.446	107.708	0.036
Brackish	77	175.740	136.806	0.029
Fresh	77	217.406	257.890	0.086

Note: HAA9 total concentrations above 1000 µg/L were considered outliers and were removed. Two outlier values were removed: a marine water concentration of 2800 µg/L and a freshwater concentration of 3400 µg/L. Table depicts author’s own work.

Appendix G: Interview Summaries

Ann Kimrey:

Our interview started with Ms. Kimrey giving us general notes on the project proposal that the team provided prior to the meeting. Ms. Kimrey's notes included general notes on the direction of the project, as well as more specific notes on phrasing and the use of acronyms. We asked questions listed in Appendix C, including expectations from Ms. Kimrey and the MSC on project deliverables. We also inquired about EPA recommendations or limits that we could use in our project to compare to the data provided to us by the USCG. Ms. Kimrey provided links to ballast water discharge limits that were then used in our analysis to compare the data against. We also asked questions about DBPs and their potential ecological effects that we should be looking into. We finished out the interview by gathering all available information that Ms. Kimrey had about the data that the USCG has been collecting as a part of the type approval process. This interview was incredibly helpful to our project progress, gaining vital information about the data we were given, DBPs, and the project trajectory.

June Mire:

June Mire works as the Director of Ecological Services at Tetra Tech. From this interview we aimed to gather an understanding of why DBPs should be regulated and if there are any specific DBPs that Ms. Mire believes warrant regulations from her observations. After introductions Ms. Mire explained to us that although she has formal studies centered in biology, when consulting you take on the challenges presented to you to help the client, so she is also involved in chemistry work and ecological risk assessments.

After asking Ms. Mire's opinion about which DBPs are worth regulating, she expressed her concern about the lack of regulations around chlorine which we have known has detrimental health impacts for a while. Ms. Mire also provided a bit of insight into how the EPA generally goes about creating chemical regulations. She enlightened us to the fact that due to the lack of financial resources, the EPA cannot test and regulate every chemical, so they have to focus on the ones we already know are harmful. In enforcing regulations around those chemicals, the hope is that the production of other, less researched chemicals will lessen as well if they come from the same source. This insight by Ms. Mire made us more confident in our decision to focus on the two groups of more researched chemicals, HAAs and THMs, because making regulations around those DBPs could also result in a decrease in the production of other DBPs because they come from the same source, the BWMSs. Ms. Mire explained that justifying the creation of chemical regulations is much easier when there is a lawsuit or talk in news sources about the harmful impacts of the chemicals.

To conclude this interview, we asked Ms. Mire about the health implications of DBPs. She explained that looking at more researched chemicals with similar structures to the chemical in question can give an idea of how the chemical would react with the body and what the implications of that would be. She also told us about the Anacostia River project she is working on where she aids in researching chemical spills. This provided a good example of how identifying harmful chemicals works in practice and how to go about choosing which chemicals to focus on removing to ensure that there is research backing up the decision to clean the spill or make regulations. The insight provided by Ms. Mire was crucial in how we chose to proceed with data analysis and archival research. It shaped our mindset to understand that providing sufficient evidence that there is an issue with a couple DBPs is better than having weak evidence for many DBPs.