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Adapting Biotoxin Monitoring For The Future: An Opportunity For A Harmful Algae Bloom (HAB) Network In Casco Bay, Maine

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Abstract

Harmful Algae Blooms (HABs) related to marine biotoxins have considerable impacts on coastal communities and have been increasing in size and frequency globally. Maine is recognized as a leader in biotoxin management as it relates to bivalve shellfish, but it has been unclear how current management practices effect the growth of shellfish aquaculture and how they will adapt to future conditions. This research uses a collaborative approach to analyze the current state of biotoxin management in Maine. First, the current management practices in Maine were compared and contrasted with five other states dealing with similar issues. Then, the perspectives of primary stakeholders in the oyster aquaculture industry were investigated through surveys and interviews. Lastly, the interactions specifically between the oyster aquaculture industry and biotoxin management were examined in Casco Bay. Comparative case study results demonstrate that Maine effectively manages biotoxins but is lacking in data transparency and stakeholder engagement. Survey results suggest, oyster aquaculturists in Casco Bay are acutely aware of issues in biotoxin monitoring and are eager to find innovative solutions, as their livelihoods are directly impacted by the closures. An independent HAB network in Casco Bay would be an effective approach to increase stakeholder engagement and transparency around closure decisions. This will require initiative from both the grower community as well as the regulators. A new HAB network has the potential to build trust between the regulators and oyster aquaculturists, as well as contribute to future HAB research.

1. Project Scope & Objectives

Harmful Algae Blooms (HABs) have had large impacts on bivalve shellfish aquaculture around the world. It has been apparent since as early as 1993 that HABs are on the rise globally (Hallegraeff, 1993; Hoagland et al., 2002). The absence of knowledge on, as well as the complexity of the driving factors of HABs makes them difficult to forecast. While there has been large growth of the aquaculture of bivalves around the world, (Wijsman, 2019) the importance of monitoring and managing these blooms cannot be understated.

Maine is a microcosm of the importance of HAB management due to the growth of shellfish aquaculture and extreme ocean warming. The monitoring and management of HABs in Maine is extremely complex as it involves knowledge of federal regulations, state leasing structure, bloom dynamics, and economic and political systems. The effect of HABs on the growth of the shellfish aquaculture industry in Maine is unclear because of these complexities. This study focuses specifically on the challenges of HABs, and their associated biotoxins, as they relate to American oyster (*Crassostrea Virginica*) farmers in the Casco Bay region of Maine due to the unique combination of biotoxin risk, new farmer entry, and growth of aquaculture in the area. The extent and intensity of closures in Casco Bay are extremely variable from year to year. The goals of this study are as follows:

1. Identify and discuss current biotoxin management frameworks in jurisdictions in North America that have similar conditions to Maine.

2. Evaluate the economic effect of biotoxin closures as well as the level of concern related to biotoxins within the oyster farming industry of Casco Bay, Maine.

3. Propose a framework to allow management of biotoxins in the Casco Bay region to adapt for the future, which can be translated to other regions around the world.

2. Background

2.1 Introduction

Oyster Aquaculture is an expanding industry in the state of Maine and vitally important to the economic growth of the state. Maine is known to have one of the largest seafood-based economies in the country. The wild fisheries that have been an integral part of Maine's economy for centuries are generally in decline and aquaculture has been proposed as a way for commercial fisherman to diversify their income (Stoll et al., 2019). When it comes to bivalve shellfish, softshell clams have been the most valuable shellfish for decades reaching a peak harvest in the 1970s at over 40 million pounds. Since then clams have been in decline. In 2019 the harvest was just over seven million pounds, and at the same time oyster aquaculture has been expanding (The State of Maine Department of Marine Resources, 2020).

Starting in the 1970s with European oysters and shifting to American oysters in the 1980s the oyster aquaculture industry in Maine has been steadily expanding. The oyster aquaculture industry is growing across the country, but Maine is unique in the fact that the state offers a Limited Purpose Aquaculture (LPA) permit that is very small and can be acquired with minimal cost and oversight. LPA's have made it possible for many small new farms to enter the industry at a rapid rate. Since 2016, the number of LPAs in the state has more than doubled from ~300 to over 650. Since 2011 the number of farm-raised oysters harvested in Maine has increased from 2 million pieces to just under 14 million pieces in 2019. In the same time frame the value of the industry has increased from $1 million to just under $10 million and this trend is expected to continue (The State of Maine Department of Marine Resources, 2020). This growing industry faces many challenges along with HABs, including changing ocean climate, lack of community support, government regulation, and access to investment capital. It is in the best interest of the economic growth in Maine to help this expanding industry succeed, and make sure that it is growing in a sustainable manner. This study focuses on the risk that harmful algae blooms (HABs) related to marine biotoxins pose to the growth of industry. Specifically, how the monitoring and management of these biotoxins can adapt for the future.

The combination of many new farmers entering at a small scale and the increasing risk of harmful algae blooms has put pressure on the state government to keep the public safe from toxic shellfish without creating barriers for entry into the industry. The increasing prominence and unpredictability of shellfish harvesting closures due to biotoxins is a significant problem for the industry and solutions exist that highlight the need for co-management between state agencies and local users.

2.2 Harmful Algae Blooms (HABs)

Harmful algae blooms, known as HABs are blooms of microscopic algae or phytoplankton that can occur in both freshwater and marine settings. They occur in bloom events that are defined by periodic dominance of one type of algae growing in large quantities in a specific area (Anderson, 2009). HABs can cover an extremely broad range of events. They cause harm ranging from economic impact to health and environmental effects. The wide-ranging costs and impacts of HABs have been thoroughly documented (Wells et. al., 2015; Anderson, 2009). They include large fish die offs, closure of public beaches and lakes, closures of shellfish harvesting, and toxic environmental conditions. In 2005 it was estimated that HABs accounted for an economic impact of $82 million a year on average (Jewett et al., 2008).

The various types of HABs can be simply divided into two general categories, non-toxin producing or toxin producing blooms (Anderson et al., 2002). The first category includes those that are not inherently toxic but grow so fast and consume so much oxygen that they create anoxic conditions in the surrounding environment. These blooms are commonly referred to as "dead zones" in the Gulf of Mexico and other estuarine environments. The nutrient runoff from developed areas can exacerbate these blooms and cause environmentally destructive conditions. Many Cyanobacteria blooms including the genuses *Gloeotrichia* and *Anabaenopsis* are known to create anoxic conditions but do not contain toxins (Paerl et al., 2016). The economic impacts of these blooms are most commonly related to tourism and ecosystem degradation.

The second category of HABs are those that contain biotoxins or poisonous substances that are deadly to animals or humans. The algae associated with these blooms synthesize toxins within their cells that are transferred up the food chain. These types of blooms are known around the world to cause die-offs of various species and are especially economically devastating to aquaculture operations. In an example of this is the species *Cochlodinium polykrikoides*, which is known around the world to cause fish kills and is a major issue in the Chesapeake Bay (Mulholland et al., 2009).

The HABs discussed in this research fall into the category of biotoxin-producing algae. Mostly the toxins are bioaccumulated in the tissue of shellfish that eat toxin producing phytoplankton (Farabegoli et al., 2018). While the toxins largely do not affect shellfish growth, they can be deadly when consumed by humans. These biotoxin come from blooms including *Alexadrium spp.* which is responsible for Paralytic Shellfish Poisoning (PSP), and *Pseudo-nitzschia spp.* which is responsible for Amnesic Shellfish Poisoning (ASP) among others. Both ASP and PSP blooms regularly occur in the state of Maine along with other states including Alaska, Washington, and Massachusetts. Another toxic algae, *Karenia Brevis*, occurs mostly in the Gulf of Mexico and is responsible for Neurotoxic shellfish poisoning (NSP). In Florida there have been blooms containing NSP causing toxins that have lasted for over 12 months (Watkins et al., 2008), closing shellfish harvesting for multiple years at a time.

2.2.1 The Global Increase in HABs

Since as early as 1993 there have been signs of a global increase in HABs frequency, duration, and species diversity (Hallegraeff et al., 1993). The factors that affect HAB dynamics range from climate change, anthropogenic influence, physical ocean dynamics, and more (Glibert et al., 2005). Places like the Gulf of Maine and Puget Sound that rarely saw blooms before the 1970s are now seeing blooms every year. *Pseudo-nitzschia spp.* has been monitored regularly in Maine, but never produced domoic acid at levels that would require closures. In 2016, *Pseudo-nitzschia australis*, a species that has never been documented before, appeared, and produced significant levels of domoic acid. This caused a major shutdown of shellfish harvesting in the state and recalls of already harvested shellfish (Daley, 2018). Blooms of *Pseudo-nitzschia australis* are now a regular occurrence in Maine. In the United States virtually all coasts are affected by HABs. Bloom dynamics and predictions have been extremely hard to study due to the many complex variables that affect HAB events. It is unclear what exactly is causing this increasing trend of HAB events, but it is very clear the trend is continuing. There is a considerable lack of standardized data or hypotheses on the factors that influence HAB events (Wells et al., 2015).

One factor that is connected to the increase in HAB events is warming waters. This is especially true in the Gulf of Maine where waters are warming at a rate faster than 99% of the oceans around the world (Pershing et al., 2015). Temperature has been connected to the expansion of blooms such as *Alexandrium cantenella and Dinophysis acuminata* using an analysis of sea surface temperatures from 1982 to 2016 (Gobler et al. 2016) and a bloom of *Pseudo-nitzschia* in the Pacific Northwest (Trainer et al., 2020). There are also theories that increased eutrophication of coastal waters, and transfer of species by ballast water from ships have played important roles in the spread of HAB species around the world (Anderson, 2009).

2.3 The National Shellfish Sanitation Program (NSSP)

The NSSP is a state and federal cooperative program recognized by the FDA that controls the sanitation of bivalve shellfish produced for human consumption. The program covers requirements for the state shellfish sanitation plan, dealer certification, classification of shellfish growing areas, laboratory procedures and more. Every two years updated guidance is published. States and industry members can give input during the updating process at the Interstate Shellfish Sanitation Conference (ISSC). For the purposes of this study, the regulations provided in the NSSP related to biotoxins are discussed below. The information comes from the most recent guidance published in 2017.

The NSSP requires states to have a marine biotoxin management plan including specific requirements for testing frequency and closure procedures for states that experience regular toxic bloom events. There are currently five known biotoxins regulated under the NSSP. These biotoxins are each related to different algae blooms and there are requirements that each state must monitor species that are present in their waters (Table 1.). As defined in the NSSP Model Ordinance Section II. Chapter IV @.04 (US Food and Drug Administration, 2017) areas that have historically seen closures due to any of the five biotoxins must have a marine biotoxin management plan in place to do the following:

(a) Maintain a routine shellfish sampling and assay program including:

    i. Establishment of appropriate shellfish screening levels

ii. Establishment of appropriate shellfish screening and testing methods
iii. Establishment of appropriate laboratories/analysts to conduct shellfish screening and testing methods
iv. Establishment of a sampling plan for both (i) and (ii) above; and
v. Other controls as necessary to ensure that shellstock are not harvested when levels of marine biotoxins meet or exceed the established criteria in Section C. (Table 1. Action Levels)

(b) Close growing areas and embargo shellfish;
(c) Prevent harvesting of contaminated species;
(d) Provide for product recall;
(e) Disseminate information on the occurrences of toxic algal blooms and/or toxicity in shellfish meats to adjacent States, shellfish industry, and local health agencies;
(f) Coordinate control actions taken by Authorities and Federal agencies; and
(g) Establish reopening criteria.

Illness	Associated Biotoxin	Most Commonly Associated Phytoplankton	Action Level	Common Laboratory Tests
Paralytic Shellfish Poisoning (PSP)	Saxitoxins	*Alexandrium spp.*	80µg/100g	Mouse Bioassay (MBA)*, HPLC Post-column Oxidation (HPLC Pcox)*, Receptor Binding Assay (RBA)
Amnesic Shellfish Poisoning (ASP)	Domoic Acid	*Pseudo-nitzschia spp.* And *Chandria armata*	20µg/100g	High Performance Liquid Chromatography (HPLC)*; Enzyme-linked Immunosorbent Assay (ELISA)
Diarrhetic Shellfish Poisoning (DSP)	Okadaic Acid	*Dinophysis spp.*	160µg/100g	Liquid Chromatography tandem Mass Spectrometry (LC-MS/MS)*, MBA
Neurotoxic Shellfish Poisoning (NSP)	Brevetoxins	*Karenia brevis*	5,000cells/L or 20MU/100g	Phytoplankton cell counts*, MBA*, ELISA
Azaspiracid Shellfish Poisoning (AZP)	Azaspiracids	*Protoperidinium crassipes*	160µg/100g	LC-MS**

Table 1. Five biotoxins regulated under the National Shellfish Sanitation Plan (NSSP) and related algae blooms.
*approved by NSSP for regulatory use.
+ US Food and Drug Administration, 2017
**AZP has not been found in the North American Shellfish – only in imported shellfish

Coastal states that do not regularly see toxic algae blooms must still have a written biotoxin contingency plan in place that address what would be done in the cause of a toxic algae bloom occurring in their waters. For example in Maine in 2016 there was a bloom of *Pseudo-nitzschia australis* that contained high levels of domoic acid which caused closures of shellfish harvesting in Downeast Maine starting in mid-September and extended as far as Penobscot Bay in October (Clark, 2019). Maine had a biotoxin contingency plan for ASP that was enacted due to this unprecedented bloom. It involved closure of shellfish harvesting and recall of affected shellfish. Now Maine has regular monitoring of ASP (White, 2016). Many states such as Virginia, Connecticut, and Rhode Island have biotoxin contingency plans in place should HABs containing biotoxins bloom in their waters. Some of these plans include regular phytoplankton monitoring, but they are not required to. The contingency plans are designed more as reactive measures to protect public health during an unexpected outbreak (US Food and Drug Administration, 2017).

While this creates a generalized standard, there is still large variety in how states carry out management of biotoxins. This can be due to variables such as funding availability, laboratory methods available, and species harvested among other factors. In some states groups from the non-profit sector help with monitoring in cases where the state does not have the resources needed or are not required to monitor based on regulations in the NSSP. Some examples are the Southeast Tribal Ocean Research (SEATOR) program or Olympic Region Harmful Algal Bloom (ORHAB) network.

The NSSP contains strict regulations on the certification of public and private laboratories for testing of shellfish samples for human pathogens. State laboratories are certified initially by the FDA. States then have the option to appoint a state shellfish laboratory evaluation officer or LEO. This person is responsible for the certification of laboratories and continued evaluation of laboratory methods used for testing shellfish samples. Very few states use LEOs, and they have very little authority in practice. Usually, FDA handles the entire certification process including follow up evaluations and reports to make sure the laboratory standards are sound.

2.4 Biotoxin Management Strategy

While the federal government has guidelines outlined in the NSSP, each state runs their own shellfish sanitation program and procedures can vary widely from state to state. States programs are largely based around the commercially important species of bivalves in their area. Each species of shellfish uptake the biotoxins at different rates and therefore require different closure periods. Species such as the blue mussel (*Mytilus edulis*) accumulate toxins quickly as well as detoxify quickly. This makes mussels a good sentinel species to assess what toxins are present in the water. Many programs around the world use mussels as the basis of their biotoxin programs. Other species such as butter clams (*Saxidomus gigantea*) and sea scallops (*Placopecten magellanicus*) take longer to uptake the toxins but retain them for much longer periods of time. There are many species that fall in between these two, so it is important for state programs to understand what is important to test in their area.

Generally, biotoxin management can be divided into current or reactive measures vs. future or preventative measures (Figure 1). Current or reactive measures are defined as management dealing with the blooms occurring in real time. These are the tasks and strategies implemented on a seasonal time scale. For most locations, this includes biotoxin monitoring which begins in March or April and lasts until the fall, but timing is variable depending of the specific bloom dynamics in the area. Government agencies are responsible for conducting this monitoring and the amount of sampling they do varies largely from state to state depending on funds available and needs of the state. For example, aquaculture and harvesting of shellfish in Oregon is limited to certain areas in the state which are easy for the government to monitor with limited resources. In places such as Alaska and Maine it is much harder due to the widespread areas of aquaculture and wild harvest, and the complex geography of their coastlines.

Future and preventative measures are those that are being done to help prepare for the future HABs landscape along with the anticipation of how aquaculture and shellfish harvesting will change. One example of a pro-active, preventative measure is the research and development of new biotoxin monitoring capabilities.

2.4.1 Toxin Level Monitoring/Real time Closures

As described in the NSSP states are required to monitor and manage biotoxins that historically occur in their states. In most states this consists of sampling of shellfish tissue from locations along the coast where wild populations of targeted shellfish exist. In some cases, such as Washington state and more recently in Maine, cages of shellfish must be placed at locations to provide sampling material in the areas that testing is required. It is up to the discretion of the state to make sure that the sampling is extensive enough to accurately depict where the blooms are occurring. When a closure is put in place state officials are required to publish legal notices informing the community of the closure along with municipalities and any commercial operations. A record of all the closure notices are archived by the government and are available to the public upon request. Also, signage is required on any public harvesting area informing the public on how to find information on closures. Regulators are under high pressure due to the balance of keeping the public safe from biotoxins and not creating major burdens to the industry.

2.4.2 Phytoplankton Monitoring

Phytoplankton monitoring is one of the more dynamic aspects of biotoxin management. It is included as both a current and future method for biotoxin management because they give early warning of blooms currently occurring as well as advance knowledge of species that might be moving into an area. Many state's run their own phytoplankton monitoring and it is an easy way for citizen science groups to get involved because it requires relatively cheap equipment and minimal training to conduct.

2.4.3 Research and Development

The timing, frequency, and intensity of these blooms depend on many variables and can be extremely hard to predict. The U.S. is divided into three main areas as it relates to HABs and biotoxin risks, the northeast, Gulf of Mexico, and west coast. There is a great deal of collaboration between states, federal agencies, and research institutions to monitor the changing dynamics of HABs in order to predict blooms in these areas. In the northeast region there are currently many new developments in monitoring technology that have the potential to drastically change how monitoring is conducted. Organizations in the northeast such as the Woods Hole Oceanographic Institution (WHOI) and Bigelow Laboratory for Ocean Sciences have spent a great deal of time working on prediction of blooms through forecasting and modeling programs. Preliminary results show that this has potential to serve as an early warning system to show when closures will take place (Grasso et al., 2019).

2.4.4 Education and Outreach

Another important aspect of future and preventative measures is in education and outreach. Many state programs include education materials on their websites that relay basic information on what biotoxins are and how they can be accumulated . Education on biotoxin data interpretation is also very important for anyone involved in the shellfish industry including aquaculturists and wild harvesters.

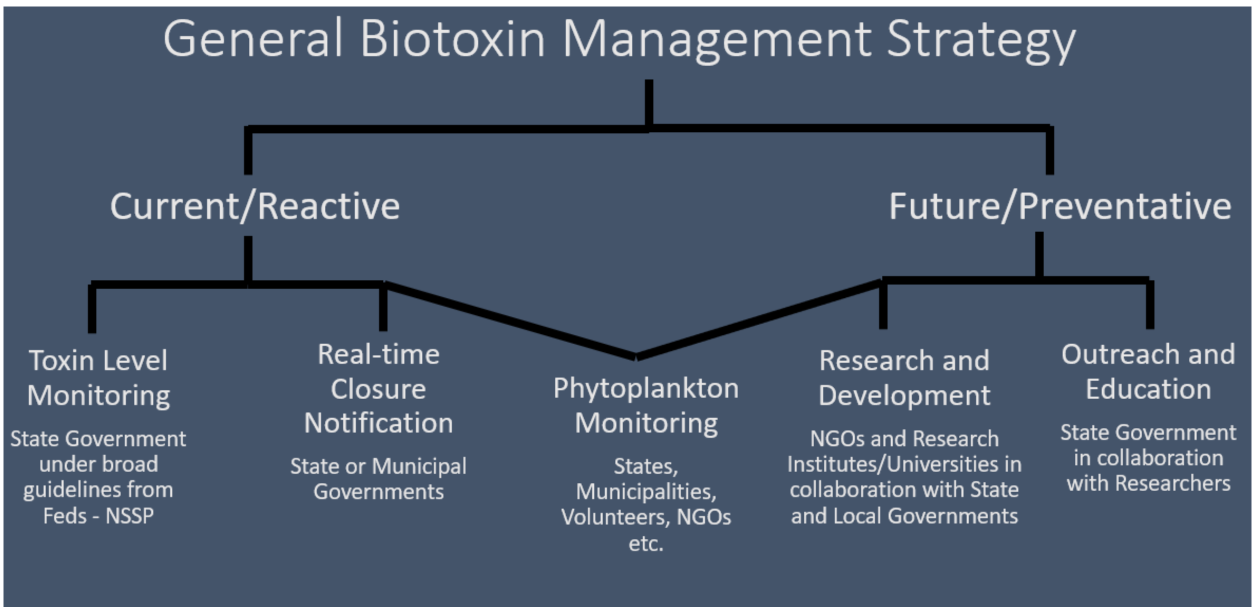


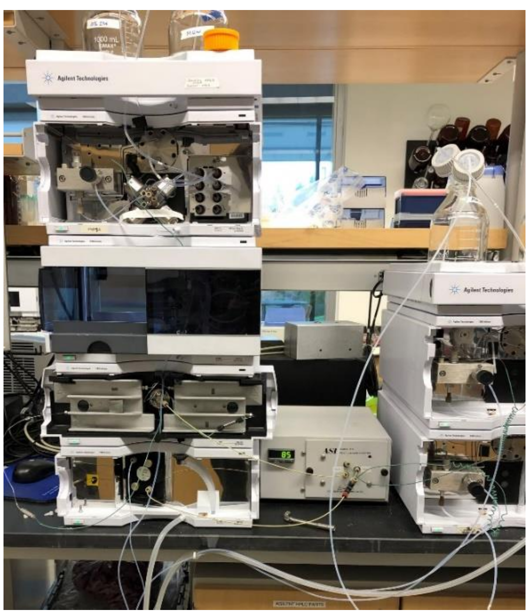
Figure 1. General biotoxin management strategy framework. Bottom level lists agencies responsible for management.

2.4.5 Laboratory Testing of Biotoxins

Many species of algae that cause biotoxins are difficult to monitor due the similarity of species within a genus and the variation in toxin production in a species. For example, the case of *Alexandrium spp.* is challenging to manage because the level of toxin within a bloom can vary widely based on biochemical factors including salinity and temperature among others (MacIntyre et al., 1997). When there is a bloom of *Alexandrium* it is difficult to determine the toxin level solely based on the phytoplankton counts. That is why testing for the biotoxins must occur in the tissue of the shellfish. On the other hand, species such as, *Karenia brevis*, responsible for the majority of the red tide events in the Gulf of Mexico, has somewhat more predictable toxin levels and can be monitored primarily on counts per liter of the species in sea water samples. The rate of uptake and elimination of toxins also varies between shellfish species. Shumway et al. 1988 describes in detail the various factors that contribute to these differences. It is important to keep in mind that all species interact with the toxins differently, therefore making it important to focus on testing all species that are consumed by humans, whether they are commercially important or harvested recreationally.

The NSSP certifies laboratory procedures through FDA laboratory standardizations as well as from input from states. As it relates to biotoxins discussed in this study there are three accepted methods for testing for PSP and one accepted method for ASP, NSP, and DSP respectively. The Mouse Bioassay (MBA) method had been the standard for PSP testing for more than 50 years (Visciano et al., 2016). Recently new methods including the Pcox method and Receptor binding assay (RBA) have been developed that have more accurate results as well as higher throughput of testing.

MBA has been the standard for testing for PSP as early as the 1920s and many states continue to use it as the primary method for detection of toxins related to PSP, DSP, and ASP. Shellfish tissue is homogenized by blending and then filtered to create an injectable substance. This is injected into mice and the time until mortality of the mice determines the level of toxin in the shellfish. This test is still widely used today because of its relatively low cost, ease of use, and quick determinations. Drawbacks to MBA include that it cannot detect toxins at low levels, has ethical concerns, and are prone to inaccuracies (Campbell et al, 2011). It is important for testing to be done in a timely manner in order to make proper closure decisions and avoid needing to recall shellfish products. It is especially important for commercial harvesters who cannot hold supply for long periods of time. The largest factor that plays a role in results turnaround is transport of samples. Today most states continue to rely on MBA testing, while Maine using HPLC Pcox



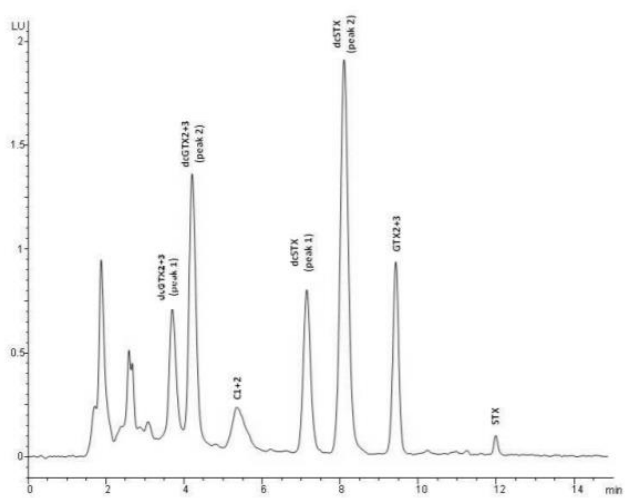


Figure 2. HPLC machine used for P-Cox method at Bigelow Laboratory for Ocean Sciences (left) and example of output results for a toxic mussel sample from Gago-Martinez, 2006 (right).

HPLC has been used to detect toxicity of shellfish since at least the 1990's but has become more prevalent in the 2010's due to reduced costs and the development of innovative techniques that simplify the procedure. It has been shown to be more sensitive to PSP toxins and therefore give an earlier warning of PSP blooms as well as proving more accurate than MBA (Lawerence et al., 2005). The method that is now accepted by the NSSP as a safe test for the toxins related to PSP is the Pcox method, which is used in Maine and Canada as well as countries in Europe (Figure 2). This method is based on reversed-phase liquid chromatography with post-column oxidation and fluorescence detection described in detail in Van De Riet et al. 2011. It is a complex method that takes highly trained scientists for both sample preparation and data interpretation. The processing time is within 24-48 hours.

Other testing methods that have become popular are the Receptor Binding Assay (RBA) for PSP and Enzyme-linked Immunosorbent Assays (ELISA) for a variety of toxins including those that cause NSP, ASP, and DSP. RBA is approved in the NSSP for use with scallops and clams and has had promising results for use with oysters in Great Britain (Turner et al., 2018). RBA has high throughput and is successfully used in a tribal program in Alaska to create shellfish harvesting advisories. The ELISA test kits have been developed for okadaic acid, domoic acid, and saxitoxins associated with DSP, ASP, and PSP respectively (Dubois et al., 2010) among others. These tests are mostly used as screening tools to see if toxins are present and are not as good for use in determining specific levels of toxins present. In Florida ELISA's are used in screening for NSP, but MBA is still used to reopen shellfish beds because it is more sensitive.

2.5 Biotoxin monitoring in Maine

PSP has been monitored in the state of Maine since 1958. After major closures in 1973 due to lack of precise knowledge, funding was secured to expand the monitoring program of the DMR (Shumway and Hurst, 1988). The most important commercial shellfish at the time were soft-shell clams and blue mussels for which the monitoring program was designed. During the bloom season which generally occurs from April until September, mussels and clams are harvested from primary sampling sites on a weekly basis to determine baseline levels. Once toxins are detected, sampling expands to secondary and tertiary sites. The goal of the program is to protect the public from potentially life-threatening illness, while minimizing closures to the extent possible to reduce the economic impact on the shellfish harvesting industry. Historically, the sampling locations were in primary locations for the wild harvest of clams and mussels. As recently as the early 2000's shellfish aquaculture began to expand in the state. The most popular species for aquaculturists is the American oyster (*Crassostrea virginica*) which is not a naturally abundant species in Maine. American oysters uptake biotoxins at a different rate than mussels and clams and therefore require additional sampling. The biotoxin monitoring was not initially designed to account for American oysters. Today, DMR generally samples from the intertidal zone at low tide when soft-shell clams and mussels are accessible. In some locations where wild resources are low in abundance or particular species are not present (e.g. America oysters) pre-stocked sampling cages are used. Samples of 12 animals per site are sent to Bigelow Laboratory for Ocean Sciences, the only NSSP certified lab in Maine, for the HPLC Pcox method. Once the biotoxin is detected at levels above the regulatory limit the aquaculturists and municipal shellfish programs and the public are notified, and a legal notice is posted online initiating a harvest closure. There needs to be two consecutive clean samples seven days apart in order for the area to be reopened to harvesting.

Maine has over 5,000 miles of coastline including all the islands associated with the state. Along with this, there is a strong tradition of small business and entrepreneurship and a large population of recreational harvesters. This combination makes biotoxin management a uniquely difficult task in Maine. With oyster aquaculture growing in the state there is added pressure to make sure the management does not negatively impact this growth. Presently, the DMR samples blue mussels at approximately 18 primary sites weekly, with additional sites and species being added as new hot spots are discovered.

In order to understand how biotoxin management effects shellfish aquaculture in Maine it is important to understand the leasing structure and how the industry is growing. There are three types of leases in Maine: The standard leases are larger scale operations, experimental leases are mid-size operations, and limited purpose aquaculture permits (LPA) are small scale (Table 2). LPAs were designed to allow farmers to test methods or get experience before moving to a larger scale lease. It is important to note, that many people entering the industry lease LPAs because they are cheap and relatively simple to maintain. Any person can own up to 4 LPAs at one time, which has led many farmers to operate profitable businesses on LPAs owned by different members of the business.

Lease/Permit Type	Maximum Size	Application Fee ($)	Annual Fee ($)	Can send samples during closures*
Standard	100 Acres	1500	100/acre	✓
Experimental	4 Acres	100	100/acre	✓
Limited Purpose Aquaculture (LPA)	400 ft^2	50	50	x

Table 2. Lease/Permit options for aquaculturists in Maine. Adapted from Stoll et. al. (2019).
*If they have signed an MOU with DMR

Due to the nature of the growth of the shellfish aquaculture industry in Maine, new challenges have arisen for monitoring. Many shellfish farms grow their product in floating bags or cages in the subtidal surface waters of bays and estuaries. Exposure time to HAB blooms for shellfish grown in this manner is dramatically longer than shellfish collected from the intertidal locations DMR has historically sampled from. In 2006, a project was developed to place mussel bags in subtidal areas to permit consistent sampling which allowed 11,000 acres of clam harvesting area to stay open during that year (Battelle & MER Assessment Corporation, 2007).

To account for this the DMR has set up a complex monitoring strategy that requires aquaculturists to either enter a memorandum of understanding (MOU) with the DMR and/or supply industry funded sample results to the DMR. This generally allows for shellfish farms utilizing leases to provide samples at their own cost during a closure, and if they fall under the regulatory toxicity level they can continue to harvest (Kanwit, 2018). MOUs are available to all lease holders, but they are considered voluntary and only utilized to keep farms open that potentially fall in closure areas based on the standard sampling structure. Generally speaking, DMR will fund samples once a week from representative aquaculture leases until the normal closure threshold is reached. For some high-risk species such as whole or roe on scallops, the grower must always fund the sampling at the discretion of the DMR. This is due to the extremely dangerous nature of the end product, the requisite sampling intensity to mitigate this risk and the fact that the state budget was never structured to accommodate sampling for such specialized products (Kanwit, 2018). The samples must be processed at a certified laboratory, Bigelow Laboratory for Ocean Sciences, and can be costly for the farms. It is important to note that before 2017 MOUs were available to leaseholders as well as LPA permit holders. Today, it is only available to farmers operating on standard or experimental leases because the DMR lacks the resources to coordinate all of the logistics necessary to sample from the large number of LPAs in the state. This has created conditions that keep many LPA based farms closed during times when nearby larger leases can stay open. For many LPA based farms and others that cannot afford testing at a certified laboratory, but still collect data that is not used to open their farm but can be helpful for internal records (Figure 3, see the orange circle). The DMR is looking for ways to improve biotoxin sampling specifically related to aquaculture because as more farms switch from LPAs to larger leases the number of samples will also continue to increase.

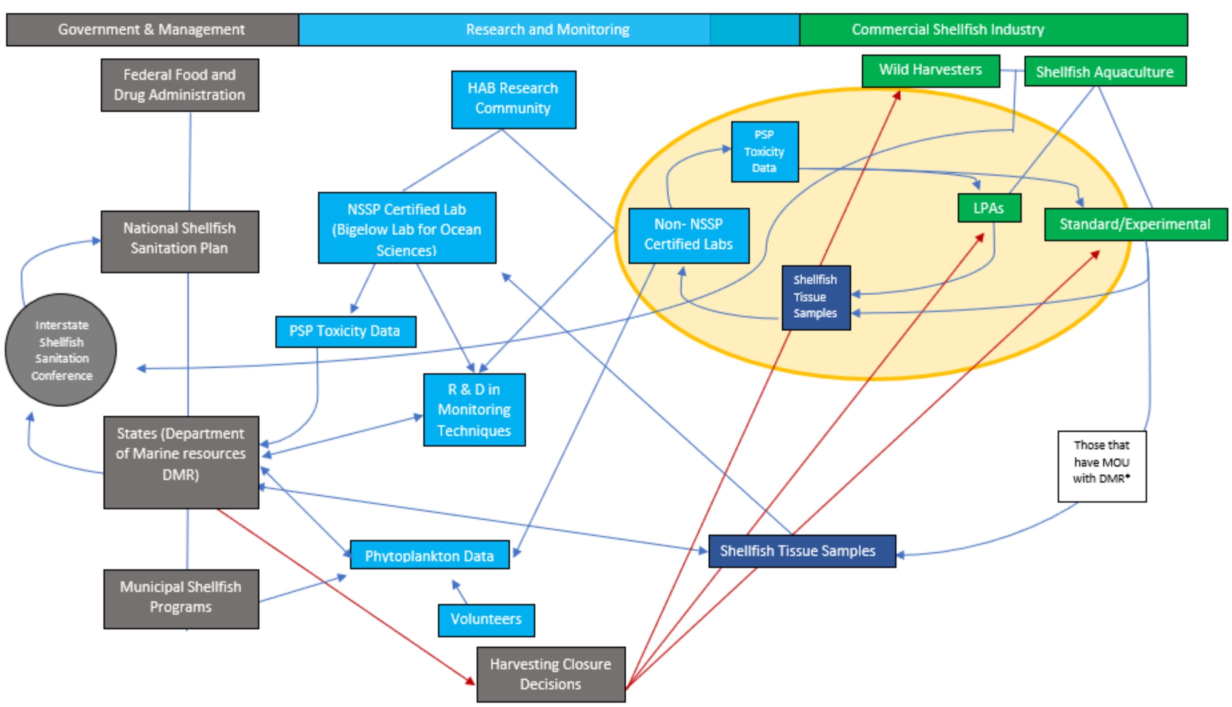


Figure 3. Conceptual Framework for PSP management in Maine. (…) represent entity in Maine. = farm sampling that is done for personal records only and can be costly, does not affect

closure decisions.
Red arrows indicate closure decision and affected stakeholders

2.6 Casco Bay: An Important Shellfish Aquaculture Region

Casco Bay, Maine is an important regional area for shellfish aquaculture in Maine. It is where the majority of the population of Maine lives and has adequate waters for growing shellfish effectively. It is the area of focus for this study due to a combination of factors that make biotoxin management challenging. These include the growth of aquaculture, complexity of the coastline, and stakeholder tensions that have boiled to the surface in the area. Some community members are unhappy DMR has allowed the industry to grow as quickly as it has, while others believe the biotoxin closures are overly strict causing major losses of revenue (Russell, 2019; Valigra, 2019). As recently as 2016 there were roughly 30 LPAs in Casco Bay for oyster aquaculture and as of the writing of this report there are over 190 (Figure 4).

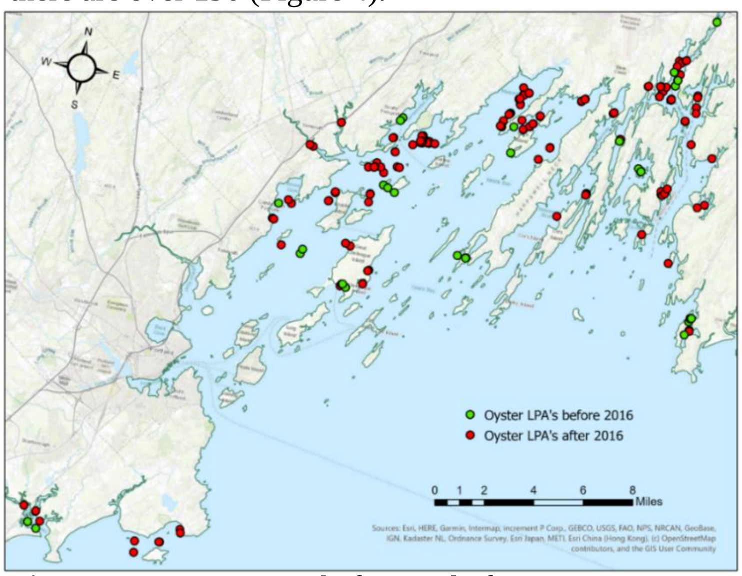


Figure 4. Oyster LPAs before and after 2016 in Casco Bay, Maine. 26 total LPAs before 2016 and 191 since.

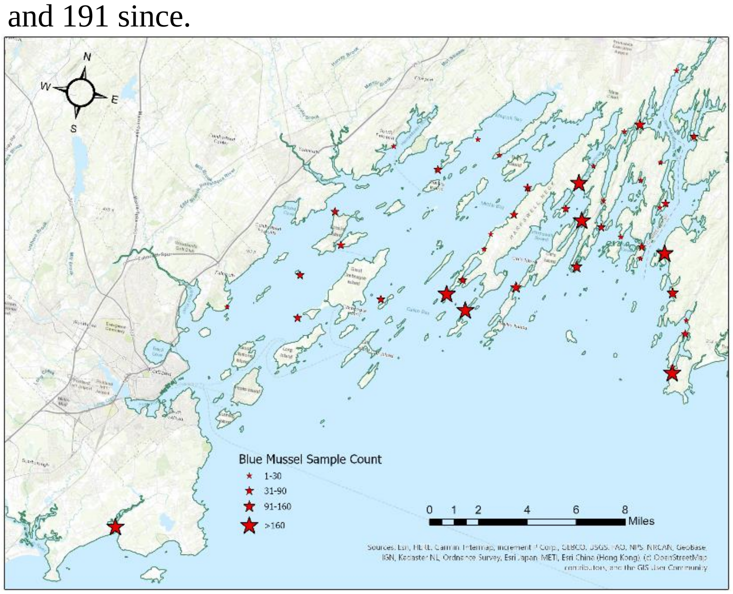


Figure 5. Mussels sampling stations used in Casco Bay from 2010 – 2018. Number of samples range from 1-230.

Most of the sampling that DMR conducts in Casco Bay is the blue mussel. This allows them to react to where the blooms are occurring, and then test other species as needed. Most of the sampling is done with wild mussels in places that are easily accessible by shore (Figure 5). Sampling is mostly broken down into primary and secondary sites so the number of samples from site-to-site can vary greatly. DMR is always adapting there sampling procedures to adjust to the historical trends they are seeing in the samples. The primary locations are those they know usually experience the first signs of blooms.

2.7 Stakeholder Engagement in Environmental Monitoring

Stakeholder engagement in the management of HABs as it relates to the shellfish aquaculture industry in Maine is vital to the successful balance of management and growth. It may involve a large group of stakeholders including farmers, state and federal government, independent research organizations, municipal planners, resource managers and more. The current program has drawbacks that become clear when speaking with stakeholders and has been reported on by the *Portland Press Herald* (Russel, 2019). Many researchers have emphasized the importance of engaging the stakeholders in research (McGreavy, 2018; Huang and London, 2016). When improving management of public resources, it is important to include those who will be affected the most. As defined in Plummer and FitzGibbon, 2004 co-management of environmental resources involves input from government, private commercial interests, and the local community. McGreavy et. al. 2018 describes the importance of sharing responsibilities between actors and institutions in the successful co-management of the soft-shell clam fishery in Maine. For shellfish aquaculture, communication and shared responsibilities between farmers, local municipalities, and state government can lead to better relationships and successful management. Gratten et al. 2016 reviews the public health concerns related to HABs and concludes the need for enhanced monitoring of blooms in collaboration between scientists, regulators, and community members along with public health officials. Protecting public health necessitates the collaboration between stakeholder and promotion of effective management of HABs.

2.8 Research Questions

In order for Maine's aquaculture industry to grow successfully, biotoxin monitoring and management needs to be adapted for the inflow of new growers and environmental concerns that will increase bloom diversity, intensity, and duration. The research questions investigated are as follows:

1. Is biotoxin monitoring a concern among oyster farmers in Maine and should it be? How do biotoxin closures effect the industry?

2. Is the Maine Department of Marine Resources management program sufficient for the needs of the growing industry and how can it adapt for future conditions?

3. What lessons can be learned from other biotoxin management programs in North America? How can these be applied to Maine?

3. Research Methods

This study used a three-pronged approach to answer if biotoxin monitoring is a concern among oyster farmers in Maine, and how management decisions effect the industry. First a review of case studies analyzing the biotoxin monitoring strategies from a select group of states and countries in North America was conducted to understand how HAB and biotoxin management is approached in different areas. This was followed by surveys given to oyster aquaculturists in the state of Maine to understand their perceptions of biotoxin monitoring in the state. Open interviews were then conducted with select farmers who filled out the survey to expand upon their answers. Finally, a case study of the region Casco Bay, Maine was conducted to see how the management currently takes place and what it could look like under a new management framework.

The study implemented a mixed method approach similar to the style used in McGreavy et. al. (2018). Collaborators and stakeholders were encouraged to contribute to the development of research methods and analysis as well as suggest ideas for innovation throughout the duration of the project. This approach was a collaborative research effort in which oyster farmers helped design and format the survey questions. Both online surveys and virtual interviews by phone call and Zoom technology were conducted. A large portion of this project consisted of informal meetings and discussions with stakeholders including DMR staff, staff from research agencies including Bigelow Laboratory for Ocean Sciences, Friends of Casco Bay, and others. A snowball sampling method was used to find stakeholders to partake in this aspect of the research (Noy, 2008).

This project was reviewed by UNE's Institutional Review Board (IRB) and was designated exempt from IRB oversight as defined by 45 CFR 46.104 (d)(2). (Appendix) This means that the anonymous study participants could not be readily identified by information given in the survey and that interview participants information give did not put them at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation.

3.1 State Case Studies

A selection of states and provincial government run biotoxin programs were analyzed to understand how HAB and biotoxin management is approached in different areas. The states were selected based on their relevance in discussing Maine's biotoxin management program using a specific set of criteria. Criteria included the types of biotoxins dealt with, shellfish industry presence, frequency and duration of blooms, and novel approaches to management. Places that experience similar biotoxin bloom species along with frequency and duration were prioritized. The states selected were Washington, Alaska, Massachusetts, and Florida and the province of British Columbia in Canada was also analyzed.

Analyzing the state biotoxin programs included informal email and phone communications with state managers of programs or other stakeholders. At least one stakeholder from each location was interviewed. The interview and email communication with state representatives was designed to help understand how the decision-making process occurs and what their concerns are for the future of HABs and biotoxins in their respective locations. Survey and Interview questions are included in appendix II. Along with interviews, literature reviews of each state's programs were conducting using online resources from the states as well as relevant scientific literature.

3.2 Maine Oyster Farmer Surveys

The second stage of the project administered an anonymous survey to oyster farmers in the state of Maine. This survey included all types of lease and permit holders and all sizes of farms. The contact information for lease and permit holders is public and was collected from the DMR. The survey collected quantitative data on the economic impact of harvesting closures and qualitative data on farmers' opinions related to how biotoxins are managed (Appendix I). The survey was co-designed with insight from industry members and the DMR. There are three main variables that were investigated using the survey:

1. What economic value from the industry is lost during biotoxin closures

2. Farmer Interest to collaborate on HAB research

3. Farmer willingness to fund research efforts

The data on interest to collaborate and willingness to fund research was triangulated by the interviews, field notes, and information discussions with stakeholders. The data on economic impact of closures was similarly triangulated using interviews and historical data from DMR. The combination of data collected was used to suggest a conceptual framework for managing biotoxins in Casco Bay that will incorporate public health, socioeconomics, and environmental conditions. Suggestions for how management can be adaptable for the future will be included in the analysis.

3.3 Casco Bay

Historical data of PSP toxin levels and biotoxin closures in Casco Bay were examined as a final case study. The data for this case study was requested from DMR through the Maine Freedom of Access Act (FOAA) on February 8, 2020 and was received on March 16, 2020. This data included all the PSP samples collected between 2010 and 2018 as well as all the closure notices from the same time period. The survey respondents who self-identify as operating in the Casco Bay growing area were separately analyzed in this case study and interested farmers were interviewed to expand upon their answers.

The sampling sites were broken down into species sampled and location of sampling. In order to classify sampling sites into primary, secondary, and tertiary the average samples per year of each site was calculated. Once the averages were calculated patterns were investigated to see where the common breaks in sampling frequency were. Primary sites are classified as being sampled at a minimum of 10/year. Secondary sites are classified as between 5 – 10/year. Tertiary sites were sampled at any amount below 5/year. It should be mentioned that not all sites are sampled every year so while this average is important it does not tell the entire story for each sampling site.

To map the locations of these sampling sites and visualize the average biotoxin levels at each site ESRI ArcGIS Pro 2.11 was used. The average biotoxin level at each site was calculated to show what areas of Casco Bay are more likely to be closed during HAB bloom events. There are a few drawbacks to this method that must be discussed further. The way that sampling is structured by DMR is that they will sample from the primary sites until biotoxins are detected and then will sample secondary and tertiary sites once the biotoxins are known to be present. This skews the averages for secondary and tertiary sites to a higher value because they are being sampled only when it is known toxins are present in the area. Average biotoxin levels are only designed to be used in combination with other factors to help determine risk level in localized areas.

It is important to mention that data from the 2019 and 2020 HAB seasons are not included in this study because the data was still be QCed. The DMR has initiated some major changes to how the monitoring of American Oysters is done in the past two years and has effectively added many sentinel sites for monitoring toxins in this species more rigorously.

Specific examples of bloom structure along with closure notices were used to infer the thinking behind closure patterns. Using an example of a new framework that was developed through this study show how the management decisions could have been different in specific scenarios and the benefits and drawbacks of the new framework will be discussed.

4. Results

4.1 State Case Studies

State	Biotoxins of Concern*	State Agencies	HAB Non-profits/Networks	Shellfish Aquaculture Industry Value** ($)	Primary Aquaculture Species
Massachusetts	PSP, ASP	Division of Marine Fisheries (DMF)	n/a	$28.6 Million (2018)	American Oysters, Hard Clams
Washington	PSP, ASP	Washington State Department of Health (WDOH)	Olympic Region Harmful Algae Bloom Network (ORHAB); Sound Toxins	$91.9 Million (2013)	Pacific Oysters
Alaska	PSP	Division of Environmental Health (DEH)	Southeast Alaska Tribal Reseach Network (SEATOR); Alaska Harmful Algae Bloom Network (AHAB)	$900,000 (2015)	Pacific Oysters
Florida	NSP	Department of Agriculture and Consumer Services (FDACS); Fish and Wildlife Conservation Commission (FWC)	n/a	$19.6 Million (2013)	Hard Clams
British Columbia	PSP, ASP, DSP	Canadian Food Inspection Agency (CFIA); Fisheries and Oceans Canada (DFO); Environment and Climate	British Columbia Shellfish Growers Association (BCSGA) HAB Network	$22.9 Million (2018)	Pacific Oysters

		Change Canada (ECCC)			
Maine	PSP, ASP	Department of Marine Resources (DMR)	n/a	$13.6 Million (2019)	American Oysters, Blue Mussels

Table 3. Comparison of state biotoxin management and shellfish aquaculture industry.
*other biotoxins have been present but are not regularly occurring
**value is in industry revenue (Sources: Hickey, 2018; Washington Sea Grant, 2013; BC Ministry of Agriculture, 2018; Pring-Ham and Politano, 2016; Adams et. al., 2014; The State of Maine Department of Marine Resources. (2020)

4.1.1 Washington State

Washington was chosen for this study due to the regular occurrence of both PSP and ASP as well as the large commercial shellfish presence. Washington is the largest producer of hatchery farmed shellfish in the country producing 25% of the total farmed shellfish in the United States with more than 300 farms. The pacific oyster is the most valuable species producing $34 million in revenue in 2013 (Washington Sea Grant, 2015). Washington most deals with closures related to PSP and occasionally has had to deal with ASP, and DSP toxins. This puts a similar pressure on biotoxin management as Maine. An interview was conducted with Jerry Borchert, the marine biotoxin lead at the Washington Department of Health (WDOH). Literature analyzed included Washington's marine biotoxin contingency plan as well as information published on the WDOH website.

Program Overview

Washington has had a marine biotoxin program since the early 1930's after reports of deaths in California from PSP (Washington State Department of Health, 2017). The program can be divided into three categories of sampling. These include commercial, recreational/ceremonial, and early warning. The commercial sampling includes a selection of over 100 farms representing all growing areas in the state. Sampling for the recreational and ceremonial is conducted by state staff, tribes, citizen volunteers, and others. Training and coordination are conducted by the non-profit Puget Sound Restoration Fund. Finally, samples for the early warning system all collected from mussel cages planted by the state in historically important sites. Because mussels uptake the toxins quickly these serve as early bloom detection sites and sampling is expanded once a toxin is detected. Samples are collected from all three categories biweekly during the off season, and weekly during the prime biotoxin season which usually runs from early spring to late fall. This season has been expanding in recent years due to warming conditions. The samples are processed in a single lab by the department of public health using the Mouse Bioassay test and are able to supply 25-35 results a day. If samples arrive before noon results can be produced the same day.

This is extremely important for commercial harvesters waiting to see if they can sell their product. The vast majority of the funding for the biotoxin monitoring program comes from a surcharge on recreational licenses for shellfish harvesting in the state.

Phytoplankton Monitoring

Along with the marine biotoxin monitoring program Washington has developed an expansive phytoplankton monitoring system in collaboration with two non-profit organizations. Sound Toxins is a non-profit that runs a phytoplankton monitoring program in the Puget Sound working with volunteers, tribes, commercial shellfish and finfish growers, and others. Data is collected from 35 sampling locations. The goal is to provide early warning systems to minimize economic impacts of HABs. Members have access to real time data and can join a listserv that publishes a monthly report. The data is not publicly available. The other non-profit is Olympic Region Harmful Algal Blooms (ORHAB). ORHAB was formed in 1999 in response to seemingly random closures of shellfish harvesting. Local municipalities, scientist, and concerned citizens got together and built a comprehensive HAB monitoring program. It was originally funded by NOAA and is now funded by a surcharge applied to all recreational shellfish harvesting licenses. Tribal partners are able to use their own funding and collaborate in the organization (Olympic Region Harmful Algal Blooms, 2019). This organization is a benefit both to the regulators, due to the increased data stream of phytoplankton data and the harvesters because it informs more localized closures and gives them early warning when closures might occur.

Data Availability

The Washington State Department of Health publishes an online map portal that shows current recreational biotoxin closures along with a variety of other information. There is no published historical data online, but public health departments from each county receive a monthly data report and at the end of each calendar year a data summary is provided to all interested organizations and can be requested from the public. Data from the Sound toxins and ORHAB is shared locally with those involved in the programs and interested community members can sign up to receive monthly reports.

Key Consideration for Maine

Washington has a much larger shellfish aquaculture industry compared to Maine and works with hundreds of farms to collect shellfish samples. This has an effect that keeps the industry more involved in the sampling process and in better understanding of when closures will occur. The division of commercial monitoring from recreational and early warning monitoring is beneficial because it allows the industry to reopen quickly when the toxin levels fall below the regulatory limit. The presence of HAB monitoring non-profits also affords the government an early warning system that allows them to respond quickly and direct resources to the most important areas.

4.1.2 Alaska

Alaska was chosen for this study due to its similarity to Maine. It has an extremely complex coastline, budding shellfish aquaculture industry, and similar biotoxins present in their waters. The biotoxin of greatest concern is PSP. There are blooms of phytoplankton, including those that can cause ASP and DSP, but there have been no documented cases of illness and no state-initiated closures in the state's history. Alaska has a small, but growing shellfish aquaculture industry. The value of the industry was reported at just under $900,000 in 2015 but has been steadily growing in the past decade (Pring-Ham and Politano, 2016). Subsistence and cultural harvest of shellfish is an extremely important aspect of shellfish harvest in Alaska that is not reflected in reports. Literature analyzed for this case study include the Alaska Biotoxin Contingency plan and the Alaska Division of Environmental Health online resources as well as an interview with Kari Lanphier, the laboratory manager, at the Southeast Alaska Tribal Ocean Research (SEATOR) program. A review of the scientific literature related to Alaska was conducted as well.

Program Overview

In Alaska, the state does not conduct routine biotoxin monitoring of shellfish areas where personal harvest of shellfish occurs due to the difficulty of determining and accessing harvest locations at the over 33,000 miles of coastline and limited funding to the state government. However, the state participates in the NSSP and routinely tests for biotoxins from commercial operations. If you are Harvesters in Alaska are required to regularly send samples to the state laboratory for testing.

The state does not charge fees for analysis; however, the costs to collect and ship is at the expense of the farm. This can add up and become a large burden for the farms in Alaska. The state laboratory uses MBA testing. The timing and frequency of the sampling is based on Alaska's contingency plan for biotoxins, and is centered on the season during which harvest occurs: "summer months" (May 1 – October 31) require testing of the first lot harvested each week of each species harvested from a defined harvest area, and "winter months" (November 1 – April 30) require testing of the first lot of each species harvested in a calendar month from a defined harvest area. If a closure is in place due to biotoxin results meeting or exceeding the set regulatory limit, then three (3) consecutive samples taken at least four (4) days apart over a minimum of 14 days with results below the regulatory limit is required before an area may be reopened for harvest (Alaska Division of Environmental Health, 2020). For regulatory samples, the state laboratory uses mouse bioassay (MBA) testing and, for non-regulatory samples submitted for analyses, the laboratory uses the High Performance Liquid Chromatography Post-Column Oxidation (HPLC/PCOX) method. The sampling strategy works for a small-scale industry but is not helpful for those recreationally harvesting and those looking to expand into new growing areas. If there is no commercial harvest in an area it is unlikely to have any historical biotoxin data. The lack of data has created a need in Alaska for regular sampling in areas where recreational and cultural harvesting is important.

SEATOR has begun to fill that need through creating a network of sampling and advisory system for recreational harvesting areas around the state. SEATOR is a network of 17 tribal communities that have a primary goal of supporting food security and access to traditional foods. One of their main projects in monitoring of toxic algae blooms that effect shellfish harvesting in these coastal communities. SEATOR has used pooled resources from the tribal communities to create regular sampling of shellfish tissue. They are able to minimize the risks associated with harvesting wild seafood by sending weekly reports and providing education and outreach material to the local communities they work with. They have created online resources and advisories on when shellfish is safe to harvest. SEATOR uses the receptor binding assay (RBA) to processes their samples due to the fact that it is logistically hard to maintain laboratory mice needed for MBA. RBA is a relatively new processing technique but has been accepted as an advisory method (non-regulatory) for PSP by the NSSP. Alaska Harmful Algal Bloom Network (AHAB) is another organization that brings together concerned stakeholders to conduct research on HABs related to biotoxins conducting both phytoplankton and shellfish tissue sampling. The goal of AHAB is to connect all stakeholders that are concerned with biotoxins to better centralize the data collection efforts. Their partners include universities, state agencies, tribal organizations, and other non-profits and concerned citizens.

Phytoplankton Monitoring

As stated earlier the state government of Alaska does not routinely monitor for biotoxins so this leaves phytoplankton monitoring up to interested non-profits or community organizations. Part of SEATOR's program is to collect phytoplankton samples on a weekly basis from the 17 tribal communities they work with. Through this phytoplankton collection they have seen both *dinophysis and pseudo-nitzschia*, which are known to cause DSP and ASP, respectively. Because the toxins associated with these species have not been detected in commercially-harvested shellfish at excessive levels, the state has not included these species in their NSSP biotoxin management plan. This does not mean there is no risk, so it is very important for groups such as SEATOR and other members of the AHAB Network who are conducting surveillance efforts, to share their finding with the state and commercial harvesters.

Data Availability

At this time, the state of Alaska does not have any online data for biotoxins but is in the process of making that data available on its site. Their official statement is that if shellfish is being sold in the store it is safe to eat and the public should not risk harvesting shellfish on their own. This does not work for many people, hence the need for groups such as SEATOR and AHAB. AHAB is currently working to centralize data collection for all agencies that collect biotoxin data in the state so it can be shared efficiently throughout the network.

Key Considerations for Maine

The SEATOR program successfully shows how independent non-profit organizations can have large impact of the ability for local communities to harvest shellfish. While this program is specifically designed for recreational and subsistence harvest a similar network could work in a place like Maine for industry members. While a network of phytoplankton or shellfish sampling would have no regulatory impacts, it would still create a clearer picture of bloom events when they happen and could spur changes within the regulatory monitoring program, which could pay off in the long run. The blooms of *dinophysis* and *pseudo-nitzschia* were only discovered in Alaska due to the work of these non-profit monitoring organizations. The existence of these programs also take pressure off the state government allowing them to focus on monitoring within commercial operations.

4.1.3 Massachusetts

Massachusetts was chosen for this study due to its proximity to Maine and similarity in bloom dynamics. The main differences between Massachusetts and Maine is the much larger and more complex coastline in Maine. Because Massachusetts has a relatively small coastline, and the PSP and ASP blooms are relatively smaller the state is able to adequately sample for biotoxins with much less resources than Maine. Massachusetts's program revolves around PSP and hasn't changed much since the early 1970's, although like other states ASP has appeared in recent years requiring additional sampling and resources. Massachusetts has a large shellfish aquaculture industry with a reported $27.6 million worth of oysters harvested in 2018 from 391 private operations (Hickey, 2018). This is similar to what the Maine aquaculture industry might look like in 5-10 years. An interview with Terry O'Neil of the Massachusetts Division of Marine Fisheries (DMF) was conducted along with a review of the relevant government and scientific literature on the program.

Program Overview

Massachusetts State Division of Marine Fisheries is responsible for the monitoring and management of biotoxins in the state. Sampling takes place starting in March and ending in November. In recent years due to warming water conditions this season is expanding. There are 11-12 sentinel stations with blue mussels that are sampled on a weekly basis and when toxins are discovered in an area there are secondary stations added. All closures in Massachusetts are based on results from the blue mussel samples. Samples are analyzed by MBA through the state laboratory in Gloucester, MA and are processed within a 24-48 hour period. Because MA is a small state the sampling primary sites and additional stations during blooms are enough to capture a full picture of the blooms occurring in the state. During large bloom seasons the single state-run laboratory manages to have enough capacity to run all the samples needed.

Phytoplankton Monitoring

Phytoplankton monitoring in Massachusetts is run by the state. They have had a program in place for the past 5 years that count the target species related to biotoxins and look for any new species. There are 12 sites overall that are different from the shellfish stations described above. This program has seen blooms of the algae responsible for ASP and DSP and because the phytoplankton and shellfish sampling are both done by the state, they can synchronize the data and are able to stay ahead of any toxic blooms.

Data Availability

PSP toxin data for the current year is posted online for those who are interested. Data includes site location, species sampled, date of sample, and toxicity. If the toxicity is above the regulatory limit it is listed in red. Data from previous years is not posted online but can be requested from the state.

Key Considerations for Maine

In Massachusetts, the leasing structure for aquaculture operations is unique and therefore important to mention here as it relates to biotoxins. When an entity would like to lease an area for aquaculture the process is primarily conducted by the municipality they would like to operate in. The towns are responsible for all shellfish management and therefore work directly with the potential aquaculturists. The town shellfish committees are inherently more involved in the communities that a potential aquaculture operation will be in rather than the overarching state agency. This allows for more direct communication between the growers and the community and has led to a more accepted aquaculture industry in MA than we see in Maine. This also has implications for biotoxin monitoring because the town shellfish commission may have a better understanding of the HAB risks in the localized area and can communicate that to the growers.

4.1.4 British Columbia

British Columbia (BC) is located on the western coast of Canada and is responsible for a large portion of the Pacific oysters and hard clams produced by aquaculture in Canada. British Columbia was included in this study due to the similarity in the biotoxins that effect their region, the similar size of the shellfish aquaculture industry, and to get an international perspective from a place that is not regulated under the NSSP. Although they are not regulated under the NSSP, Canada is a member of the ISSC and has been evaluated by the US FDA and is considered in compliance with the NSSP standards. Other countries including New Zealand, Mexico, and Korea are under the same arrangement (personal communication, Kanwit, 2020). Biotoxins that are experienced in BC include PSP, ASP, and DSP. The aquaculture industry in BC is relatively small with a reported value of $22.9 Million in 2018 (BC Ministry of Agriculture, 2018). For this case study Elysha Gordon, the Canadian Shellfish Sanitation Program (CSSP) coordinator and Department of Fisheries and Oceans (DFO) resource management biologist, was interviewed and relevant government and scientific literature was reviewed.

Program Overview

The Canadian Food Inspection Agency (CFIA) is responsible for monitoring for biotoxins in the entire country. They work in collaboration with the DFO. DFO is responsible for implementing the closures by the recommendations of CFIA. The overarching document in is the Canadian Shellfish Sanitation Program (CSSP). It is very similar to the NSSP with th e only major difference being that the federal government is tasked with the management as opposed to the provinces. CSSP requires regular monitoring of biotoxins based on historical data. The frequency and timing are at the discretion of CFIA who works in partnership with local communities (Canadian Food Inspection Agency, 2019). Canada uses the HPLC Pcox method for all laboratory tests of biotoxins and uses results from blue mussel samples to implement closures in areas. Tests are analyzed in 24-48 hours and recommendations communicated with DFO immediately if a closure is required. DFO maintains a public online mapping program that updates regularly with shellfish area classification as well as biotoxin closures as they occur. There is no immediately available public record of data, but it may be requested by interested individuals.

Phytoplankton Monitoring

In BC there is no government sponsored phytoplankton monitoring program. Historically an initiative started by the government and now run by a private operation assists with support and training of phytoplankton monitoring in the salmon aquaculture industry. In 2013 the British Columbia Shellfish Growers Association (BCSGA) started an industry centered harmful algae bloom network that trained growers to collect phytoplankton samples and analyze them for HAB species related to PSP, DSP, and ASP (McIntyre et al., 2013). This group was formed after a bloom of *Dinophysis acuminata* caused a DSP outbreak in the area.

Key Consideration for Maine

The creation of an industry run HAB monitoring program in BC is a great example of how the industry can take on some responsibility in HAB management to the benefit of all stakeholders. Not only do the farmers have a renewed sense of scientific purpose, but the added data helps the regulators better understand the bloom dynamics by increased samples over areas that they cannot feasibly get to. This allows the regulators to focus resources on areas of importance with the limited funding they possess. While some growers in Maine do provide phytoplankton data a regular and centralized data collection network would encourage increased participation in monitoring.

4.1.5 Florida

Florida was chosen for this study because it has a long history of dealing with the Florida red tide species *Karenia brevis*. This species has been studied off the west coast of Florida since the mid 1940's (Steidinger, 2009). It regularly causes destructive blooms in Florida impacting commercial fisheries and tourism. Nowhere on earth are there blooms that last as long or are as frequent as *Karenia brevis* (Steidinger, 2009). Neurotoxic Shellfish Poisoning (NSP) is a result of the brevetoxins in *Karenia brevis* and has impacted the shellfish industry in a similar but more intense way to PSP in Maine. The shellfish aquaculture industry in Florida has historically been hard clams, but in the last 5-7 years oyster aquaculture is increasing, and Florida will have to work with industry to place operations away from these devastating HABs. Shellfish aquaculture has brought in $19.5 Million in revenue in 2012 (Adams et al., 2014) and work is being done to continue to add more species to the list of aquaculture products in Florida. The Florida shellfish industry has been devastated by closures that have lasted for more than 18 months. For this case study Jillian Fleiger of the Department of Agriculture and Consumer Services (FDACS) was interviewed and relevant government reports and scientific literature was reviewed.

Program Overview

Biotoxin monitoring in the state of Florida is run by FDACS who also coordinate with the Fish and Wildlife Conservation Commission (FWC). FWC collects samples from 1,200 stations across the 37 growing areas in the state. Once the cell count exceeds 1,000 cells/L the sampling is expanded and monitored closely to determine the extent of the bloom (Florida Department of Agriculture and Consumer Services, 2019). The NSSP requires the closure of harvesting due to NSP when the cell counts of *Karenia brevis* exceed 5,000 cells/L (US Food and Drug Administration, 2017) and once this occurs FDACS staff then begin shellfish tissue collection for processing via the MBA method. During the 2019 ISSC, membership voted to remove the requirement for closure a 5,000 cells/L because tissue samples have shown that toxins can still be below the regulatory toxin limit even when cells are higher than 5,000 cells/L. All the shellfish tissue for the MBA analyses are sent to the Fish and Wildlife Research Institute (FWRI), which is run by FWC. Once samples are below 20 MU/100g the harvesting areas can be reopened. Florida also experiences irregular blooms of *pseudo-nitzschia* and *Pyrodinium bahamense* which has been known to cause PSP, but do not have as regular monitoring in place for these blooms.

Phytoplankton Monitoring

Because closures in Florida depend on cell counts the phytoplankton monitoring in the state is quite extensive. FDACS does their own weekly sampling year-round and relies on FWC to collect samples as well during high bloom periods. The state does not have the need for citizen science or non-profit phytoplankton monitoring because their program is so extensive. There is a HAB and red tide task force appointed by the Governor of Florida to enhance communication of HABs to the public and improve government policies to mitigate and prevent the impacts of HABs in Florida.

Data Availability

The FWC maintains an online map that shows the *Karenia brevis* cell count results for the past 8 days on a scale of: not present - very low – low – medium – high (Figure 12). This map is a great balance between providing no information on present blooms and providing too much that might confuse people looking at it. The ranges allow people to quickly grasp where blooms are happening and if they should worry about where they are harvesting. This is one of the better examples of how to actively inform the public of the current HAB conditions. This is done in Florida because high intensity blooms of *Karenia brevis* have been known to cause respiratory issues for people exposed to the surf (Hoagland, 2009).

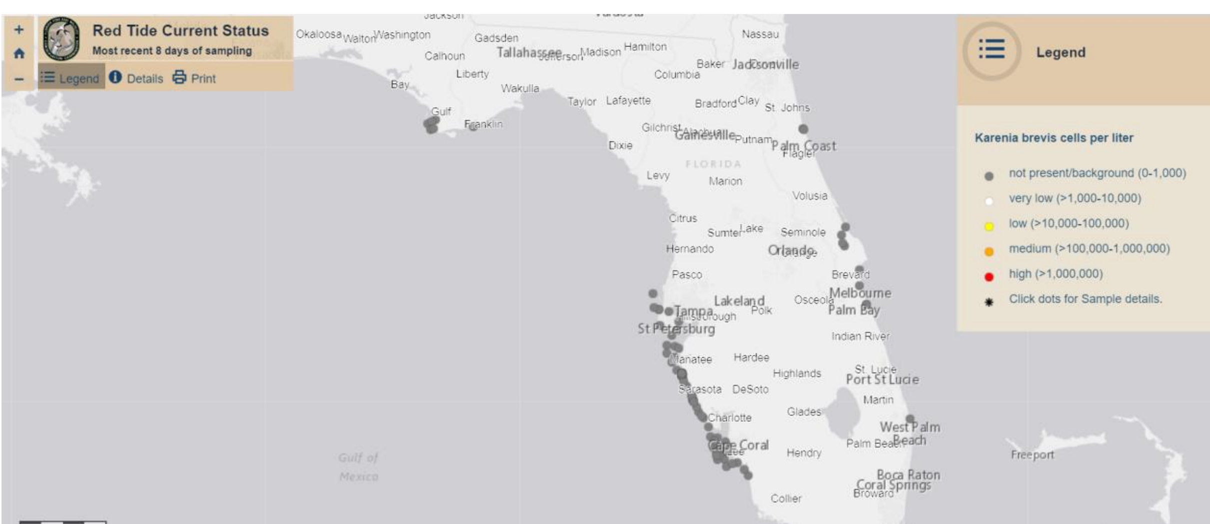


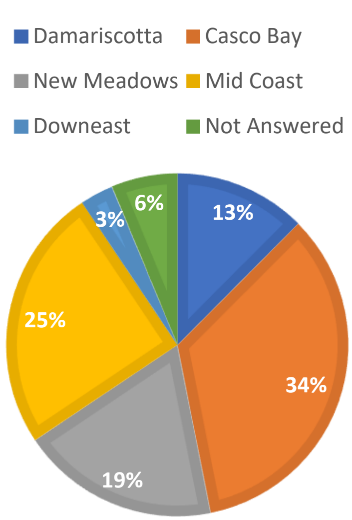
Figure 12. Florida's interactive red tide status map.
https://myfwc.maps.arcgis.com/apps/View/index.html?appid=87162eec3eb846218cec711d16462a72

Key Considerations for Maine

What Florida's program does best, is the up-to-date red tide phytoplankton map and close interactions with aquaculture operations. Jill Fleiger mentioned that the state government works closely with shellfish aquaculturists to collect shellfish tissue and discuss closure policy. This shared responsibility can help considerably in the trust between the two stakeholder groups. Also, the easily accessible data online allows those who are interested to stay updated on the blooms as they are occurring.

4.2 Survey Results

Thirty-one oyster farmers responded to the survey representing most of the coastline of Maine with 4 respondents from the Damariscotta River, 7 from Mid-Coast, 17 from Casco Bay including the New Meadows River area, 1 from Downeast, and 2 from undisclosed locations (Figure 6). From this point forward New Meadows River respondents were lumped in with Casco Bay because the New Meadows River is within the bounds of Casco Bay. Of all the respondents 32% (10) experienced closures due to PSP in 2019, 8 of which were Casco Bay farmers, 1 Mid Coast, and 1 that did not give a location. This can be attributed to the fact that Casco Bay is listed as one of the most high-risk areas for PSP (Kanwit, 2018). The size of farms of the respondents can be interpreted in two ways. First by the types of leases or permits they are working on and secondly by the number of oysters they reported harvesting. Almost half of the respondents (47%) come from farms run on LPAs only, with 35% owning the larger standard leases.



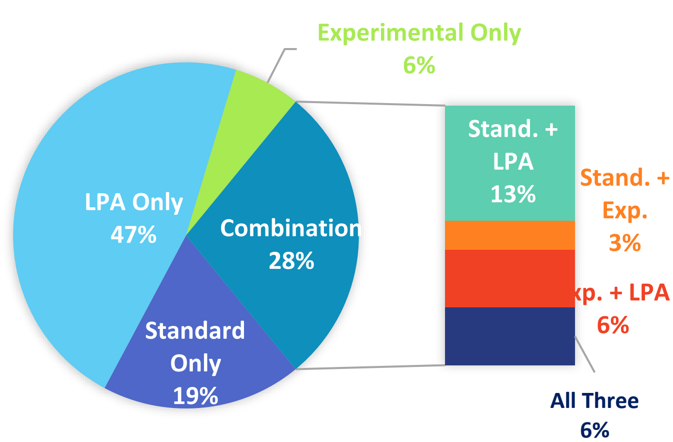


Figure 6. Breakdown of location of farms (right) and type of lease operating on (left) of respondents to the survey. Lease and permit holders can have multiple of each type of lease. (N = 32)

Although many farmers did not experience closures, they still showed high levels of concern about biotoxins and generally approve of how DMR manages biotoxins. Responding to the statement “Management of PSP is not a concern to me” 77% (24) of respondents disagreed with this statement with more than 50% (16) saying they strongly disagree with this. Responding to “I believe DMR manages biotoxins effectively” 64.5% (20) agreed with this statement while 19.4% (6) disagreed, and 16.1% (5) were neutral (Figure 7).

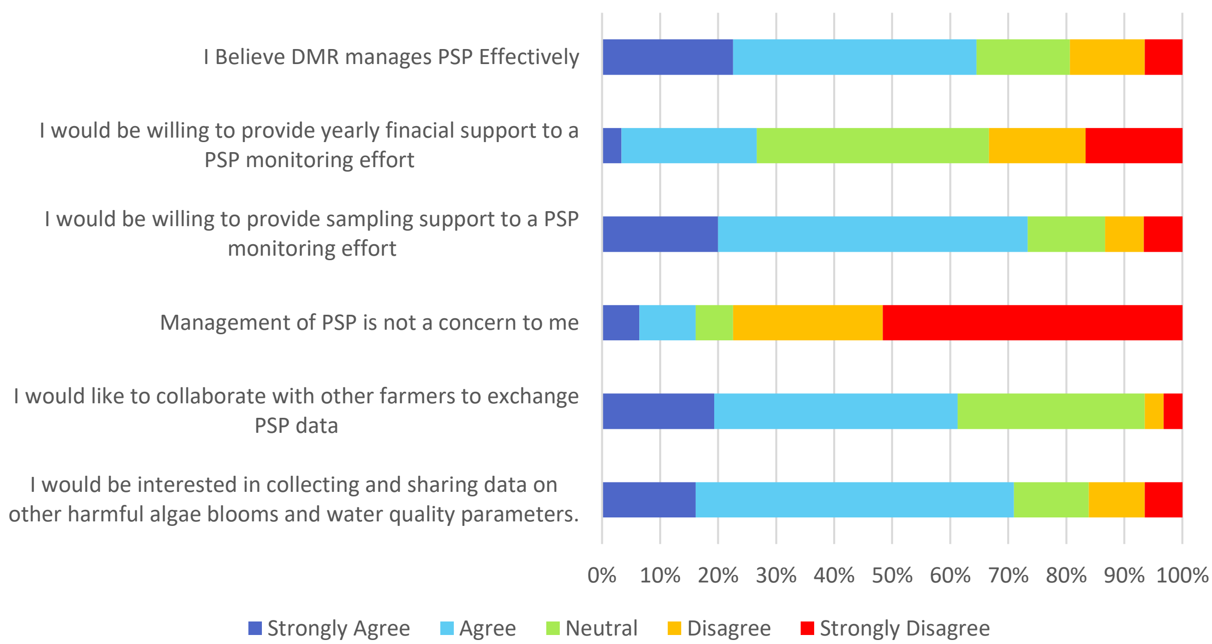


Figure 7. Respondents’ level of agreement to all 6 Likert Scale questions from strongly disagree to strongly agree (0-4). N = 31

When it comes to being involved with PSP monitoring farmers seem to be ready and willing to help. When it comes to supporting a PSP monitoring effort, 64.5% (20) farmers would be willing to provide sampling support, while only 12.9% (4) would not. For financially supporting a monitoring effort, the response was split with the 38.7% (12) farmers neutral, 25.8% (8) supportive, and 32.3% (10) unsupportive of it (Figure 7). Farmers also generally want to collaborate and work together on both PSP and other water quality parameters.

4.3 Casco Bay

Referencing DMRs lease and permit holder data at the time of this study there are approximately 250 leases and permits in Casco Bay, 230 of which are LPAs. Of the Casco Bay respondents, 88% hold an LPA with 59% exclusively working on LPAs. This confirms that the survey respondents properly reflect the landscape in Casco Bay. Only 12% operate on exclusively standard or experimental leases. Along with this it is apparent that many of these small-scale farmers want to grow with 82% saying they would like to expand their LPAs to a lease within the next 3-5 years.

Of the eight Casco Bay farmers that were closed due to PSP in 2019 seven of them operate on LPAs. The eight farmers closed lost between 0-15% of their revenue with an average of 3%. Using an average price per piece of $0.58 as estimated by the Hale Group in 2016, reported losses due to PSP closures range from $0 - $34,800. In Casco Bay many small growers are relying on a higher price per piece of about $0.75. If we use this higher value, the range of loss is extended to $45,000. With many companies already operating at low margins this can have a large impact on their ability to grow their business. The closure length for those that were closed during the 2019 season ranged from 2-10 weeks. Combining the 13 farms in Casco Bay that included harvest numbers in the survey, they harvest approximately 27,000 oysters a week in the summer months. That accounts for 15 – 20 thousand dollars of revenue lost each week these farms cannot harvest their product. When comparing the operations that are most effected by closures it is clear the burden falls on the smaller LPA run businesses (Figure 8.) This makes sense due to the fact that standard and experimental lease holders can have biotoxin MOUs with DMR for site specific testing and can fund their own sampling during an area-wide closure to remain open.

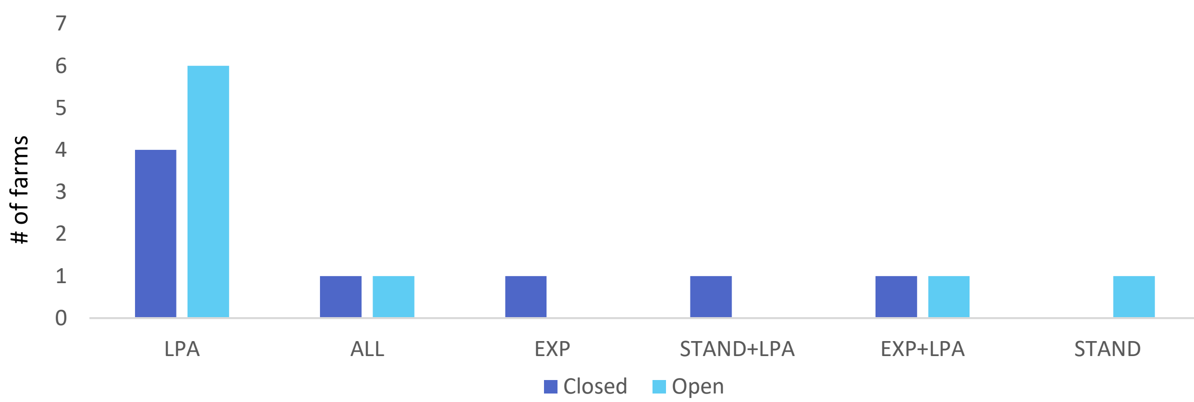


Figure 8. Number of farms closed in Casco Bay compared to leases operated on. N = 17

When looking at the Casco Bay farmers responses to the Likert Scale questions there are some key differences to point out. Only 43.8% (7) think that the DMR manages PSP effectively. Higher percentages of respondents are concerned with PSP monitoring and are willing to collaborate on monitoring and exchange of data (Figure 9). Also, because Casco Bay farmers are more likely to be affected by closures there is a greater willingness to provide financial support to a monitoring program. Two farmers were interviewed who operate in the Casco Bay growing area. Both operate on a combination of standard leases and LPAs and both interviewees have experienced times in which their area was closed by the DMR and they chose to pay for additional samples. They mention various factors that go into this decision making process, including if they could afford it, how long they sense the bloom will last, and what other farm work needs to be done. Sometimes they value the closure time as periods when they can work on other farm tasks that have been neglected. The farmers recognize the limited resources the DMR is able to work with and for the most part understand that they are doing the best they can.

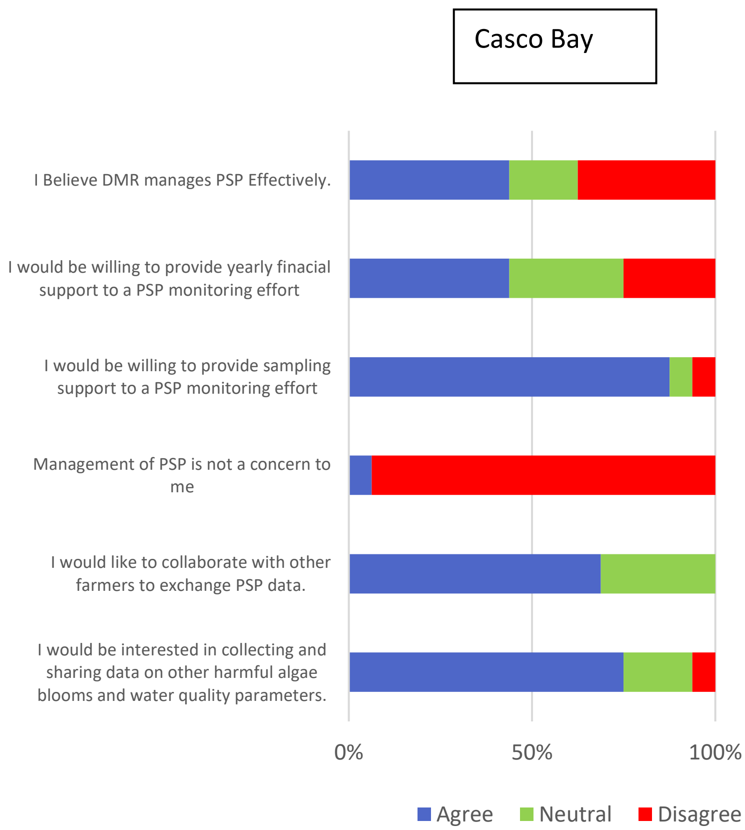


Figure 9. Casco Bay growers' vs. All other growing areas responses to all 6 Likert Scale questions. Strongly agree and agree as well as strongly disagree and disagree were combined. Casco Bay N=17; all others N=15

4.3.1 PSP Monitoring in Casco Bay

Casco Bay's coastline is one of the most complex areas in Maine with many long peninsulas and islands that create a large need for sampling across the bay. In the past 9 years of sampling there are 52 mussel sampling sites that DMR has used to inform closures in the area. The number of samples from each site range from 1 – 230 over the 9-year period of 2010 – 2018. There were 14 sites that averaged at or above 10 samples/year, 15 sites between 5-10 samples/year, and 10 between 1-5 samples/year. 13 sites were samples at a rate less than once a year. This includes sites that sampling was either discontinued or changed. When looking at PSP toxicity it is important to understand that average toxicity over a 9-year period is a very broad number that highly simplifies an extremely complex data set. These numbers simply show a trend in data that must be analyzed with other context to understand fully. Over the entire 9-year period of this study sampling averages ranged from 0 – 118 µg/100g (Figure 10). During the bloom season of 2017, 29 mussel sampling sites were used. There were 7 sites that were sampled at or above 10 times, 18 sites sampled between 5-10 times, and 4 sites sampled below 5 times (Figure 11). This shows that once the blooms were detected the sampling at the secondary sites became more regular.

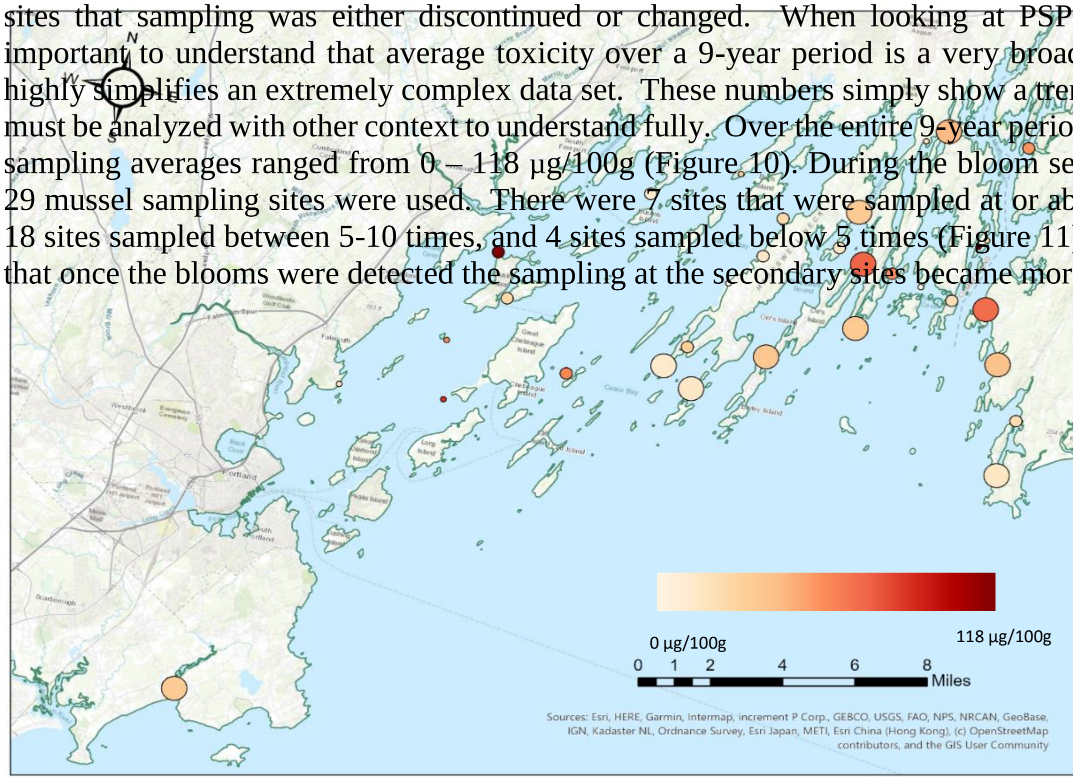


Figure 10. Average PSP toxicity at mussel sampling stations over 9-year period from 2010-2018 in µg/100g based on MBA testing before 2014 and HPLC Pcox after 2014. Size of circle correlates to number of samples at that location.

In 2017, there were large blooms of *Alexandrium cantenella* that closed shellfish harvesting in most of the region for harvesting of mussels, European oysters, and carnivorous snails from April 3rd until July 27th with exceptions in certain small areas where shellfish tissue testing revealed lowered PSP levels. For American oyster harvesting, blooms shut down the majority of Casco

Bay for a period of 2-5 weeks in June of 2017. There was no extensive sampling of American oysters during this time because of the lack of wild populations in the state. The decisions for closures were made from samples collected from farms that signed a MOU with the state. As these data are paid for and owned by the lease holder they are not part of the public record. Based on the historical data it is impossible to interpret how the closure and opening decisions were made at the time. Although there is no American oyster data the areas that were closed for the longest do correlate to the stations that have the highest PSP toxicity averages on the western side of Casco Bay. For any LPA based farms or leased farms that did not have MOUs with the DMR it is understandable that they might have felt left in the dark when it comes to the closures.

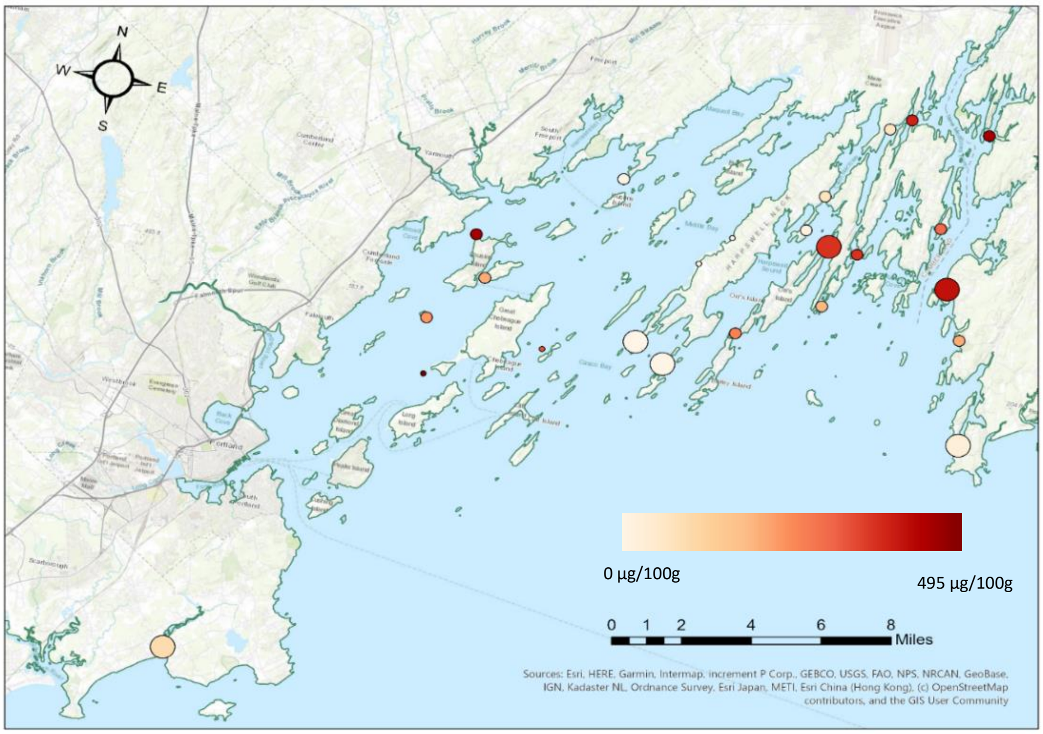


Figure 11. Average PSP toxicity at mussel sampling stations for the 2017 season. Samples processed by HPLC Pcox method and size of circle correlates with number of samples at that site.

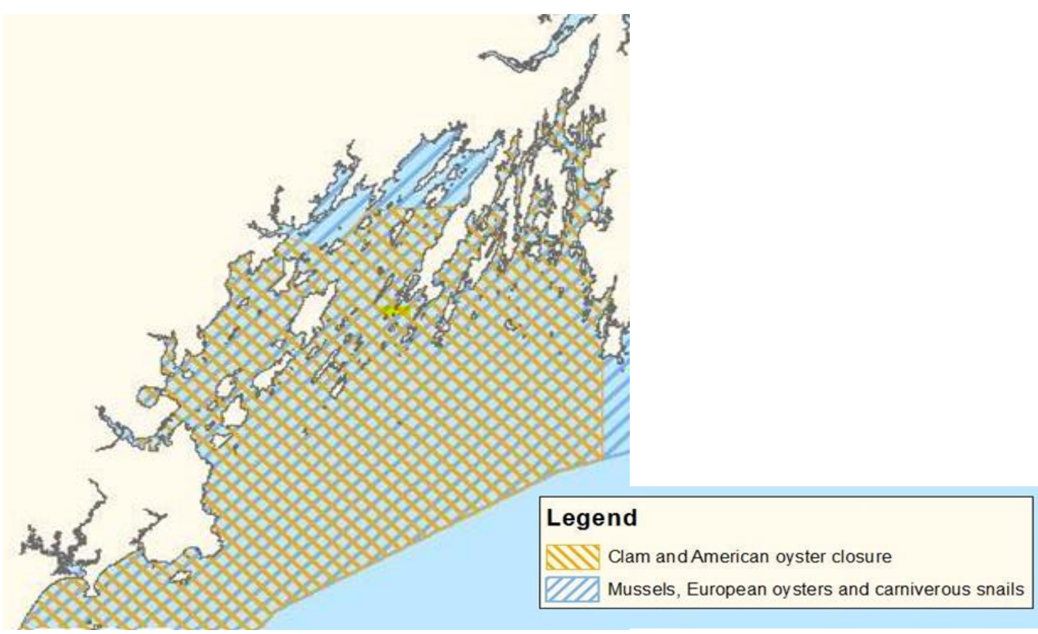


Figure 12. Shellfish harvesting closure area in Casco Bay from June 14th, 2017 – until June 30th, 2017 with some sections being closed up to 5 weeks. Adapted from DMR legal closure notices (June 2017).

5. Discussion

The goal of this research is to understand the importance biotoxins play in the growth of the aquaculture industry in Maine, specifically in Casco Bay. It is clear based on the results that biotoxins will have an increasingly large impact on the industry and the communication on risk and data resolution of blooms can be improved in Maine. Right now, public health is protected effectively, but the burden on the industry is significant and there are ways in which it can be reduced that would benefit both industry and regulators. There are also secondary benefits to research on HABs and monitoring of other water quality parameters that could be achieved. The evidence based recommendations that will be discussed in the following sections do not require large structural changes to Maine's biotoxin program but require additional support in order to augment what the state program already does via funding, data collection, and community action.

5.1 Themes in State Programs

Through the case studies of Washington, Alaska, Massachusetts, British Columbia, and Florida clear themes emerged regarding how each are planning for the future and managing HABs. While the regulations laid out by the NSSP remain constant, there are important differences in management structure that have affected how shellfish aquaculture operates in those places. Each location has unique challenges and it is important for management to focus on the needs of the local communities they regulate.

5.1.1 Emerging species and Increasing Bloom Length

As stated in the introduction, HABs have been increasing globally over the last few decades. It is clear that this trend holds true in the case studies analyzed. Every state biotoxin manager interviewed commented on the increasing frequency and intensity of blooms as well as new bloom species that they are keeping close watch on. State managers mention the increased need for sampling is not adequately balanced with increased funding. States have either had to solicit help from other organizations or broaden closures due to larger more widespread blooms.

In all the states studied excluding Alaska stakeholders mentioned the timeframe in which they are required to sample is expanding and this will require additional funding in the near future. Part of the reason Alaska is not included is because they do not have a long enough history of data collection. Some of the phytoplankton species states are starting to see around the country include *pseudo-nitzschia* and *dinophysis*. Massachusetts and Maine have seen blooms of *Karenia Mikimotoi*, which is in the same genus as the NSP causing algae in Florida but do not produce the same toxins. In Washington and Massachusetts new experiences with *pseudo-nitzschia* seem to coincide with the outbreak in Maine in 2016. The domoic acid levels have not been as high in Washington and Massachusetts, but they still require additional resources and monitoring because the factors that cause toxins to accumulate are not well understood. Some states have gone to year-round sampling because blooms are occurring earlier in the spring and later in the fall than historically seen. Some states are worried about the resources available to them and have to consider increasing fees including those on recreational harvest licenses and aquaculture applications to support their programs. If this trend should continue Maine will need to apply more resources to monitoring of blooms, because they are already working under limited funding.

5.1.2 Stakeholder Engagement in Monitoring

In designing biotoxin management plans it is important to understand the monitoring needs of the local areas where blooms are occurring. States such as Alaska and Washington have done great work with non-profit organizations that focus on involving their local communities in the monitoring of HABs. For example, in Washington all the sampling for regulatory closures still occurs through the WDOH, but stakeholder groups work with the state and help inform WDOH sampling. This allows the state to strictly follow the NSSP guidelines and still gain input from other stakeholders. Biotoxin monitoring needs to be set up in a way that takes all stakeholder groups into account equally. Whether it be aquaculturists, wild harvesters, recreational harvesters etc. This can be simple in states such as Massachusetts or Florida where there are clear designated areas where most of the shellfish aquaculture and harvesting occurs. The government is able to focus their resources on the areas that need the most attention. In places such as Maine or Alaska it can be much harder because there is a wider area of shellfish harvesting and aquaculture.

Stakeholder engagement in monitoring has significantly helped some states stay ahead in funding and awareness of new species as well as serving as a way for interested industry members to get involved. Maine already has a sense of community within the shellfish aquaculture industry that has done wonders for the expansion of the new young farmers getting into it. Some of the larger farmers are willing to help support the smaller growers in a way that benefits all (personal communication, anon. oyster farmer). There is a large opportunity here to expand the data set of phytoplankton and toxicity levels during large bloom events. The expense of running samples through the state certified laboratory is a limiting factor, but there are cheaper ways to analyze results through independent laboratories that can still give the department valuable information on how the bloom events occur. If interested stakeholders could get involved in monitoring at any level it has the potential to lead to more trust in the data as well. It has been shown that when stakeholders get more involved in monitoring and research it leads to more trust in the scientific conclusions and mutual understanding between the groups (Hartley and Robertson, 2006).

In Casco Bay, stakeholder engagement is a clear area of need within the biotoxin monitoring framework. While some farmers are able to conduct sampling through an MOU with DMR, many farmers that do business using LPA permits are not. This has created a tension between a segment of the industry and DMR, and more farmers in Casco Bay do not think DMR is doing a good job of management than any other growing area in the state.

5.1.3 Data Availability and Communication

Some of the frustration in the oyster aquaculture community is harvest closures that are seemingly random due to the perceptions of unclear decision making process behind the closures. Based on the results from the case study of Casco Bay, the way closures were put in place in 2017 made this clear. There was no public data available for American oysters and if the decisions were made based on sampling from private companies it is difficult for LPA owners to see what is going into the decisions and therefore are not anticipating a closure. Because the DMR will sign MOUs with certain farms to collect and report toxicity, other farmers feel left in the dark about how decisions are made. More educational resources online as well as regular communication of data would be significant to building trust between regulators and industry members. It should be noted that since 2017 the DMR has changed the way they collect data on American oysters. They currently place American oyster, among other species in cages in primary sampling locations. This creates better coverage for species that are not as commonly found in the wild and a public data record for all important species. While this is an important step in the right direction there are still gaps in data communication in Maine.

Many states with successful biotoxin management work hard to communicate the data and educate the impacted communities about how to interpret the data. The SEATOR program in Alaska shares their PSP reports with a selection of community partners. Part of the process in becoming a partner is receiving education on how to interpret the PSP toxicity results. They are taught about the uncertainty and unpredictability of toxicity as well as how to understand the signs and symptoms of PSP. Because SEATOR is not a regulatory agency they are not liable for public safety and are able to advise community members to evaluate the risk of harvesting on their own.

Florida FWC does an excellent job communicating the data via a real-time map online. They are able to refer any interested parties to the map for data that is easy to interpret using ranges of values to simplify the data sets. While other places including Washington and Canada use a real time open and closure status of areas. States with smaller biotoxin programs such as Massachusetts publish the raw data from the current years sampling on their website. It is clear that no matter how a specific state operates, data communication is a valuable part of their programs. Matching the type of data reporting with the needs of the community can be done effectively.

In Maine there is no clear data reporting when it comes to biotoxin monitoring. Those that are interested can request the data through a FOAA request such as used for this report, but there is not real time data reporting for the local community or the state. If data reporting is done in a targeted way it can have major benefits for everyone. There are ways to narrow the group communicating to that make sure only those that are truly interested are looking at the data. A weekly or monthly electronic report that interested parties can sign up to receive would be one way to focus the reporting. If farmers are trusted more to understand the results, they will have more advanced knowledge of closures as well as better ability to understand the risks involved in certain growing areas. Some immediate improvements to Maine's biotoxin program involve better data availability, education, and communication of the results. Many biotoxin monitoring programs from other states have comprehensive data portals online that inform the community of current HAB status. While there may be hesitation to provide the public data that is complex and difficult to understand, and while this consideration is valid, data communication can be done in a way that avoids this problem. For example, in Alaska, the SEATOR program actively works to educate the communities that are impacted the most on how to interpret the data and what the risks of biotoxins really are.

5.2 Perceptions of Biotoxin Management in Casco Bay

Through this research it is clear that farmers in Casco Bay are acutely aware of the issues in biotoxin management and have increased concern in the how the DMR operates closures. This is due in part because of the increased risk of biotoxins in Casco Bay (Kanwit, 2018) and because of the influx of small growers into the industry. Some farmers are losing up to $35 - 45 thousand a season due to biotoxin closures and there is clear interest in funding and collaboration on a monitoring effort. Along with this, there is an interest within the farming community to share and collaborate on data collection and transparency. There is some disparity in the farming community on if farmers would be willing to fund a biotoxin monitoring effort. Some farmers believe that funding monitoring will save them money in the long run by reducing the closure periods in the area. It is still unclear if this would be the case because the hydrodynamics that affect how blooms spread is not well studied. Many of the farmers surveyed were more willing to provide sampling support than funding. This is most likely due to the fact that they are working on the farms regularly and feel that the act of sampling would not be particularly difficult.

5.3 Community Based Framework - A need for a HAB Network in Casco Bay, Maine.

One of the distinguishing characteristics of the shellfish aquaculture industry in Casco Bay is the comradery between the small operations, the desire to be connected, and a tendency toward altruism, or at least mutualism. This was shown both through the survey results and interviews and is especially true for Casco Bay. At the same time, the DMR Bureau of Public Health is constrained by limited funding. A major defining aspect of successful HAB management programs is strong commitment to community engagement and informed data dissemination. The lack of community HAB monitoring in Maine is an obvious need within the biotoxin management framework. A coalition of state officials, scientist, and growers could add value beyond simply the localization of closure areas. Casco Bay is in a unique place where many small LPA growers are scattered across the bay and are out working on their farms almost every day during the high bloom seasons. Data collection from these farms during a bloom would yield much higher data resolution and effectively take a spatial snapshot of bloom dynamics over time. This has the potential to help with forecasting research and research on the biological factors that affect blooms. The DMR is limited in what they can do when it comes to the regulatory framework because of the strict regulations from the NSSP on how data is collected and processed, but if a HAB network is formed that demonstrates effective data collection this would help DMR make more accurate decisions on sampling in later years.

A HAB network in Casco Bay has the potential to dramatically impact the economic and environmental sustainability of the shellfish aquaculture industry and would have secondary benefits beyond aquaculture. It would be important for the HAB network to be a neutral third party organization consisting of an advisory board that consists of a cross section of stakeholders. This is important because it allows all perspectives to be heard. Also, if a HAB network is to form in Casco Bay, an increase in sample analysis capacity would be needed. To start this could be done through labs that are not certified by the NSSP using whatever analysis method is most accessible. Once the network is more established and possesses regular funding it may be possible to run the samples through Bigelow Laboratory using the HPLC Pcox method. This would be important during the earlier stages of a bloom to create an early warning because HPLC Pcox can detect PSP toxins at lower levels than MBA.

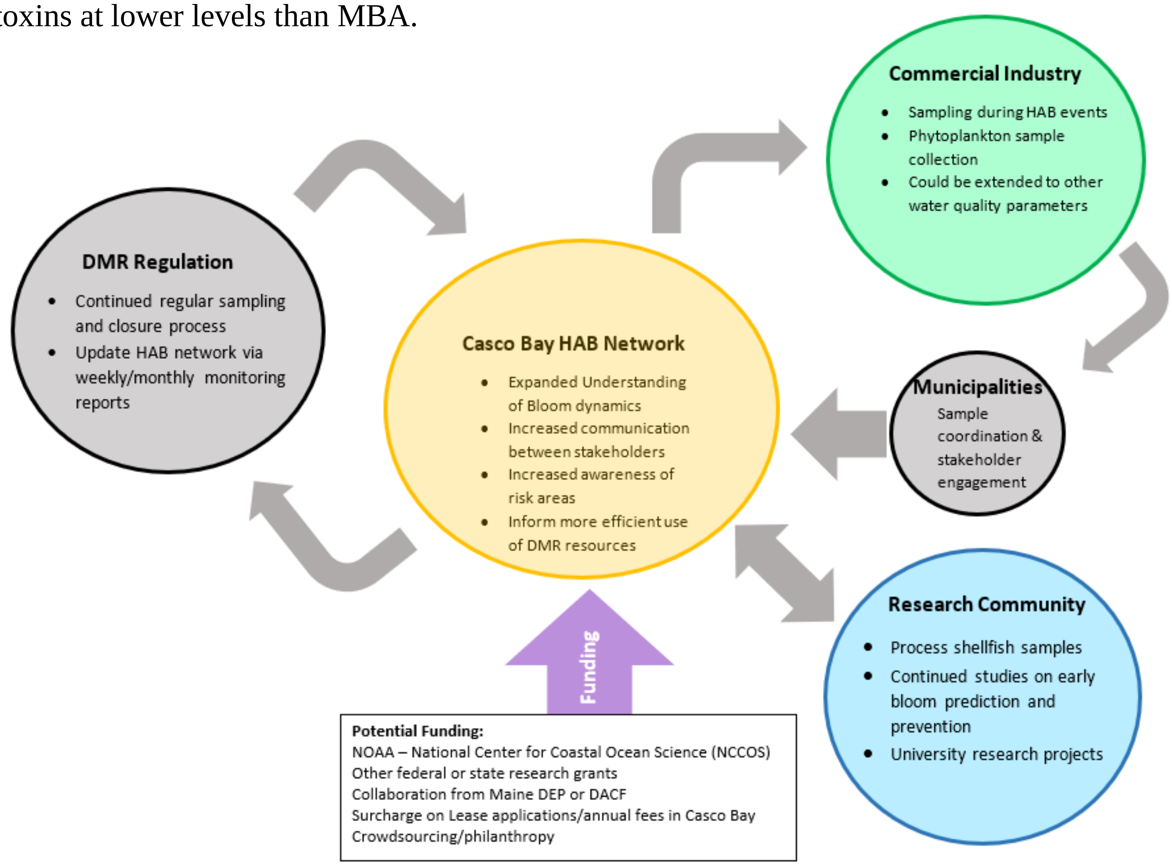


Figure 13. Conceptual Framework for HAB Network in Casco Bay**.**

5.3.1 HAB Network is a Transdisciplinary System

It is important to discuss the significance of transdisciplinary collaboration that a HAB network would bring to the region. Transdisciplinary science is a growing field that focuses on community-based, interactive, and participatory science as defined in Lang et. al. 2011. HAB management is an environmental issue that does not have a clear solution. It is a "wicked" problem as defined by Rittel and Webber, 1973. This means that the problem is different for many stakeholders and in turn there is not one clear solution. One of the best ways to approach these "wicked" problems is to work with all stakeholders involved to better understand the issue. Understanding the perspectives of everyone involved in the problem is important to lead to a better solution.

Transdisciplinary work is labor intensive, and it can be very difficult to keep all necessary stakeholders engaged in a meaningful way. Although it is difficult, if the effort is undertaken it has been shown to lead to many benefits (Mattor et. al., 2014) that in this case could extend well beyond the issue of biotoxin management. Being a wicked problem HAB management needs to lean on a transdisciplinary approach in order to keep all stakeholders happy and illicit desired responses within a complex adaptive system. In the case of Casco Bay, oyster farmers feel left out of monitoring and not heard when giving input to make the system better.

5.3.2 Pathway to a HAB Network.

Forming a HAB Network in Casco Bay will be a slow process that may take multiple years to fulfill all its potential. To begin to draw interest and collaboration, a symposium would be an effective way to gauge interest and support and also deliver education on monitoring and management practices. The initial formation of a volunteer harmful algae bloom network in British Columbia began at a symposium discussion the importance of HABs after a bloom related to DSP caused major shutdowns and recall of shellfish (McIntyre et. al., 2013). This would serve as a basis for partnerships to grow and could become a yearly event to bring the HAB community in the state together.

For stakeholders within the shellfish aquaculture community that are interested in involvement, the use of existing or establishment of new regional grower's associations would be a great place to start gauging interest within the local community. An initial way to begin data collection would be to collect and process phytoplankton samples during bloom periods. The equipment and training required to detect species of concern related to biotoxins is relatively cheap and straight forward. With collaboration from the DMR or other independent research organizations a group of growers could begin by collecting same day samples across all farms during bloom events. Over time this could turn into weekly or biweekly sampling during bloom seasons and with enough momentum this could draw collaboration from government agencies.

5.3.3 Barriers to a New Framework

DMR is charged with complying with the NSSP in order to protect public health public health from potentially deadly illnesses caused by toxic HABs. The responsibility to protect public health is of utmost importance to DMR and is rightfully the principal mission of the Bureau. However, this will likely create barriers to large changes in how closure decisions are made. This means that a HAB network would need to achieve multiple years of successful sampling before any significant regulatory changes would be possible.

Shellfish aquaculture in Maine currently operates on low margins and have many concerns to worry about on top of the increase of HABs in the area. There are contentious debates within the industry on leasing requirements, public perception, marketability, and more. Until biotoxin closures start impacting the industry more negatively there will not be a concerted effort to address the issue collectively. Many of the small scale aquaculturists are focused on what they need to do in the immediacy to return a profit and because of the Covid-19 impacts on the restaurant industry, their focus is not on HABs or other environmental factors.

Another barrier to a HAB network is funding. Right now, DMR is already limited in their regular monitoring by the funding they receive from the state legislation. Shellfish aquaculture in Maine brought in an estimated $15 million in value and the market is projected to grow dramatically over the next few decades (The Hale Group and Gulf of Maine Research Institute, 2016). More funding should be directed by the legislature to allow the industry to grow in a sustainable way and part of that needs to be funding for HAB research and management. In order for the growth of the industry to be successful, there needs to be more done to decrease the impact of biotoxins on the industry. Alternative opportunities for funding include grant funding from various national and regional funders including National Center for Coastal Ocean Sciences and Sea Grant's regional funding opportunities, among others.

5.4 Future Research Needs

There are multiple areas of collaborative research that could be addressed in the near future to better understand HAB trends in Maine and effects on aquaculture. Finding committed partners within the industry to develop a preliminary HAB network is an important next step. That would serve to start some data collection and begin to gain trust from other agencies including the DMR. Also, it would allow for some initial testing of variables that may cause changes in toxicity. It is already anecdotally known that there are differences between tidal flats and subtidal environments, but this has not been rigorously tested in Casco Bay. It would also be valuable to further quantify the economic impact of HABs in Maine related to all types of industry and commerce. This would help the state legislature understand how much this problem is really costing the state and give them incentive to better balance the costs with funding.

6. Conclusion and Recommendations

Based on this study it is clear that HABs are going to have an increasing impact on the growth of the bivalve shellfish industry in Maine and more needs to be done to both monitor the blooms more efficiently and communicate the risks of biotoxins more effectively to the end users and public. If Maine is going to continue to be a leader in biotoxin management there needs to be more support. A HAB network has the potential to both assist the DMR in more site specific management of blooms as well as keep stakeholders more involved in the monitoring practice. Based on the surveys and interviews with oyster farmers in Casco Bay, it seems like the group is excited and ready to collaborate on a monitoring effort. While there are some barriers to formation of a HAB Network, this study shows the long-term benefits a HAB Network could have in Casco Bay, to conclude there are also a number of smaller scale recommendations that both the regulators and commercial industry could do to encourage better engagement between the two stakeholder groups.

6.1 Recommendations for Regulators

The first goal of this research was to better understand the biotoxin management strategy in Maine and discuss it in comparison with other locations that face similar issues. It is evident that although Maine does have one of the most advanced monitoring programs in the country, there are areas that can be improved upon to adapt for the growing industry and future climate conditions. The largest barriers to a more advanced program in Maine is funding and the lack of stakeholder engagement and collaboration between organizations. DMR will not be able to balance all the needs by themselves and must gain support in monitoring from other organizations. Improvements will largely depend on a concerted effort of collaboration. Progress in trust and collaboration between the DMR and aquaculture industry will take a willingness to work together from both sides. There are some things that the DMR can do in the immediate or near future that will gain trust in the aquaculture community and are not expensive or difficult. These changes would have indirect benefits to DMR as well. Some of these changes would be as follows:

- Increased effort in data communication and transparency in closure decision making processes.
    - Weekly or monthly reports on data in certain areas – sent via email listserv to those who sign up.
    - Educational resources targeted to new aquaculturists on biotoxins present in Maine and risks associated
    - Addition of biotoxin layer on the online aquaculture mapping portal of simplified data results from most recent sampling.
- Option for industry funding sampling to be added to public record by permission of the farm
- Organize biotoxin management symposium for regulators, growers, and community members to come together to talk about management practices and ideas for improvement
    - This is where partnerships can begin to form either a HAB monitoring network or at minimum begin talks that may lead to expanded monitoring efforts.
- Work with other government agencies either the Department of Environmental Protection (DEP) or Department of Agriculture, Conservation, and Forestry (DACF)
    - Other places including Florida and British Columbia divide management tasks between agencies to lessen the pressure on any single agency.
- Increased Lease fees in high risk areas to better fund monitoring.

6.2 Recommendations for Industry

There are also ways that the industry can create their own impact by acting independently to promote data collection networks to improve upon the overall dataset available for DMR to make decisions. Having their own data on biotoxins will benefit farmers in a variety of ways regardless of impact on DMRs regulatory decisions. Biotoxin data will help farmers understand the risks in their area and well as get an understanding of the science behind the closure decisions. Increased collaboration with other farms could lead to other marketing and farm maintenance benefits as well. Over time this data collection effort could inform DMR and could lead to changes in monitoring structure leading to more localized closures. This will take a large effort and commitment from farmers and may require grant funding or collaboration with the scientific community.   Some immediate efforts made by industry members could be as follows:

- Continue to work with local harbormasters and municipal governments to expand sampling for phytoplankton and biotoxins.
    - Begin on a small scale using growing area associations
    - Start with coordinated one time sampling during blooms
    - Once funding and trainings are established sampling could be expanded to weekly or biweekly during bloom season

- Form area monitoring network for example, Casco Bay HAB network.
    - Coordinate data collection between farmers on a weekly or biweekly
    - Collaborate with lab to analyze samples and report back to farms
    - Most important to do this during bloom periods in May – August

- Move away from LPA based operations to more standard leases thereby opening up the opportunity to sign MOUs with DMR to conduct site-specific management.

7. Impact Statement

Maine has a growing shellfish aquaculture industry that is vital to the state's economy. Every effort should be made to help the industry continue to be successful and to promote its growth in a sustainable manner. This research was focused on the role that biotoxin management plays in the growth of the industry. The goal was to understand the complexities of the current biotoxin program and to provide stakeholders in Maine a framework to improve management of biotoxins and support cooperation between stakeholder groups.

There are various approaches to biotoxin monitoring and lessons from other states focusing on community outreach and data transparency can inform the path forward for Maine. The monitoring effort and closure procedure in Maine is effective, but minimal education and outreach effort make it difficult for stakeholders to understand the risk. There is a perceived lack of clarity on decisions about who gets closed and who stays open. It is clear that biotoxin management is important to the shellfish growers in the state and the community is ready to get involved.

This report gives a framework for the Department of Marine Resources and stakeholders in the commercial shellfish harvesting community to begin the first steps in working together toward an improved, equitable, transparent, and targeted biotoxin management effort. Developing a more stakeholder engaged program will lead to mutual understanding between the stakeholder groups and more localized biotoxin closures, which would save significant money for the industry. Also, this framework would lead to larger datasets of toxicity and phytoplankton that could be used to better predict future HAB conditions.

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Appendix I: Consent Form/Survey Instrument

Maine Oyster Farmer Survey

Please read the below Consent form. The survey will appear once consent is given and should not take more than 10 minutes to complete. Once you submit the form a link will appear to give **Optional** contact information for a follow up. This **Will Not** be connected to your survey answers in any way. Email zgordon@une.edu or hjaegerman@une.edu with any questions.

Thank you!

Zach Gordon and Hillevi Jaegerman

UNIVERSITY OF NEW ENGLAND

CONSENT FOR PARTICIPATION IN RESEARCH

Principal Investigator(s): Zachary Gordon and Hillevi Jaegerman both currently work in the oyster aquaculture industry and are students in UNE's Ocean Food Systems Professional Science Master's program. Raw survey results will only be shared with University of New England advisors and published results will be publicly available.

Introduction:

- Please read this form. You may also request that the form is read to you. The purpose of this form is to give you information about this research study, and if you choose to participate, document that choice.
- You are encouraged to ask any questions that you may have about this study, now, during or after the project is complete. You can take as much time as you need to decide whether or not you want to participate. Your participation is voluntary.

Why is this research study being done?

There are two studies this survey will inform. One study is evaluating the effectiveness of the current paralytic shellfish poisoning monitoring and management in Maine, to understand the needs of stakeholders in the industry, and develop suggestions for how management can be improved.

The other study will assess the accuracy of past industry growth and value projections of the Maine oyster. The study will analyze the value of the Maine oyster as it pertains to supply chain, place-branding, and new market potential.

Who will be in this study?

All members of the oyster farming industry in Maine are invited to participate in the online survey portion of this study. Members from the oyster industry in Casco Bay, Department of Marine Resources, Independent Analysis Labs may be asked to participate in an interview or focus group.

What will I be asked to do?

You will be asked to fill out an online survey.

What are the possible risks of taking part in this study?

There is a less than minimal risk your opinions and answers may become known by others in the industry. All precautions are being taken to keep survey answers anonymus.

What are the possible benefits of taking part in this study?

The benefits of taking part in this study will be to help inform a improved biotoxin monitoring plan and a potential export market for Maine oysters. Additionally, the final determination of Maine oyster industry readiness to export to new markets will be made available to the public.

What will it cost me?

There are no costs associated with taking the survey and for the interview/focus group stage participants will be asked to get their own transportation to the locations.

How will my privacy be protected?

The surveys will be kept completely anonymous. The researchers will never know the identity of survey respondents and if interested in the interview and focus group your contact information will be collected in a separate form. Survey responses regarding pricing and product values will be aggregated and no potentially individually- identifying data will be published in the final research report.

What are my rights as a research participant?

- Your participation is voluntary. Your decision to participate will have no impact on your current or future relations with the University.
- Your decision to participate will not affect your relationship with the department of marine resources or anyone in the shellfish aquaculture industry.
- You may skip or refuse to answer any question for any reason.

- If you choose not to participate there is no penalty to you and you will not lose any benefits that you are otherwise entitled to receive.
- You are free to withdraw from this research study at any time, for any reason.
    - If you choose to withdraw from the research there will be no penalty to you and you will not lose any benefits that you are otherwise entitled to receive.
- You will be informed of any significant findings developed during the course of the research that may affect your willingness to participate in the research.
- If you sustain an injury while participating in this study, your participation may be ended.

What other options do I have?

- You may choose not to participate.

Whom may I contact with questions?

- The researchers conducting this study are Zachary Gordon and Hillevi Jaegerman
- For more information regarding this study, please contact Zachary Gordon at zgordon@une.edu or Hillevi Jaegerman at hjaegerman@une.edu
- If you have any questions or concerns about your rights as a research subject, you may call Mary Bachman DeSilva, Sc.D., Chair of the UNE Institutional Review Board at (207) 221-4567 or irb@une.edu.

Will I receive a copy of this consent form?

You will be given a copy of this consent form.

Thank you!

I have read the information above and agree to participate in this study.

- [x] Yes
- [ ] No

reset

What type of Lease do you grow oysters on?

- [ ] Standard
- [ ] Experimental
- [x] LPA

Do you plan on expanding your LPA(s) to a Experimental or Standard Lease in the next 3 - 5 years?

- [ ] Yes
- [ ] No

reset

Prior to COVID19 events, who did you consistently sell your product to?

Check all that apply.

- [ ] Direct to private-sale consumer
- [ ] Company farm-stand
- [ ] Event buyers
- [ ] Direct to restaurant (in state)
- [ ] Direct to restaurant (out of state)
- [ ] Wholesale distributor (in state)
- [ ] Wholesale distributor (out of state)
- [ ] Grocery store
- [ ] Processing provider
- [ ] Other

Are you concerned about an over-saturation of the oyster market?

- [ ] Yes
- [ ] No

Please Explain.

In a normal season (or in past seasons) what months have you harvested market size oysters?

Check all that apply.

- ☐ January
- ☐ February
- ☐ March
- ☐ April
- ☐ May
- ☐ June
- ☐ July
- ☐ August
- ☐ September
- ☐ October
- ☐ November
- ☐ December

Within the next 3 years do you plan to expand your harvesting season by increasing the number of months per year that you harvest oysters?

○ Yes ○ No ○ Unsure ○ Does not apply

reset

How many oysters do you harvest per week on average?

In the Fall

In Spring.

In the Summer.

In the Winter.

Approximately how many employees work for your business during peak harvesting season? (part time employees can be accounted for as "0.5")

Approximately how many employees work for your business during your "off-season? (part time employees can be accounted for as "0.5")

Prior to 2020 and COVID19 industry setbacks, have you ever had a surplus of oysters that you couldn't sell?

○ Yes

○ No

reset

Please Explain

In the past 12 months have you had an order that you couldn't fulfill?

- ○ Yes
- ○ No

reset

Please Explain.

[ ]

Were you closed due to PSP during the 2019 season?

- ◉ Yes
- ○ No

reset

Approximately how long were you closed for in weeks?

[ ]

Approximately what percent of your total yearly revenue did you lose due to PSP closures?

[ ]

Would you allow the Department of Marine Resources (DMR) to use samples you paid for during a closure to classify the surrounding area?

- ○ Yes
- ○ No
- ○ Unsure

reset

What area do you operate in?

[▽]

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I believe DMR manages PSP effectively.	○	○	○	○	○
I would be willing to provide yearly financial support to a PSP monitoring effort.	○	○	○	○	○
I would be willing to provide sampling support to a PSP monitoring effort.	○	○	○	○	○
Management of PSP is not a concern to me.	○	○	○	○	○
I would like to collaborate with other farmers to exchange PSP data.	○	○	○	○	○
I would be interested in collecting and sharing data on other harmful algae blooms and water quality parameters.	○	○	○	○	○
I would be interested in joining with other farmers in an association or collaborative to promote the joint branding of the Maine oyster.	○	○	○	○	○
If there was an opportunity to export your product to a new market, your business would be ready to take on a new large buyer	○	○	○	○	○

reset

	Price decrease of $0.20 or more	Price decrease of $0.10 - $0.20	Haven't experienced price change	Price increase of $0.10 - $0.20	Price increase of $0.20 or more
					reset
In the past 3 years how has your price per piece changed on average from buyers?	○	○	○	○	○

Would you be interested in a follow up interview or focus group about biotoxin monitoring?

○ Yes ○ No

reset

Link to add contact info will appear on the next page. Contact information WILL NOT be connected to survey answers.

Any additional Comments?

Submit

Appendix II: IRB Approval

UNIVERSITY OF NEW ENGLAND

Institutional Review Board
Mary DeSilva, Chair

Biddeford Campus
11 Hills Beach Road
Biddeford, ME 04005
(207)602-2244 T
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Portland Campus
716 Stevens Avenue
Portland, ME 04103

To: Zachary Gordon

Cc: Adam St. Gelais

From: Lliam Harrison, M.A., J.D. CIM

Date: November 25, 2019

Project # & Title: 19.11.12-005 The Cost of Paralytic Shellfish Poisoning (PSP): An Analysis of the Monitoring and Management of PSP and its Effects on Industry Growth in Casco Bay, Maine

The Institutional Review Board (IRB) for the Protection of Human Subjects has reviewed the materials submitted in connection with the above captioned project and has determined that the proposed work is exempt from IRB review and oversight as defined by 45 CFR 46.104 (d)(2).

Additional IRB review and approval is not required for this protocol as submitted. <u>If you wish to change your protocol at any time, including after any subsequent review by any other IRB, you must first submit the changes for review.</u>

Please contact Lliam Harrison at (207) 602-2244 or wharrison@une.edu with any questions.

Sincerely,

William R. Harrison, M.A., J.D. CIM
Director of Research Integrity

IRB#: 19.11.12-005
Submission Date: 11/11/19
Status: Exempt, 45 CFR 46.104 (d)(2)
<u>**Status Date: 12/04/19**</u>