Facing Increased Health Risks of Harmful Algae Blooms (HABs):

An analysis of HAB dynamics and potential climate change related impacts to the Lummi Nation

Artwork provided by the Salish Sea Research Center

Lummi Natural Resources Department
Harvest Management Division
Megan Hintz, Shellfish Biologist
March 3, 2020

Suggested citation:
Hintz, M. E. 2020. Facing Increased Health Risks of Harmful Algae Blooms (HABs): An analysis of HAB dynamics and potential climate change related impacts to the Lummi Nation. Technical Report, March 2020. Lummi Natural Resources Department, Bellingham, Washington. 44 pp.

Summary

Some naturally occurring phytoplankton can be harmful when abundant in the sea creating harmful algae blooms (HABs); HABs have a wide range of harmful impacts on the ecosystem, human health, and fisheries. Harmful algae blooms, commonly called "red tides," have had significant ecological and socio-economic impacts on coastal communities in the Pacific Northwest for decades and their prevalence has been increasing. Washington marine waters are home to a number harmful algae boom (HAB) species that can produce toxins that accumulate in shellfish making them unsafe to consume. Shellfish, such as clams, mussels, and oysters, filter feed on phytoplankton and when harmful algae become abundant shellfish bioaccumulate the toxins they produce making the shellfish unsafe for humans to consume. The environmental conditions that have supported the undeniable increase in HABs globally and locally are largely anthropogenic, and HAB events are predicted to continue to increase with climate change.

With the increasing risk of HABs globally, the objective of this report is to assess current HAB dynamics directly impacting Lummi shellfish harvesting opportunities. HAB dynamics were evaluated for all of Whatcom County tidelands by examining the temporal-spatial accumulation of toxins produced in shellfish (Fig 2). This report aims to: 1) determine if closures are lasting longer and occurring during different seasons than previously, 2) determine if shellfish are more becoming more toxic than before, 3) determine if there is a different level of risk of HABs on the Lummi Reservation compared to surrounding areas, and 4) review existing literature to evaluate the predicted impacts of climate change on HABs.

Biotoxin closures have increased in length and expanded in seasonality limiting safe shellfish harvest opportunities. The total number of days tidelands have been closed to shellfish harvest due to elevated levels of biotoxins each year has been increasing. There has been an average increase of 2.4 closure days per year in this region, despite high variability spatially and annually. Additionally, there have been biotoxin closures every year since 2008 (11 years) in all the bays off the Lummi Reservation (biotoxin closures could not be determined for tidelands on the Reservation). These closures have obstructed shellfish harvesting opportunities for 20% of the year on average. Furthermore, the window of opportunity for HAB events has been expanding. Biotoxin closures generally occurred from May-October in Whatcom County which is consistent with patterns of HABs along the West Coast. However, in recent years biotoxin closures have been occurring earlier and lasting later in the year, starting in March and lasting through the winter into the following year. Increased closures have limited safe shellfish harvesting for ceremonial, subsistence, and commercial purposes.

Biotoxin closures are a result of harmful marine algae that cause two shellfish poisonings, Paralytic Shellfish Poisoning (PSP) and Diarrhetic Shellfish Poisoning (DSP). Paralytic Shellfish Poisoning toxins have been around for centuries but have only been monitored for the last five decades. Since monitoring began, PSP toxins have reached levels of concern for human health in nearly 100% of the years in at least one of Lummi's main shellfish harvest areas, but not all harvest areas. However, in recent years PSP toxins have been reaching levels of concern in almost all of the harvest areas every year. Therefore, it is becoming increasingly difficult to find areas to harvest shellfish that are safe for human consumption. Furthermore, the toxicity of PSP detected in shellfish has increased significantly lately. In three of the last ten years (2009-2018), PSP levels exceeded the maximum levels previously detected by two to three times, reaching nearly 100 times the closure level. Diarrhetic Shellfish Poisoning toxins appeared in Puget Sound shellfish in 2011 and have contributed to increased biotoxin closures and health risks since. Since monitoring for DSP toxins began in 2012, toxin levels have exceeded closure levels every year in at least one bay in Whatcom County. Furthermore, in 2014, DSP was the only biotoxin causing closures in both Drayton Harbor and Portage Bay while PSP toxin levels remained low. The health risk of harvesting shellfish has been redefined with new biotoxins and higher toxin levels.

HABs dynamics can be highly localized and as a result levels of biotoxins often vary between shellfish collected in nearby bays. The most important tidelands for intertidal shellfish harvest are within the 7,000 acres of tidelands located on the Lummi Reservation. The health risk for HAB events from these tidelands can vary significantly from nearby areas. Historically, shellfish samples were only periodically collected from Portage Bay and Lummi Bay; therefore it was not possible to develop a full biotoxin closure history for these beaches on the Lummi Reservation. Despite the irregular sampling, there is still plenty of data to evaluate changes and make comparisons to other bays in the region. In Portage Bay biotoxin levels have surpassed levels of concern in over 80% of the years, while in Lummi Bay levels have only reached concern for 22% of the years monitored, indicating potential health risks and shellfish harvest closures. Furthermore, Portage Bay shellfish frequently detected the highest levels of PSP toxins in the region whereas the highest levels of toxins have never been detected in shellfish from Lummi Bay. Lummi Bay has had significantly lower levels of biotoxins than all other areas in Whatcom County equating to a much lower health risk and far fewer harvest closures. If Lummi Bay continues to elude high biotoxin levels in shellfish it will become an even more important area for safe shellfish harvest in the future.

Coastal communities that depend on fisheries resources are particularly vulnerable to HAB events. Harvest closures can cause severe social, cultural, and economic disruptions. Closures lead to food insecurity from loss of subsistence harvesting and disruption of cultural practices, and loss of community identity tied to resource use. Intertidal shellfish resources also support an important commercial fishery of Manila clams, which is already limited by HAB events. The expanding season of HAB risk will further limit commercial shellfish harvest opportunities. Additional fisheries have the potential to be impacted by HAB events, particularly the geoduck clam and Dungeness crab fishery. Economic loss associated with lost fishery landings can cause financial insecurity for families that rely on fishing income.

Harmful algae have presented a significant threat to human health and have limited safe shellfish harvesting opportunities locally for at least the last four decades. In recent years, marine HABs have undeniably increased the health risks to the Lummi People in their main shellfish harvesting areas. In particular, levels of biotoxins have increased in toxicity, new biotoxins have emerged, and biotoxin closures are lasting longer. The increased health risk from biotoxins is limiting safe shellfish harvest opportunities for subsistence, ceremonial, and commercial purposes. The high annual and spatial variability in biotoxin closures, expanding season of HAB risk, and complex environmental conditions that favor HAB events make predicting future closures impossible. Therefore, it is important to sample important tidelands regularly to protect people from shellfish with high levels of biotoxins and maximize safe shellfish harvesting opportunities.

[This page intentionally left blank]

Introduction

Phytoplankton are a central component of coastal marine ecosystems forming the base of the food web. Harmful algae are naturally occurring phytoplankton that represent a very small percentage (<1%) of all known phytoplankton species that pose a threat to ecosystems and human health globally. Under certain environmental conditions these algae increase rapidly creating high biomass "blooms" that have a wide range of impacts on the ecosystem, human health, and fisheries are referred to as harmful algae blooms (HABs). Harmful algae blooms, commonly referred to as "red tides," have had significant ecological and socio-economic impacts on coastal communities in the Pacific Northwest for decades and their prevalence has been increasing**.** These HAB events pose a serious threat to coastal communities causing food insecurity from loss of subsistence harvest and disruption of culture practices and community identity (Moore et al. 2019).

The major HAB concerns in the Pacific Northwest are harmful marine algae that directly produce toxins that bioaccumulate in filter feeding shellfish. Bivalve shellfish such as clams, oysters, and mussels filter water feeding on the available phytoplankton. When harmful algae that produce toxins become the abundant food source in the water shellfish become toxic and can be unsafe for human consumption. Harmful algae bloom events are often triggered by a combination of environmental conditions including nutrient availability, light availability, warm water temperatures, and complex interactions with co-occurring organisms (Shumway et al. 2018). The relationship between environmental conditions and HAB events is complex and quantitative predictions continue to elude scientists and resource managers (Moore et al. 2008).

Harmful algae blooms have increased globally in the last five decades presenting a constant threat to coastal communities. The environmental conditions that have supported the undeniable increase in frequency, duration, and geographical range globally are predominantly anthropogenic (Shumway et al. 2018, Fig 1). The global increase in HABs has been attributed to human caused nutrient inputs into coastal waters, introduction of non-native harmful algae species, and changing climate patterns (Moore et al. 2011). Increased nutrient inputs are a major pollution problem globally, resulting from human population growth and the agriculture, increasing the frequency and duration of HAB events (Shumway et al. 2018). Harmful algae species have been introduced to new areas via ballast water from ships and the expansion of aquaculture (Shumway et al. 2018). Climate change is predicted to increase HABs in both frequency and severity due to global changes in temperature, stratification, ocean acidification, increased nutrient inputs, and ecosystem wide changes (Wells et al. 2015).

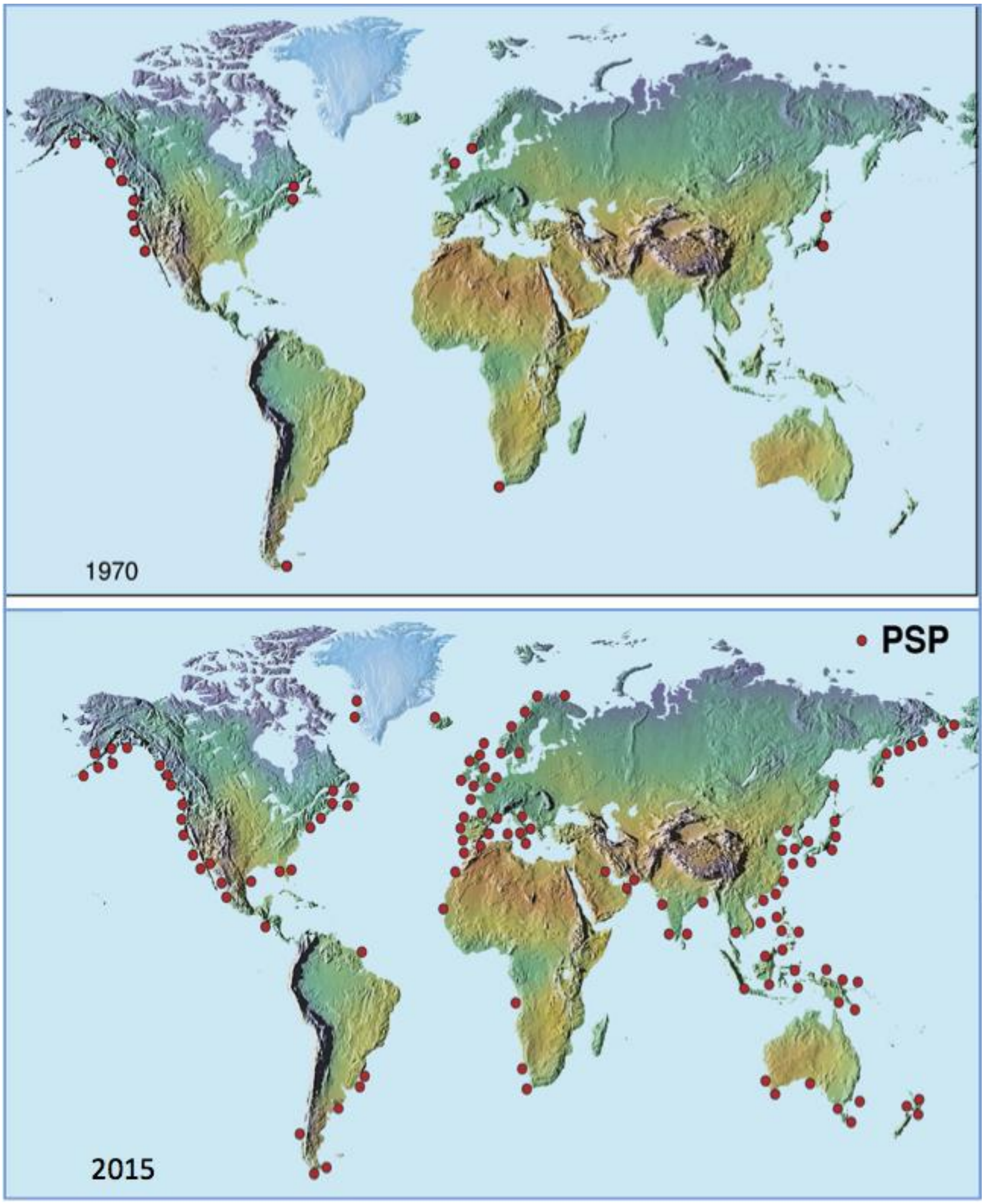

Figure 1. Global distribution of the harmful algae bloom (HAB) PSP toxins detected in 1970 versus 2015. (Source: US National Office for Harmful Algae Blooms)

Harmful algae blooms in Washington

Washington State marine waters are home to a number of marine harmful algae bloom (HAB) species that can produce toxins that accumulate in shellfish, making them unsafe to consume. One of the most concerning harmful algae present in this region are the dinoflagellates in the genera *Alexandrium* which produce the toxins that cause Paralytic

Shellfish Poisoning (PSP). *Alexandrium spp.* produces a suite of potent neurotoxins comprised of saxitoxin (STX) and its derivatives, collectively known as paralytic shellfish toxins (PST). Several species of the diatom genus *Pseudo-nitzschia* produce the toxin domoic acid which causes Amnesic Shellfish Poisoning (ASP). The third marine biotoxin of concern locally is okadaic acid produced by the dinoflagellates *Dinophysis spp.* which causes diarrhetic shellfish poisoning (DSP). Monitoring for levels of these biotoxins in shellfish is the only way to determine if the shellfish are safe for human consumption.

Monitoring for levels of PSP in Whatcom County shellfish has been conducted since 1973 even though PSP has been an issue in the Pacific Northwest long before. The first documented human deaths attributed to PSP date back to 1793 in British Columbia (Lewitus et al. 2012**,** Trainer et al. 2003, Horner et al. 1997). Washington State Department of Health (WADoH) implemented the first shellfish harvest closure due to biotoxins in 1942 after PSP outbreak lead to 3 fatalities (Lewitus et al. 2012). Sedimentary records suggest *Alexadrium* cyst beds date back until at least 1878 but increased rapidly in 1950 in Puget Sound (Moore et al. 2010), and it is generally accepted that *Alexandrium* and associated PSP illness have been present in Puget Sound waters for centuries (Horner et al. 1997). Traditional ecological knowledge from Northwest Indigenous Peoples includes shellfish harvest strategies that avoid harvest during times of high risk of biotoxins (Horner et al. 1997**,** Shumway et al. 2018).

More recently new marine biotoxins have been discovered in Washington shellfish. Shellfish toxicity and associated poisoning due to domoic acid (ASP) was first found in Washington in 1991, when the West Coast was hit with a large ASP event that spanned from the coast of California to Washington (Lewitus et al. 2012). Domoic Acid or ASP toxins were incorporated into WADoHs monitoring effort promptly after the ASP event in 1991. Another new toxin causing DSP showed up in shellfish on the west coast in the early 2000s, and by 2011 DSP caused multiple illnesses in Washington (Sequim Bay) and British Columbia (Gorge Harbour) (Trainer et al. 2013; Lewitus et al. 2012). Following the DSP illness in the summer of 2011, WADoH included DSP toxins in its monitoring of as well. To date, three marine biotoxins have been detected in Washington shellfish which are now monitored for regularly to protect public safety.

With the increasing risk of HABs globally and regionally, the objective of this report was to assess current HAB dynamics directly impacting Lummi shellfish harvesting opportunities. HAB dynamics were examined for all of Whatcom County tidelands referred to as Lummi's main shellfish harvest area (Fig 2). This is not to say Lummi tribal members only harvest shellfish within Whatcom County, rather Lummi's Usual & Accustom Area (U&A) extends far beyond the county boundaries and so do the tribe's shellfish harvest. However, tidelands within Whatcom County are where the majority of intertidal shellfish harvest currently occurs, especially the tidelands on the Lummi Reservation, because of proximity and ease of access. This report aims to: 1) determine if closures are lasting longer and occurring during different seasons than previously, 2) determine if shellfish are becoming more toxic than before, 3) determine if there is a different level of risk of HABs on the Lummi Reservation compared to surrounding areas, and 4) review existing literature to evaluate the predicted impacts of climate change on HABs.

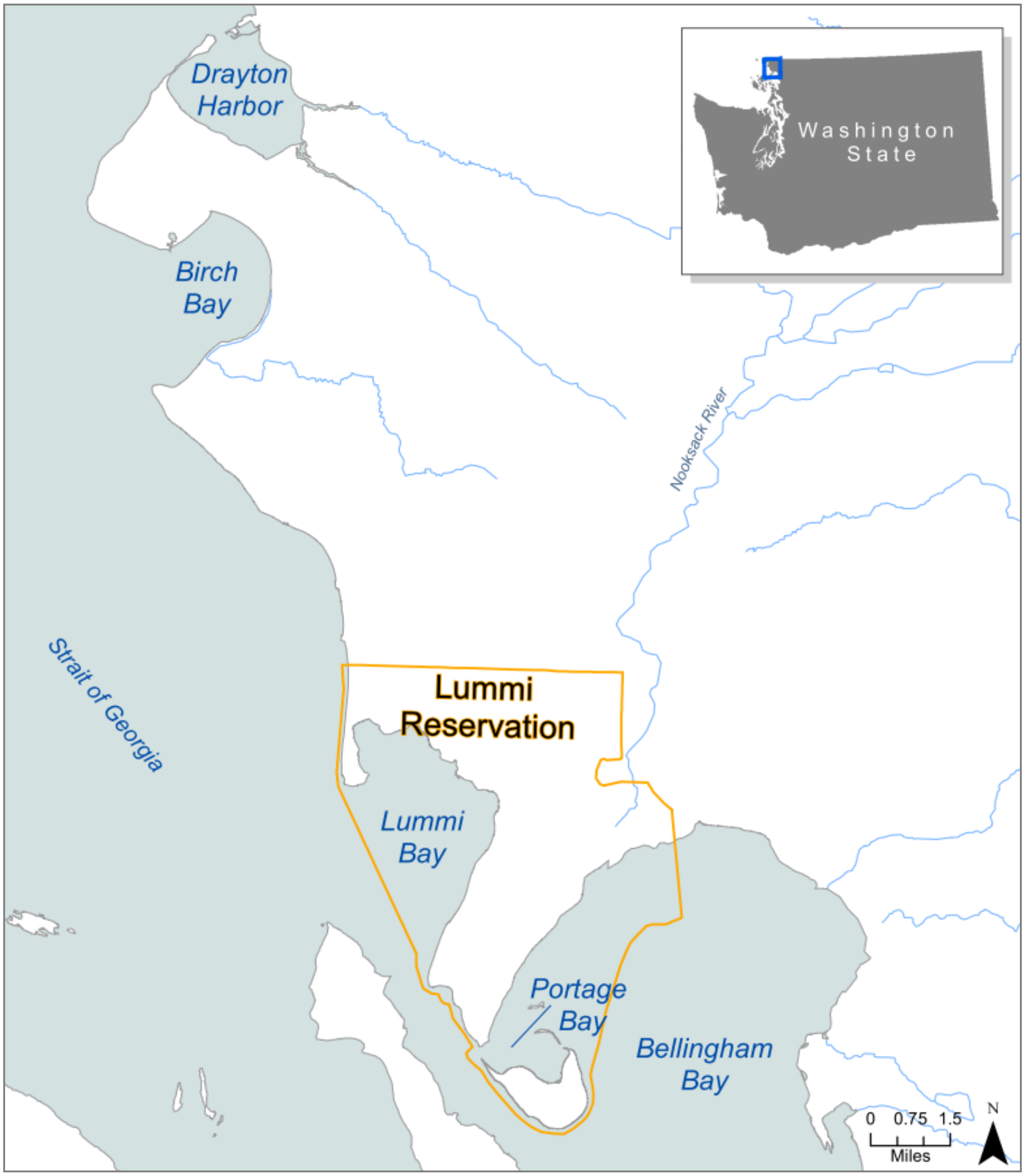

Figure 2. Map of shellfish biotoxin monitoring sites in Whatcom County, Washington including Lummi Reservation tidelands.

Methods

Trends in HABs were evaluated by examining the temporal-spatial accumulation of toxins produced in shellfish. Toxin levels in shellfish are used as a proxy for blooms of harmful algae, however high levels of toxin accumulated in shellfish do not always accurately represent the concentration of harmful algae. The increase in toxin levels in shellfish can be caused by hydrodynamic processes that concentrate harmful algae in an area, the growth or bloom of harmful algae in that area, or the lasting toxins in shellfish tissue after a bloom. Shellfish toxicity data were used for two reasons: 1) there is an extensive record of shellfish toxicity data in the region at a scale of interest to resource managers and no such record exists for harmful algae concentrations in the water, and 2) the human impacts of HABs arise when concentrations of toxins produced accumulate in shellfish regardless of the underlying process that lead to the accumulation in the first place. Although the patterns in shellfish toxicity cannot be used synonymously with concentrations of HABs in the water because of the complex relationship between the two, shellfish toxicity data do provide the best way to assess human impacts of HABs.

Regional trends in HAB dynamics in Whatcom County were explored with shellfish toxicity data (Fig 2). All data used to examine the dynamics of HABs in Whatcom County were shellfish toxicity data from the Biotoxin Monitoring Program at the Washington Department of Health (WADoH). Monitoring efforts initially focused on commercial and recreationally important shellfish species, and then with the Sentinel Monitoring Program in 1991 WADoH transitioned into a focus of monitoring HABs using mussels (Moore et al. 2009). Within Whatcom County, shellfish toxicity data collection began in 1953 but was inconsistent until the 1970s and progressed into monitoring at regular intervals with the implementation of the Sentinel Monitoring Program in 1991. Initially, WADoH monitored shellfish for levels PSP toxins then in 1992 they began monitoring for the ASP toxin domoic acid, and in 2012 they add DSP toxins to the suit of toxins tested for in shellfish in Whatcom County.

Shellfish toxicity is determined by testing shellfish tissue in a lab for levels of biotoxins. The method used for determining levels of PSP toxins is the standardized mouse bioassay (Association of Official Analytical Chemists 1990) which measures PSP toxins, saxitoxin equivalents. This method has been used by WADoH for all PSP shellfish toxicity testing. The method used for determining levels of DSP toxins is High Performance Liquid Chromatography with Diode Array Detection (HPLC/DAD) whereas the method for determining levels of ASP toxins (domoic acid) is High Performance Liquid Chromatography Mass Spectrometry (HPLC/MS/MS). All data were provided from the Washington Department of Health (WADoH) Office of Shellfish and Water Protection Division of Environmental Public Health.

Biotoxin closures were inferred from the biotoxin results provided by the WADoH for three bays, Bellingham Bay, Birch Bay, and Drayton Harbor, subject to regular sampling from 1991-2018 (Fig 2). Test results from butter and varnish clams were removed from the data set because they are slow detoxifiers and closures can remain in effect for those species for longer periods of time compared to other species of interest; hence the biotoxin closures used in this analysis were for all species of shellfish and did not include selective closures for species that retain toxins for longer periods of time. The regulatory action level to implement a closure for shellfish harvesting is 80 μg/100g of PSP toxins, 16 μg/100g of DSP toxins, and 20 ppm of ASP toxins or Domoic Acid (F.D.A. 2019). Any shellfish sample that tested for levels above the regulatory action level for any of the biotoxins would indicate a closure, and a closure would remain in place until there were 14 days without further samples above the regulatory limit for any biotoxin. This was done following the WADoH biotoxin closure protocol, which requires two samples to be below the regulatory limit 14 days from the last sample above the closure level to reopen an area for harvest. Biotoxin closures for each calendar year (Jan 1 – Dec 31) were summed up to determine the annual number of total biotoxin closure days then fit with a linear regression. Seasonal trends in biotoxin closures were explored by determining the proportion of days closed to biotoxins for each month every year. Biotoxin testing for shellfish from the Lummi Reservation beaches was done mainly during higher risk periods (e.g. summer and fall) for HAB events and not at regular intervals; therefore, detailed information on specific closures for reservation beaches was unattainable.

Maximum levels for each biotoxin were determined for each calendar year (Jan 1 – Dec 31) from 1973-2018 for all of Whatcom County and each bay independently. As stated above, testing of shellfish for biotoxin levels on Lummi Reservation beaches was conducted only sporadically, and therefore no data exists for some years even though the maximum level might have been higher than detected due to lack of sampling. Biotoxin levels can change rapidly and can vary between short geographic distances; therefore the sampling frequency and spatial coverage could result in an underestimation of maximum biotoxin levels.

Results

Levels of biotoxins:

The longest record of relatively continuous biotoxin levels in Whatcom County is for PSP toxins. WADoH has been routinely testing for PSP since 1973. Maximum levels of PSP toxins are highly variable from year to year and between bays (Fig 3-8). Within the same year on many occasions, levels of PSP toxins have surpassed lethal levels (>1,000 μg/100g) in one bay while other bays within the region remained below the action level (80 μg/100g) (Table 1). The maximum toxicity of shellfish each year within the region varied from 73 – 7,920 μg/100g (Fig 3-8). In almost every year since monitoring began levels of PSP surpassed the action level resulting in a closure in at least one bay in this region with only one exception in 1995. For the past 46 years that shellfish have been monitored for PSP, toxins have reached levels of concern for human health nearly 100% of the years in at least one of Lummi's main shellfish harvest areas.

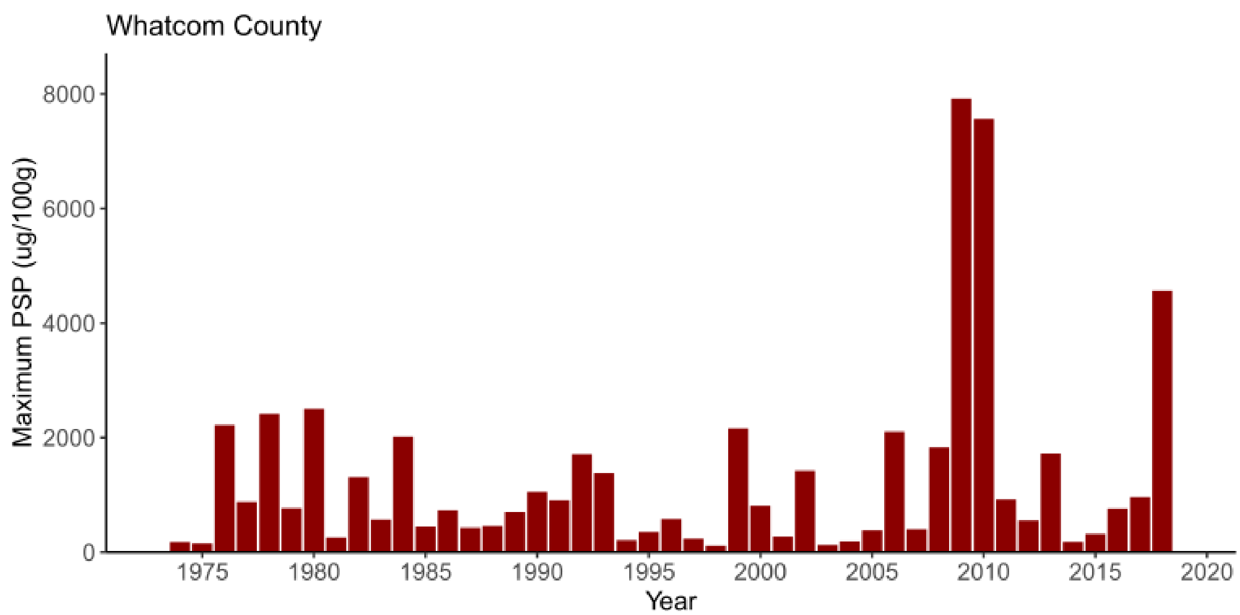

Figure 3. Maximum Paralytic Shellfish Poisoning (PSP) toxin levels detected in shellfish from Whatcom County annually.

No one "hotspot" was detected in the region that constantly had the highest levels of PSP. The maximum levels of PSP each year were widely distributed amongst the bays. For the 46 years of monitoring, Bellingham Bay and Portage Bay had the most maximum values with 14 and 13 years each, respectively followed closely by Birch Bay and Drayton Harbor with 10 and 9 years each, respectively (Fig 3-8, Table 1). Lummi Bay is the only area that never had the maximum levels of PSP for the region (Fig 3-8, Table 1). Lummi Bay generally had much lower values of PSP in shellfish. In fact, from 1991-2018 when sampling became more frequent there were only three years with PSP levels initiating closures in Lummi Bay. Besides the lower risk of PSP in Lummi Bay, all other areas in this region appear to have approximately equal PSP risk suggesting there is not just one harvest area that should be avoided due to PSP risk.

The PSP toxicity in shellfish has been increasing in recent years. Levels of PSP toxins have reached levels upwards of three times more than what had been detected historically in three of the last ten years (Fig 3). In 2009 and 2010, maximum PSP toxin levels reached nearly 8,000 μg/100g (7920 and 7565 μg/100g, respectively). Again in 2018, PSP toxin levels reached much higher levels when they climbed over 4,500 μg/100g (4567 μg/100g), whereas before, the maximum levels of PSP toxins only occasionally reached about 2,000 μg/100g (Fig 3, Table 1).

Testing for DSP toxins in Washington State began in 2012 after a reported illness from diarrhetic shellfish poisoning occurred the previous year. Every year DSP levels in shellfish have been monitored, levels exceeding the regulatory limit have led to closures in Bellingham Bay every year; however DSP toxin levels have not led to as many closures in other bays in Whatcom County (Table 1). For example, closures have occurred in 5 of the 7 years (71%) of testing in Portage Bay and only 4 out of 7 years (57%) of testing have resulted in closures at Birch Bay and Drayton Harbor (Table 1). Lummi Bay has never had DSP levels surpass the regulatory limit since monitoring began in 2012 (Table 1).

Levels of Domoic Acid (ASP toxin) have been detected in shellfish from Whatcom County, but never above levels that would pose a public health concern; therefore, there have not been any biotoxin closures due to elevated levels of domoic acid.

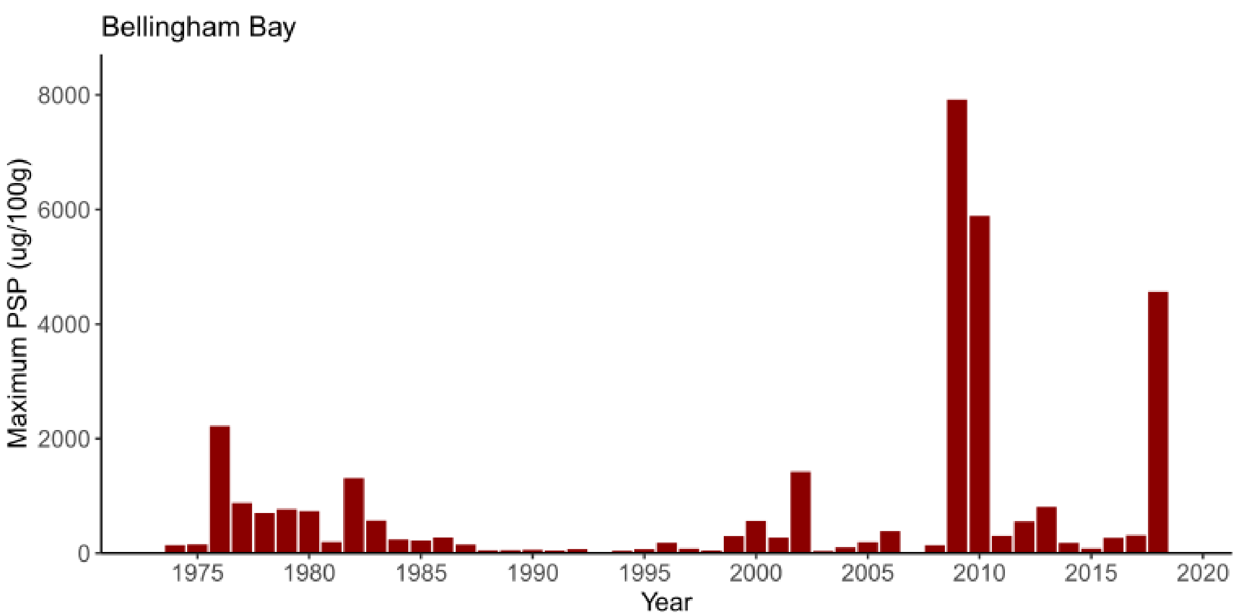

Figure 4. Maximum Paralytic Shellfish Poisoning (PSP) toxin levels detected in shellfish from Bellingham Bay annually.

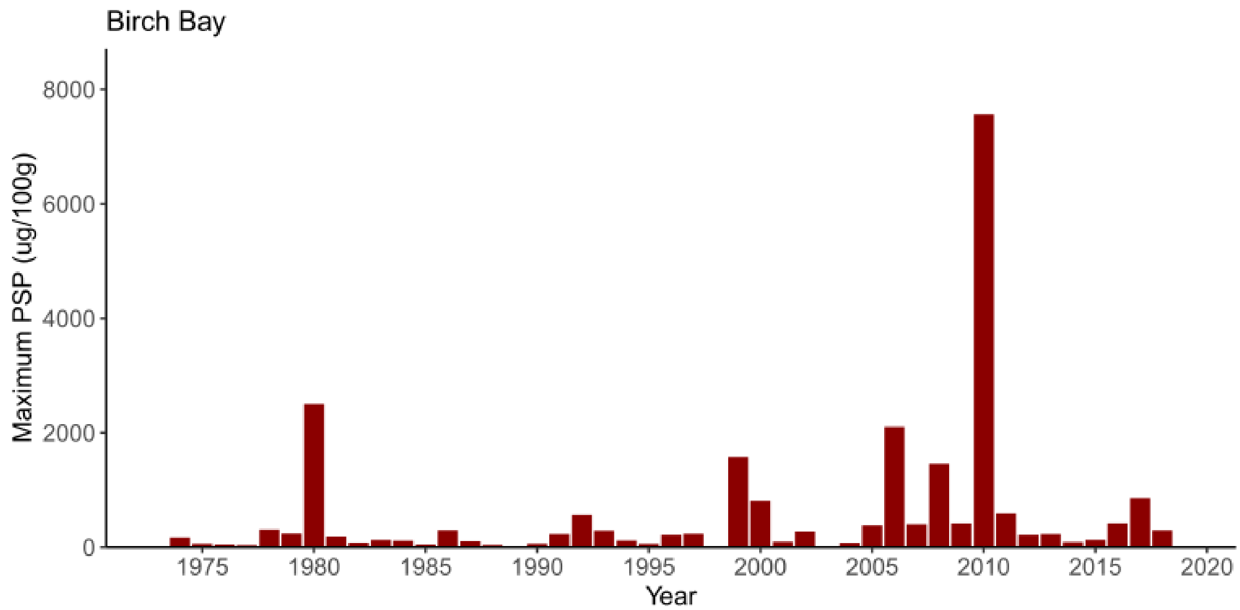

Figure 5. Maximum Paralytic Shellfish Poisoning (PSP) toxin levels detected in shellfish from Birch Bay annually

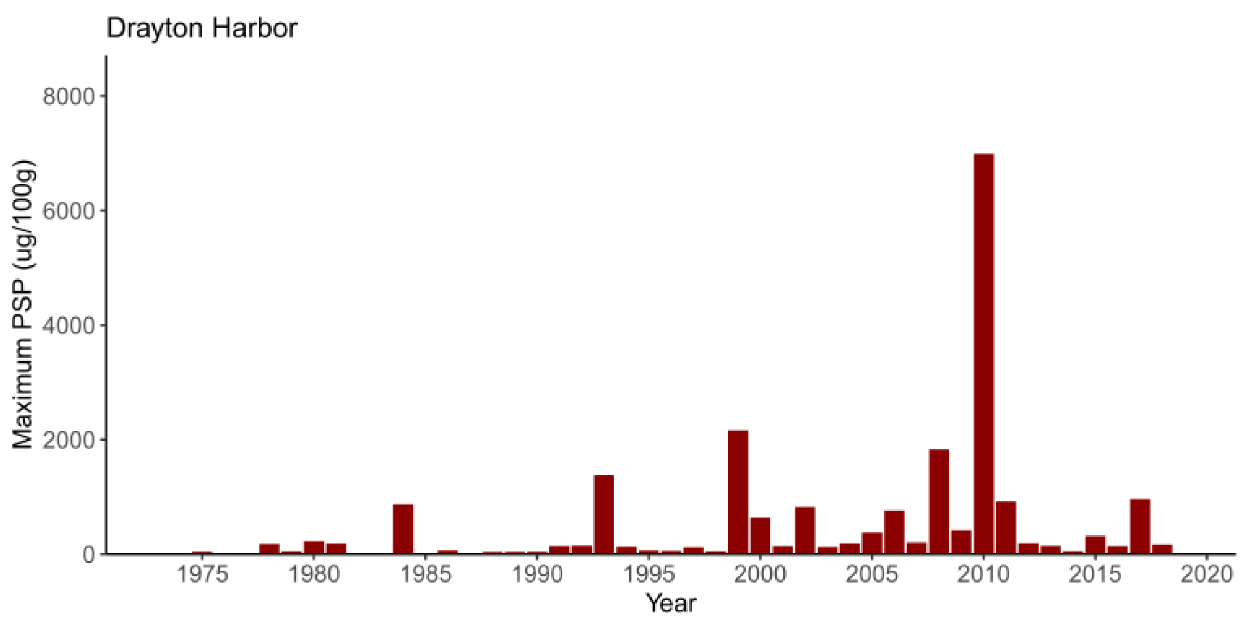

Figure 6. Maximum Paralytic Shellfish Poisoning (PSP) toxin levels detected in shellfish from Drayton Harbor annually.

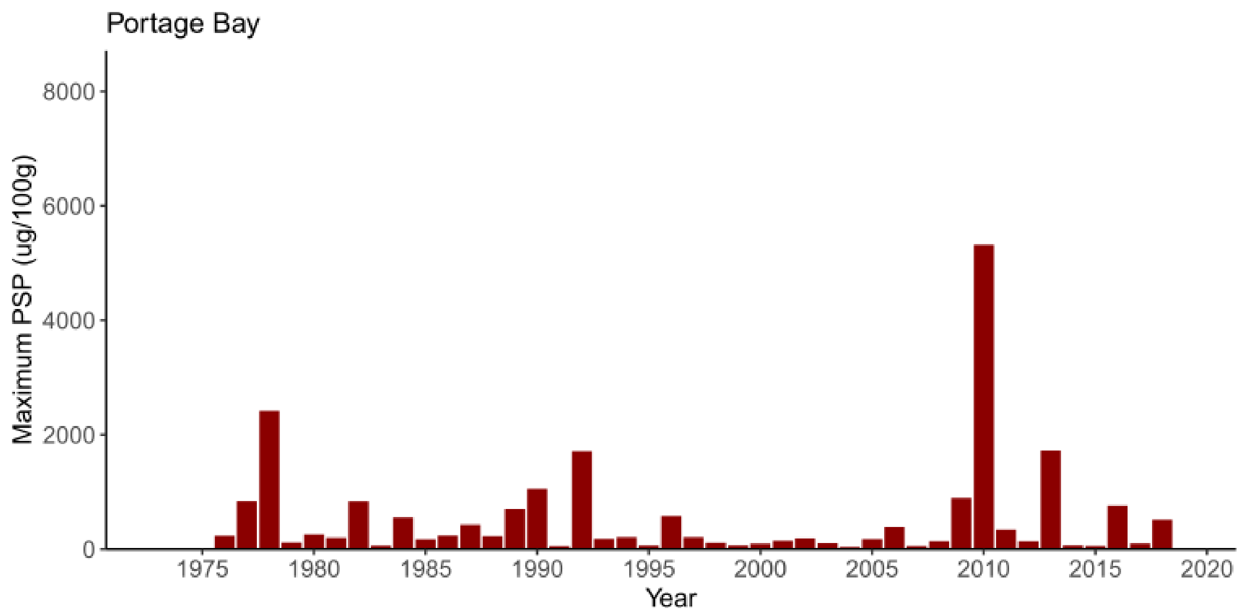

Figure 7. Maximum Paralytic Shellfish Poisoning (PSP) toxin levels detected in shellfish from Portage Bay annually.

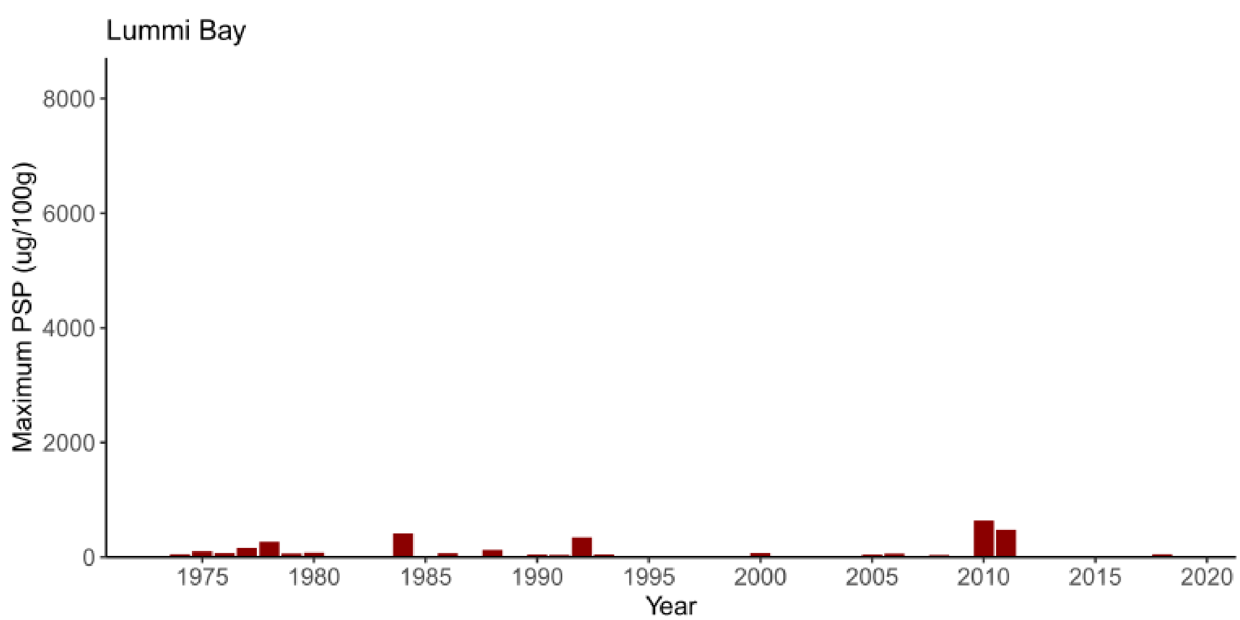

Figure 8. Maximum Paralytic Shellfish Poisoning (PSP) toxin levels detected in shellfish from Lummi Bay annually

Table 1. Maximum toxin levels of three biotoxins, Paralytic Shellfish Poisoning (PSP), Diarrhetic Shellfish Poisoning (DSP), and Amnesic Shellfish Poisoning (ASP, domoic acid) in shellfish tested from five different bays each year within Whatcom County, Washington State. (1 of 2)

	Bellingham Bay			Birch Bay			Drayton Harbor			Lummi Bay			Portage Bay			Maximum		
Year	PSP max	DSP max	ASP max	PSP max	DSP max	ASP max	PSP max	DSP max	ASP max	PSP max	DSP max	ASP max	PSP max	DSP max	ASP max	PSP max	DSP max	ASP max
1973	270	-	-	135	-	-	35	-	-	52	-	-	375	-	-	375	-	-
1974	140	-	-	170	-	-	-	-	-	-	-	-	-	-	-	170	-	-
1975	154	-	-	62	-	-	45	-	-	102	-	-	0	-	-	154	-	-
1976	2220	-	-	49	-	-	0	-	-	74	-	-	234	-	-	2220	-	-
1977	880	-	-	38	-	-	0	-	-	163	-	-	840	-	-	880	-	-
1978	701	-	-	309	-	-	182	-	-	269	-	-	2418	-	-	2418	-	-
1979	769	-	-	239	-	-	51	-	-	67	-	-	115	-	-	769	-	-
1980	737	-	-	2503	-	-	224	-	-	81	-	-	258	-	-	2503	-	-
1981	198	-	-	189	-	-	189	-	-	-	-	-	200	-	-	200	-	-
1982	1314	-	-	78	-	-	0	-	-	-	-	-	838	-	-	1314	-	-
1983	567	-	-	127	-	-	-	-	-	-	-	-	65	-	-	567	-	-
1984	238	-	-	115	-	-	875	-	-	418	-	-	554	-	-	875	-	-
1985	218	-	-	47	-	-	0	-	-	-	-	-	174	-	-	218	-	-
1986	275	-	-	297	-	-	68	-	-	72	-	-	237	-	-	297	-	-
1987	152	-	-	106	-	-	-	-	-	0	-	-	428	-	-	428	-	-
1988	52	-	-	41	-	-	41	-	-	124	-	-	226	-	-	226	-	-
1989	54	-	-	0	-	-	42	-	-	0	-	-	701	-	-	701	-	-
1990	62	-	-	63	-	-	44	-	-	46	-	-	1055	-	-	1055	-	-
1991	47	-	-	230	-	-	142	-	-	40	-	-	56	-	-	230	-	-
1992	74	-	6	564	-	0	150	-	0	342	-	-	1710	-	-	1710	-	6
1993	0	-	1	291	-	1	1381	-	0	49	-	-	182	-	-	1381	-	1
1994	43	-	-	117	-	0	129	-	0	0	-	-	209	-	-	209	-	0
1995	73	-	-	61	-	0	67	-	0	0	-	0	67	-	0	73	-	0

Table 1. Maximum toxin levels of three biotoxins, Paralytic Shellfish Poisoning (PSP), Diarrhetic Shellfish Poisoning (DSP), and Amnesic Shellfish Poisoning (ASP, domoic acid) in shellfish tested from five different bays each year within Whatcom County, Washington State. (2 of 2)

	Bellingham Bay			Birch Bay			Drayton Harbor			Lummi Bay			Portage Bay			Maximum		
Year	PSP max	DSP max	ASP max	PSP max	DSP max	ASP max	PSP max	DSP max	ASP max	PSP max	DSP max	ASP max	PSP max	DSP max	ASP max	PSP max	DSP max	ASP max
1996	185	-	-	216	-	0	60	-	0	0	-	0	578	-	0	578	-	0
1997	81	-	0	235	-	0	118	-	0	0	-	-	209	-	-	235	-	0
1998	48	-	0	0	-	0	51	-	0	0	-	0	111	-	-	111	-	0
1999	302	-	0	1574	-	0	2160	-	0	0	-	-	68	-	-	2160	-	0
2000	561	-	-	810	-	0	643	-	0	75	-	-	97	-	-	810	-	0
2001	273	-	0	96	-	0	141	-	0	0	-	-	148	-	-	273	-	0
2002	1422	-	-	276	-	0	825	-	0	0	-	-	192	-	-	1422	-	0
2003	39	-	0	0	-	0	125	-	0	0	-	-	104	-	-	125	-	0
2004	101	-	0	75	-	0	192	-	0	0	-	-	40	-	-	192	-	0
2005	195	-	0	384	-	0	379	-	0	46	-	-	178	-	-	384	-	0
2006	386	-	0	2104	-	0	764	-	0	65	-	-	390	-	-	2104	-	0
2007	0	-	0	403	-	0	204	-	0	0	-	-	58	-	-	403	-	0
2008	139	-	0	1456	-	0	1831	-	0	38	-	-	140	-	-	1831	-	0
2009	7920	-	0	419	-	0	421	-	0	0	-	-	894	-	-	7920	-	0
2010	5890	-	0	7565	-	0	6990	-	0	642	-	-	5319	-	-	7565	-	0
2011	306	-	0	592	-	0	921	-	0	477	-	-	339	-	-	921	-	0
2012	554	184	0	216	23	0	194	45	0	-	-	-	139	73	-	554	184	0
2013	808	29	0	230	20	0	146	23	0	0	0	-	1722	23	0	1722	29	0
2014	183	81	0	90	31	1	52	75	0	0	1	0	69	25	0	183	81	1
2015	83	19	0	128	3	0	319	3	0	0	1	0	59	8	0	319	19	0
2016	269	31	0	420	6	1	141	8	1	0	1	0	763	16	0	763	31	1
2017	313	17	0	861	10	0	965	15	0	0	1	-	100	10	0	965	17	0
2018	4567	44	0	296	14	0	170	11	0	52	2	0	518	19	0	4567	44	0

Biotoxin Closures:

Biotoxin closures were inferred for Bellingham Bay, Birch Bay, and Drayton Harbor from 1991 to 2018. Shellfish harvest closures due to biotoxins were implemented for PSP toxin levels only until testing for DSP started in 2012. Domoic acid levels have never reached regulatory action levels causing any closures.

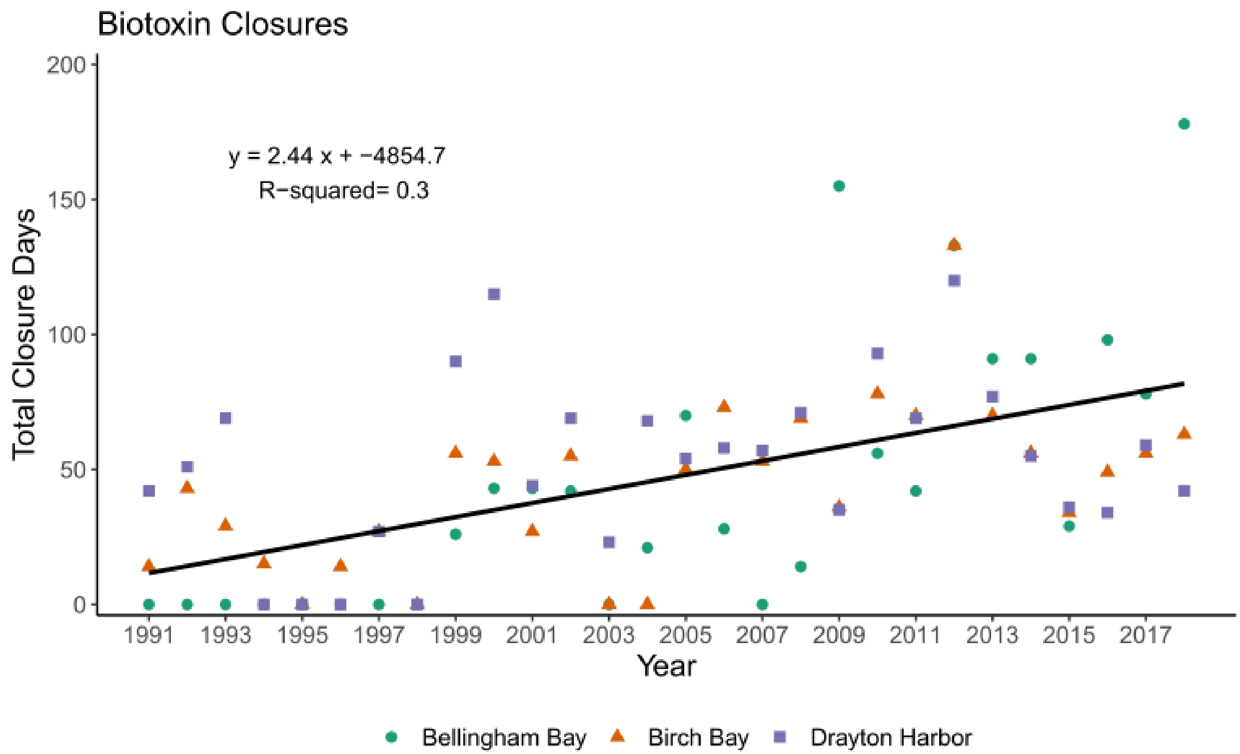

Figure 9. Total number of days that were closed to shellfish harvest each year from 1991-2018 in three different bays within Whatcom County, Washington because of elevated levels of biotoxins detected in shellfish. Elevated levels of Paralytic Shellfish Poisoning (PSP) and Diarrhetic Shellfish Poisoning (DSP) led to these closures. Combined data were fit with a linear regression line (y =2.44x – 4854.7, $R^2 = 0.3$, $F_{(1,85)} = 35.8$, $p < 0.001$)

There is considerable variability in the number of days closed to shellfish harvest due to elevated biotoxin levels between bays and years (Fig 9). The duration of biotoxin closures ranged from 14 days (when only one sample exceeded the regulatory limit) to 155 days. Despite the high variability, there is a weak but highly significant trend of increasing closures from 1991 to 2018 (Fig 9). There have only been two years (1995 and 1998) where there were no biotoxin closures in Whatcom County (Table 2). From 1991 to 1998, there were no closures in Bellingham Bay yet there were closures in 50% and 75% of the years in Drayton Harbor and Birch Bay, respectively (Table 2, Fig 10). For the next nine years (1999-2007), both Bellingham Bay and Birch Bay had closures in 78% of the years, and Drayton Harbor had closures every year (Table 2). The proportion of years with biotoxin closures continued to increase, and since 2008 there have been biotoxin closures in all bays every year (Table 2).

Not only has the occurrence of biotoxin closures increased, but so has the impact of the closures. The total number of days each year where biotoxin levels led to harvest closures for health concerns has increased. Using a linear regression, calendar year was found to explain 30% of the variability in total biotoxin closure days in Whatcom County from 1991-2018 with an approximate increase of 2.4 closure days per year [$F_{(1,85)} = 35.8$, $p < 0.001$] (Fig 9). The total closure day increase is a result of increased closure length, multiple closures in a year, and multiple biotoxins leading to closures. Since 2012 (the year DSP toxin monitoring started) there have been more than one separate biotoxin closure period in each bay for over 70% of the years, implying more than one bloom of harmful algae within the area. Generally, spikes in PSP toxins occur in the late spring/early summer and/or in the late summer/early fall with DSP toxins spiking during the summer. The HABs that produce PSP and DSP toxins often overlap in time and space leading to times where shellfish are high in levels of both toxins. The majority of the biotoxin closures are due to elevated levels of PSP, but DSP levels have surpassed the closure levels every year in Bellingham Bay and in four of the seven years in both Birch Bay and Drayton Harbor (Table 2). Furthermore, in 2014 PSP levels did not exceed regulatory limits but elevated levels of DSP toxins led to harvest closures in both Drayton Harbor (a 55 day closure) and Portage Bay.

The increase in biotoxin closures and length varied between bays. The most significant increase in total biotoxin closure length was in Bellingham Bay. The total biotoxin closure days increased by approximately 4.2 days each year where calendar year explained 51% of the variability in total biotoxin closure days [$F_{(1,27)} = 27.7$, $p < 0.001$] (Fig 10). In 2018, Bellingham Bay had the highest total biotoxin closure days (n= 178 days) resulting in months of closures to harvest due to biotoxins. Bellingham Bay also had a particularly high number of total biotoxin closure days in 2009 and 2012 with 155 and 133 closure days, respectively (Table 2). Birch Bay has also had a significant increase in total biotoxin closure days with an approximate increase of 2.05 biotoxin closure days per year with calendar year explaining 34% of the variability in total biotoxin closure days [$F_{(1,27)} = 14.04$, $p < 0.001$] (Fig 10). The maximum total biotoxin closures days in Birch Bay was 133 days in 2012 (Table 2). The maximum total biotoxin closure days for the region ranged from 133-178 days in a year, with an average of 74 total closure days in the last 10 years (Table 2).

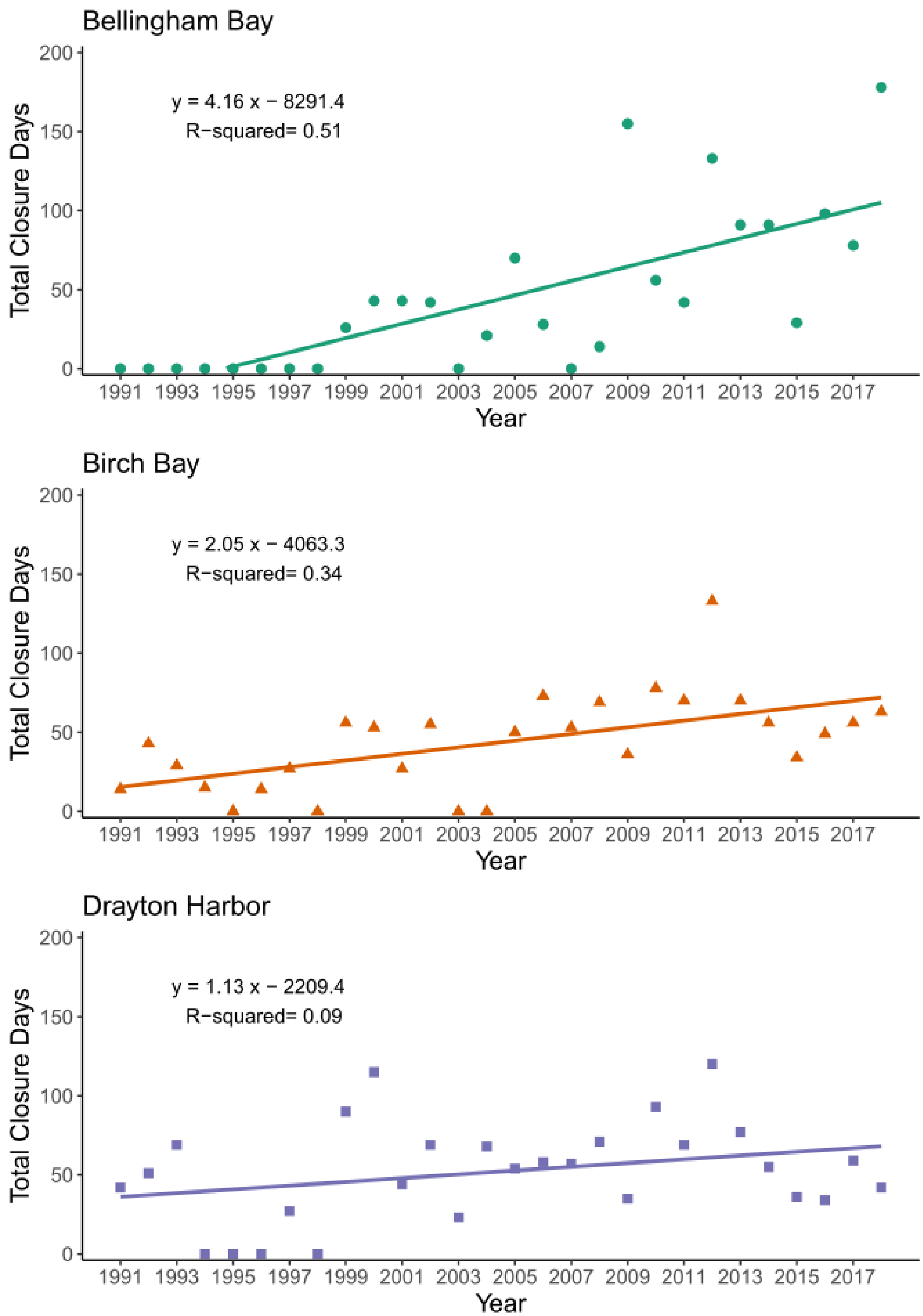

Figure 10. Total days three bays in Whatcom County were closed to shellfish harvest each year from elevated levels of biotoxins fit with a linear regression (Bellingham Bay: $y = 4.16x - 8291.4$, $R^2 = 0.51$, $F_{(1,27)} = 27.7$, $p < 0.001$); Birch Bay: $y = 2.04x - 4063$, $R^2 = 0.34$, $F_{(1,27)} = 14.04$, $p < 0.001$; Drayton Harbor: $y = 1.12x - 2209$, $R^2 = 0.09$, $F_{(1,27)} = 2.806$, $p = 0.1055$)

Table 2. Summary of biotoxin closures for Whatcom County Bays from 1991-2018

Year	Bellingham Bay Closure Days	Bellingham Bay Average Closure Length	Bellingham Bay # of Closures	Bellingham Bay First Closure	Bellingham Bay Last Closure	Birch Bay Closure Days	Birch Bay Average Closure Length	Birch Bay # of Closures	Birch Bay First Closure	Birch Bay Last Closure	Drayton Harbor Closure Days	Drayton Harbor Average Closure Length	Drayton Harbor # of Closures	Drayton Harbor First Closure	Drayton Harbor Last Closure
1991	0	0	0	-	-	14	14	1	10/23	11/6	42	42	1	9/25	11/6
1992	0	0	0	-	-	43	21.5	2	7/14	11/4	51	25.5	2	7/1	11/4
1993	0	0	0	-	-	29	29	1	6/29	7/28	69	69	1	6/16	8/24
1994	0	0	0	-	-	15	15	1	8/23	9/7	0	0	0	-	-
1995	0	0	0	-	-	0	0	0	-	-	0	0	0	-	-
1996	0	0	0	-	-	14	14	1	8/14	8/28	0	0	0	-	-
1997	0	0	0	-	-	27	27	1	10/29	11/25	27	27	1	10/29	11/25
1998	0	0	0	-	-	0	0	0	-	-	0	0	0	-	-
1999	26	26	1	7/29	8/24	56	56	1	6/29	8/24	90	45	2	6/23	11/17
2000	43	43	1	8/7	9/19	53	26.5	2	5/22	10/4	115	38.3	3	4/18	10/19
2001	43	21.5	2	7/10	10/15	27	27	1	7/12	8/8	44	14.7	3	7/10	11/29
2002	42	42	1	10/2	11/13	55	27.5	2	5/29	10/29	69	34.5	2	5/29	10/29
2003	0	0	0	-	-	0	0	0	-	-	23	23	1	37761	37784
2004	21	21	1	10/5	10/26	0	0	0	-	-	68	34	2	5/19	11/23
2005	70	35	2	10/10	12/31	50	50	1	5/16	7/5	54	54	1	5/12	7/5
2006	28	28	1	1/4	10/23	73	36.5	2	6/5	11/7	58	29	2	6/5	10/23
2007	0	0	0	-	-	53	26.5	2	39176	39258	57	28.5	2	39160	39258
2008	14	14	1	6/24	7/8	69	69	1	5/21	7/29	71	71	1	5/19	7/29
2009	155	155	1	9/14	12/31	36	36	1	9/28	11/3	35	35	1	9/29	11/3
2010	56	56	1	2/16	8/16	78	78	1	6/7	8/24	93	93	1	6/7	9/8
2011	42	21	2	7/5	11/7	70	70	1	5/17	7/26	69	69	1	5/3	7/11
2012	133	133	1	7/3	11/13	133	66.5	2	5/7	9/24	120	120	1	5/7	9/4
2013	91	91	1	9/16	12/16	70	23.3	3	6/3	11/4	77	25.7	3	5/20	11/4
2014	91	30.3	3	6/30	11/3	56	28.0	2	5/19	7/21	55	55.0	1	6/9	8/3
2015	29	14.5	2	6/8	7/21	34	17	2	5/4	6/15	36	18	2	4/13	5/26
2016	98	32.7	3	5/2	11/1	49	49.0	1	4/4	5/23	34	17.0	2	4/4	5/16
2017	78	26	3	6/26	11/6	56	56	1	6/5	7/31	59	29.5	2	6/5	8/15
2018	178	59.3	3	6/4	12/31	63	31.5	2	5/14	10/14	42	21.0	2	4/30	6/18

Drayton Harbor however has not had a significant increase in total biotoxin closure days. The linear regression determined that calendar year was not a significant predictor in the variability of total biotoxin closure days [$F_{(1,27)}$ = 2.806, p =0.1055] (Fig 10). Drayton Harbor had a relatively high number of total biotoxin closure days the first few years of the Sentinel Monitoring Program (1991-1993) compared to the other bays in Whatcom County (Table 2), and although there was only one short (27 day) biotoxin closure in the following five years biotoxin closure days spiked again in 1999 and 2000 resulting in 90 and 155 total closure days, respectively (Table 2). While there is high year to year variation in total biotoxin closure days, the range of total closure days has not increased significantly from 1991 to 2018 (Fig 10).

Seasonality of biotoxin closures

In Bellingham Bay, biotoxin closures began in the late spring to early summer (May – early July) and lasted through the fall into winter (November – February) (Table 2, Fig 11). For the past 10 years, the highest proportion of closure days occurred in July and

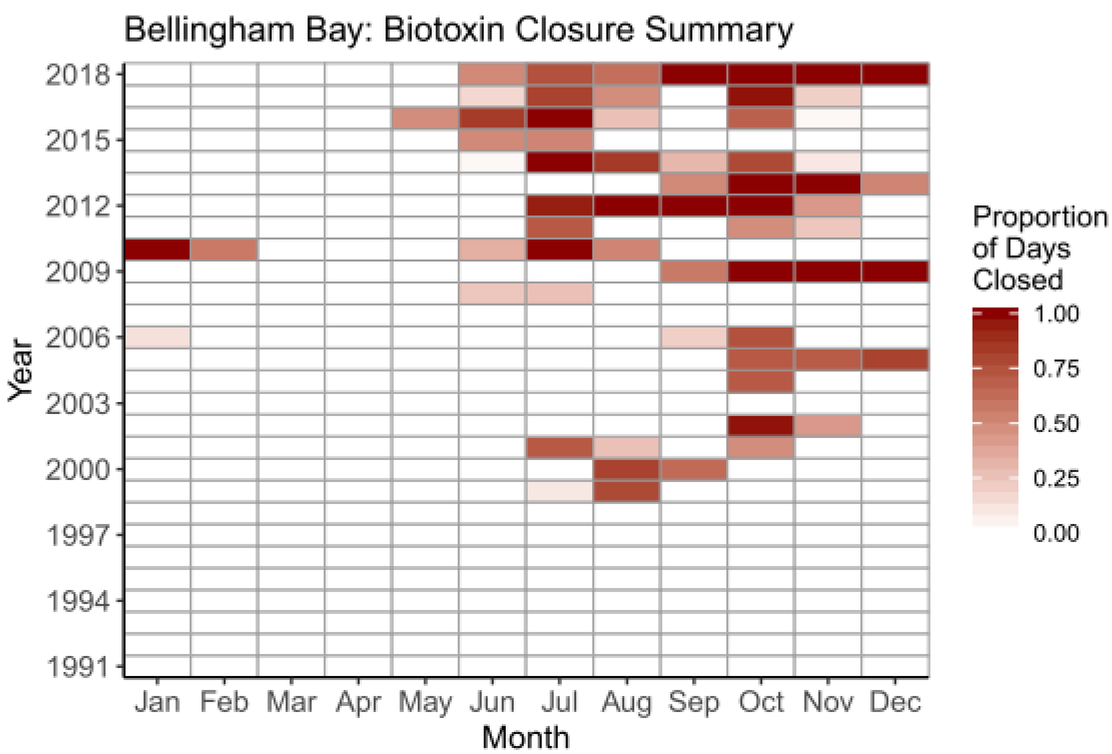

Figure 11. Proportion of days each month Bellingham Bay in Whatcom County, WA was closed to shellfish harvest due to elevated levels of biotoxins from 1991-2018.

October with an average of 67% and 69% of days closed to biotoxins those months while the months in between (i.e. August and September) had much lower average proportion of closure days (37% and 34%, respectively). This shows a bimodal pattern of peak closures observed during the summer and then again in fall regularly, supporting two separate HAB events annually.

In Birch Bay, biotoxin closures began in the spring (April – May) and carried into the fall (October – November) (Table 2, Fig 12). In the last 10 years, the peak proportion of closure days occurred in June and July with an average of 67% and 48%, respectively, of the days these months were closed for biotoxins. There were also considerable biotoxin closures in May (37%) and October (24%). Overall, biotoxin closures in Birch Bay have occurred from late spring into midsummer (May-July) with occasional fall closures. These October closures were due to an independent HAB event in the fall separate from any HAB event that may have occurred during the spring or summer evident by the break in biotoxin closures the preceding month. This supports an occasional bimodal pattern, the trend observed in Bellingham Bay.

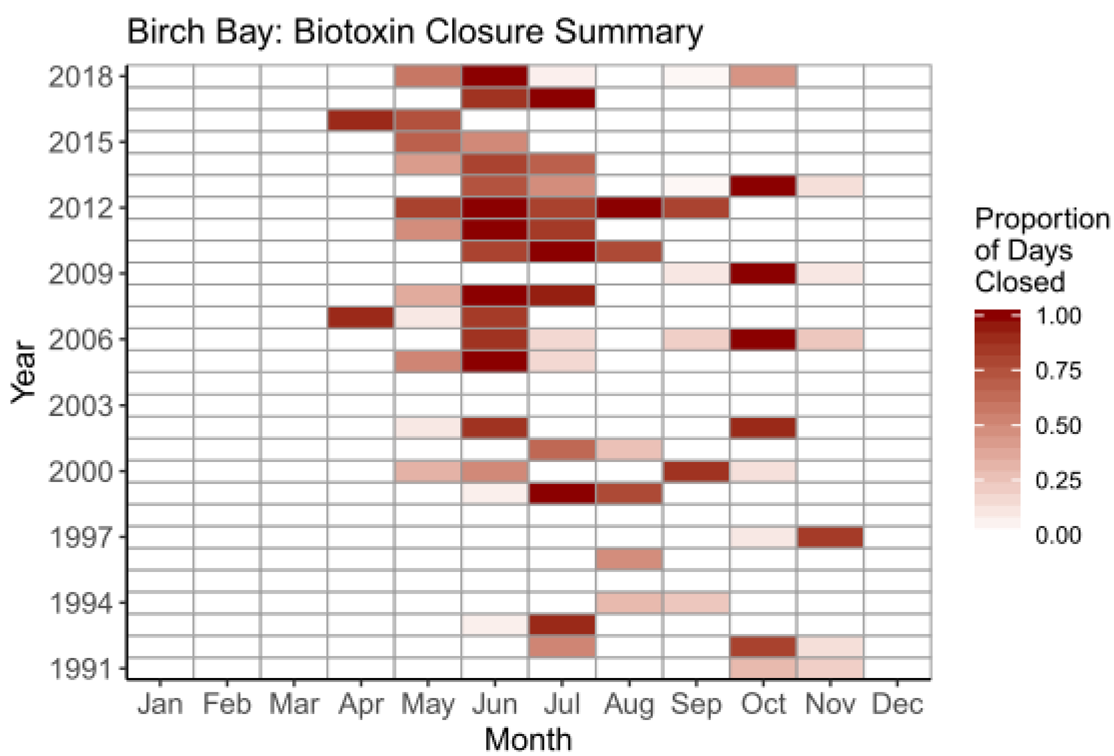

Figure 12**.** Proportion of days each month Birch Bay in Whatcom County, WA was closed to shellfish harvest due to elevated levels of biotoxins from 1991-2018.

In Drayton Harbor, biotoxin closures regularly occurred during the spring (March-May) through the fall (October – November) (Table 2, Fig 13). Within the last 10 years, peak proportion of closure days happened from May – July with an average of 43% (May), 57% (June), and 42% (July) of the days these months closed due to biotoxins. A smaller average proportion of peak closure days occurred in August and October with an average of 26% and 20% of the days closed these months, respectively. September had a much lower average percentage of closure days with only 5% closure days, and this very low closure day average between much higher average closures in August and October indicates the closures in October are the result of an independent bloom of harmful algae and accumulation of biotoxins in the fall, further supporting an occasional bimodal trend.

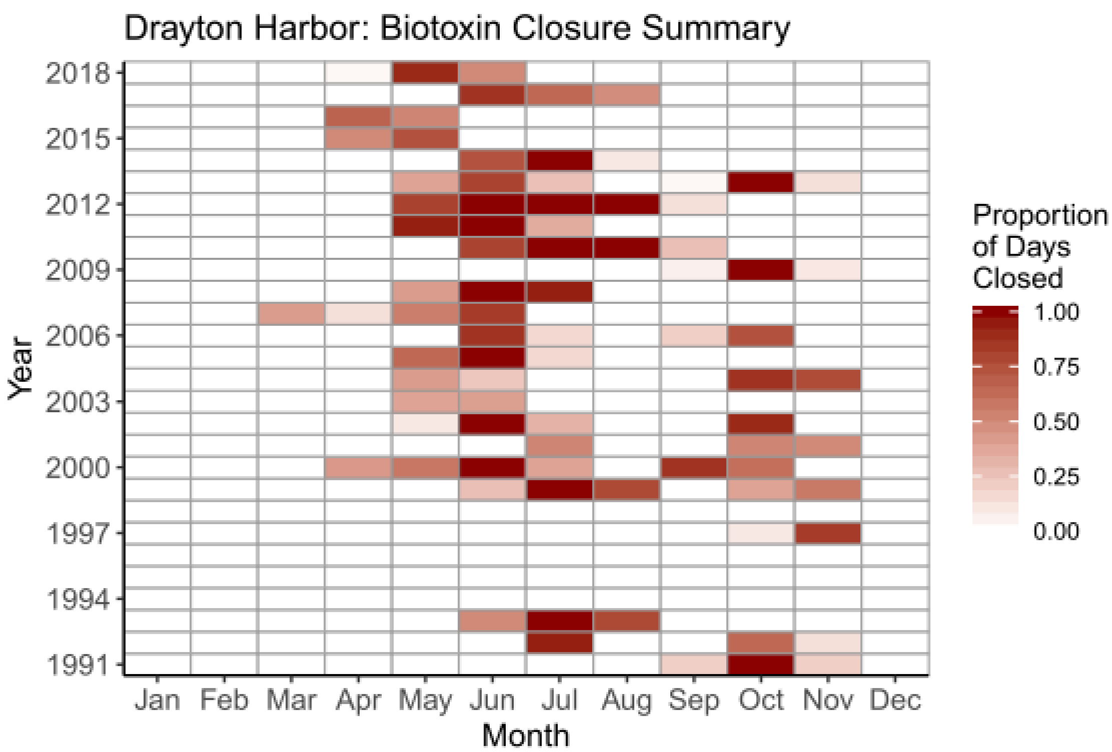

Figure 13. Proportion of days each month Drayton Harbor in Whatcom County, WA was closed to shellfish harvest due to elevated levels of biotoxins from 1991-2018.

Overall, the timing of biotoxin closures varied from year to year but a bimodal trend of HAB events occurring during the spring-summer and again in the fall was reoccurring in all bays. There were 3 general trends observed in the seasonality of biotoxin closures: 1) one relatively short closure in either the spring or the fall, 2) bimodal pattern with two clear closure seasons with one in the spring to summer and the second in the late summer to fall, and 3) one long relatively continuous closure season lasting from the spring into the fall. There were years where all three bays in Whatcom County followed the same general biotoxin closure pattern, such as in 2008 where all bays had a relatively short spring closure season or in 2012 where there was only one summer closure in each bay (Fig 11-13). However, even when all of these bays followed the same general biotoxin closure pattern the timing of these closures varied between bays (Fig 11-13). While in other years (see 2005, 2006, 2017, or 2018 for examples), the seasonal closure patterns were different for each bay and ranged through all three trends observed (Fig 11-13). The high variation in biotoxin closures annually and spatially between bays makes predicting the timing and length of future biotoxin closures incredibly difficult.

Discussion

Levels of biotoxins

Shellfish biotoxin toxicity has increased significantly within the last 10 years (2009-2018). In three of the last ten years, PSP toxins have been detected in levels three times greater than had been historically, far exceeding lethal levels. In fact, PSP toxins have been reaching levels of concern so frequently recently that it is becoming increasingly difficult to find areas to harvest shellfish that are safe for human consumption. New biotoxins have emerged, posing new health risks. Levels of DSP toxins have regularly exceeding levels of concern in Whatcom County since monitoring began in 2012. Moore et al. (2009) found no significant increase in severity or magnitude of PSP events in Puget Sound from between 1993 to 2007, but the increased severity of PSP detected locally began in 2008 and DSP appeared in 2012. Risk of biotoxins is relatively well mixed throughout the area where all bays have seen significant health risks from biotoxins. Thankfully, levels of domoic acid (ASP) toxins have not yet reached a threshold of health concern to cause a shellfish harvest closure in Whatcom County, although low levels of the toxin have been detected in shellfish.

Biotoxins closures

Shellfish harvest closures due to elevated biotoxin levels have undeniably increased in recent years. There has been an increase in total harvest closure days due to a combination of increased closure length, multiple closures in a year, and presence of multiple biotoxins that lead to closures. The appearance of DSP toxins has contributed to increased biotoxin closures; in fact in 2014 DSP was the only biotoxin exceeding regulatory limits in both Drayton Harbor and Portage Bay while PSP toxin levels remained low there. However, PSP toxins remain the primary biotoxin of concern causing harvest closures. Biotoxin closures have limited shellfish harvesting opportunities every year since 2008 (for the last 11 years) in all of the bays off the Lummi Reservation (biotoxin closures could not be determined for tidelands on the Reservation). There is an average increase of 2.4 closure days per year in Whatcom County, despite high variability with location and year. Shellfish harvesting opportunities have been obstructed for an average of 20% of the year due to biotoxin levels in the last 10 years. Moore et al. (2009) also found no robust evidence to suggest the frequency or duration of PSP events increased in Puget Sound between 1993 and 2007, however again much of the increase in biotoxin closures was observed after 2008 in Whatcom County.

Seasonality of biotoxin closures

Biotoxin closures generally occurred from May-October in Whatcom County which is consistent with patterns of HABs along the west coast driven by increased light availability and warmer waters during our spring-fall seasons. Along the west coast of North America, marine HABs generally occur from May – October (Horner et al 1997), and in Puget Sound, HABs normally occur from July – November with high variability between sites (Moore et al. 2009). All phytoplankton production increases, including harmful algae, in Washington State when the days are longer, when there is increased light availability, and when warmer temperatures occur during the spring to fall. There was high variability between years and bays but overall there was a reoccurring bimodal pattern of peak closure days with two separate HAB events triggering closures within the spring-fall season consistent with pervious patterns observed in this region (Moore et al. 2009). However, it is apparent that the seasonal window of HABs is increasing. Biotoxin closures have been occurring earlier and lasting later in recent years. Biotoxin closures have started as early as March, lasting through the winter into January and even February of the following year. Moore et al (2009) also found a significant trend of HAB triggered shellfish closures occurring earlier in the year from 1993-2007 throughout Puget Sound, which is consistent with the results in Whatcom County from 1991-2018.

Lummi Reservation tidelands

The most important tidelands for Lummi intertidal shellfish harvest are within the 7,000 acres of tidelands located on the Lummi Reservation (Kuhlman et al. 2016, Fig 2). These productive tidelands are owned and managed by the Lummi Nation, and 100% of the shellfish located on these tidelands are for tribal harvest exclusively, whereas treaty tribes have rights to harvest 50% of the harvestable biomass of shellfish on public and private tidelands. Portage Bay and Lummi Bay have >1,500 acres of actively managed tidelands for commercial shellfish harvest. Historically, shellfish samples were only periodically collected from these tidelands for biotoxins testing when shellfish from other bays in the region had elevated levels of biotoxins; therefore it was not possible to develop a full biotoxin closure history for beaches on the Lummi Reservation. To rectify this, the Lummi

Natural Resources Department (LNR) increased sampling frequency in spring of 2018 to better characterize HABs dynamics on the Lummi Reservation, and to accurately close beaches when testing suggested a localized health risk. Despite the irregular sampling effort on reservation beaches, there is still plenty of data to evaluate changes and comparisons to other bays in the region.

HAB dynamics can be highly localized and as a result, biotoxin levels often vary between shellfish collected in nearby bays. Even though Portage Bay is located in Bellingham Bay, and Lummi Bay is adjacent to Portage Bay, the levels of biotoxins in shellfish from these areas can vary significantly (Fig 2). For example, in 2013 shellfish in Portage Bay were more than twice as toxic as shellfish from Bellingham Bay, but in 2002 Bellingham Bay shellfish had 7 times as much PSP toxins as Portage Bay (Table 1). In both of these years no PSP toxins were detected from shellfish sampled in Lummi Bay (Table 1). Portage Bay shellfish frequently detected the highest levels of PSP toxins in the region whereas the highest levels of toxins have never been detected in shellfish from Lummi Bay (Table 1). Furthermore, levels of DSP toxins have never surpassed the closure level in Lummi Bay, while DSP exceed levels for health concerns in over 70% of the years tested in Portage Bay and every year in Bellingham Bay. Trends in biotoxin levels in Portage Bay reflect those in Bellingham Bay more closely than any of the other sampling locations due to their proximity and location (Fig 2).

Although biotoxin closure history was unattainable for Portage Bay, any biotoxin harvest closure for Bellingham Bay during these years would have likely extended into Portage Bay. This is because Portage Bay is located within Bellingham Bay (Fig 2), and the WADoH closure region for Bellingham Bay includes Portage Bay in the absence of sufficient shellfish sampling to prove shellfish were safe to consume in Portage Bay. Thus, the increase of approximately 4.2 closure days annually in Bellingham Bay can likely be extrapolated to increased closures in Portage Bay. In Portage Bay, biotoxin levels have surpassed levels of concern in over 80% of the years shellfish were tested, indicating harvest closures and health risks of consuming shellfish. It is important to note that Portage Bay tidelands have been regularly closed to harvest due to poor water quality, further increasing the health risk and limiting shellfish harvesting opportunities.

Lummi Bay has had significantly lower levels of biotoxins, signifying a lower health risk and fewer harvest closures. It is much harder to estimate past biotoxin closures for Lummi Bay, but anytime there were closures from all other regular biotoxin monitor sites (Bellingham Bay, Birch Bay, and Drayton Harbor) WaDOH would have issued a Whatcom county-wide closure, including Lummi Bay. Levels of PSP have consistently been lower in Lummi Bay than all other areas in Whatcom County. In fact, PSP toxin levels in shellfish have only surpassed the action level of human health concern that would lead to a closure in 22% of the years shellfish have been tested. Furthermore, since biotoxin monitoring became more regular in 1991 there have only been three years when biotoxin levels reached closure levels in Lummi Bay. Additionally, DSP toxins have never reached levels of concern and Domoic Acid (ASP toxin) has never been detected. The reason Lummi Bay has much lower biotoxin risk is unclear but could be linked to average currents and water flow patterns through Lummi Bay, nutrient inputs, and sources of harmful algae.

The majority of the actively managed tidelands on the Lummi Reservation are located in Lummi Bay. Over 1,200 acres of incredibly important tidelands for all shellfish harvesting are located in Lummi Bay. The tidelands in Lummi Bay produce the majority of the manila clams on the Reservation. For example, in 2018, 84% of the harvestable biomass of Manila clams on the Lummi Reservation came from Lummi Bay, providing the majority of the commercial harvesting opportunities (Hintz 2018). Therefore, if Lummi Bay continues to elude high biotoxin levels in shellfish it will become an even more important area for safe shellfish harvest in the future.

Climate change impacts on harmful algae

Climate change is predicted to increase harmful algae blooms in both frequency and severity. Phytoplankton dynamics will be influenced by changes in temperature, stratification, ocean acidification, increased nutrient inputs, and ecosystem wide changes (Wells et al. 2015). Temperature is one of the main environmental factors that affects phytoplankton physiology influencing growth, germination, motility, nutrient uptake, and many other physiological processes (Wells et al. 2015). Increased sea surface temperature will alter seasonal patterns and lengthen the windows of opportunity for growth, altering both species selection and population dynamics (Wells et al. 2015). Warmer temperatures will increase the toxicity of shellfish during a HAB event due to the synergistic effects of increased harmful algae abundance and increased feeding rates of shellfish, where feeding rates increase in warmer temperatures causing shellfish to consume more toxic algae, thus accumulating more toxins (Moore et al. 2010).

The surface of the ocean is projected to become increasingly more stratified with increased temperatures, glacial snow melt, and intense precipitation events (Wells et al. 2015, Moore 2008). Changes in the seasonality of peak river flows and precipitation will also alter the seasonality of stratification (Moore et al. 2008). Increased stratification will alter nutrient availability and create a competitive advantage for phytoplankton that can vertically migrate through the layers, and unfortunately many harmful algae species can flourish under well stratified conditions (Wells et al. 2015). Net increases in precipitation and intense precipitation events will increase and intensify episodes of high nutrient inputs into the coastal waters, increasing and altering phytoplankton communities (Wells et al. 2015). The combination of warm, stable, and nutrient rich conditions will likely favor harmful algae species blooms (Wells et al. 2015).

Ocean acidification may also play an important role in the changing phytoplankton communities. Changes in acidification and the available calcium carbonate structures may result in enhanced growth of certain species and/or inhibited growth of other calcifying species of phytoplankton (Moore et al 2008). Some harmful algae have been shown to produce more toxins under projected future ocean acidification conditions (Tatters et al. 2013). Therefore, this research suggests that harmful algae blooms of the same magnitude could be more toxic under future ocean conditions.

Along with climate change, continuous human population growth near costal habitats will exacerbate HAB. Population growth is increasing nutrient inputs and other anthropogenic stressors on the environment, which will in turn contribute to increase shellfish toxicity from HABs (Moore et al. 2010, Moore et al. 2011). Despite all of the unknowns, evidence from past ocean conditions strongly suggest future ocean conditions will favor a group of phytoplankton called dinoflagellates, which includes the most species of harmful algae (Moore et al 2008). It is important to note that temperature changes and other climate change impacts to the marine environment will cascade through the ecosystem, complicating predictions; therefore there is little understanding of what those changes will be and how they will affect phytoplankton and HAB dynamics (Wells et al. 2015).

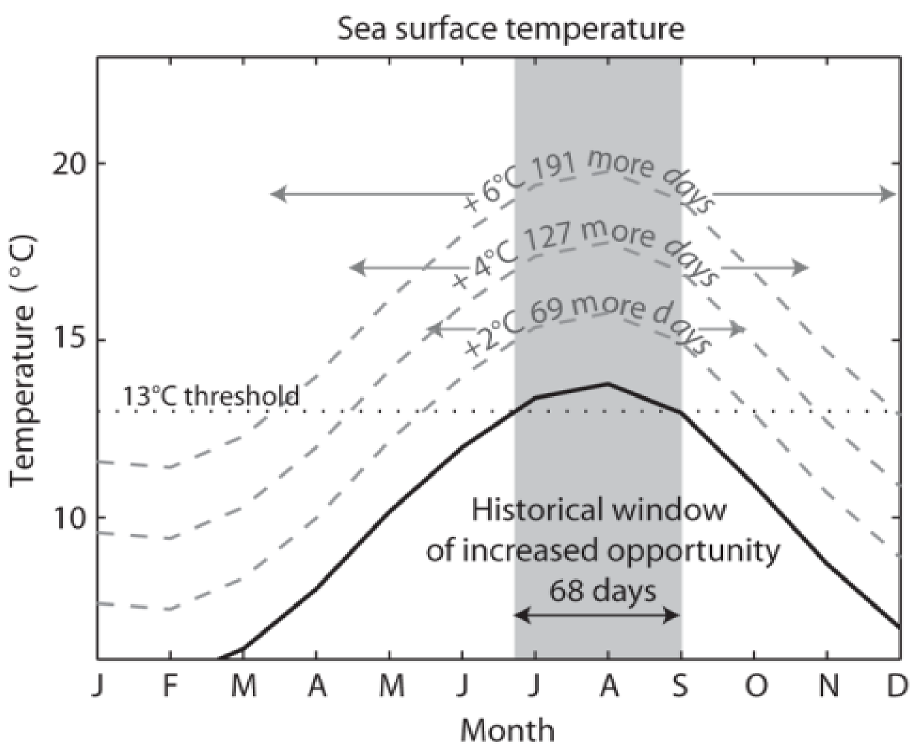

Figure 14. Potential impact of increasing sea surface temperatures on harmful algae blooms (HABs) in Puget Sound, WA (Moore et al. 2008)

Predicting future risks of HABs locally is challenging given the complexity of environmental changes and ecosystem- and species-specific responses. In Washington, sea surface temperatures are predicted to increase, the waters are predicted to become more stratified, the ocean is becoming increasingly acidic, and fresh water inputs into the marine environment are predicted to become more extreme and change in seasonality (Roop et al. 2020, Snover et al. 2013). Currently there are three harmful algae of concern in Puget Sound marine waters (*Alexandrium, Dinophysis*, and *Psuedo-nitzschia*) and future climate conditions will likely provide favorable conditions for all three of these harmful algae. By the end of this century, warmer sea surface temperatures in Puget Sound are expected to cause an average annual increase of 13 more days with favorable water temperatures to support HAB events (Fig 14; Roop et al. 2020; Moore et al. 2011). Additionally, the seasonal window for HAB events is predicted to be extended by three months, occurring two months earlier and one month later in the year than what has been seen in the past (1970-1999) (Moore et al 2011). Furthermore, the annual window for HAB growth is predicted to increase by over 70% of the year (259 days) when sea surface temperatures increase by 6° C in Puget Sound (Fig 14; Moore et al. 2008; Moore et al. 2011).

Warmer sea surface temperature is the strongest driver of increased *Alexandrium* blooms in Puget Sound, and largest increase in favorable HAB conditions is predicted to occur in Lummi's main shellfish harvest areas (Moore et al. 2015). Additionally, increased stratification in Puget Sound might indirectly favor all three of the harmful algae present locally. Swimming dinoflagellates, *Alexandrium* and *Dinophysis,* can vertically migrate to deeper nutrient rich waters unavailable to most phytoplankton (Moore et al. 2015; Moore et al. 2008), and although it is rare for stratified waters to favor diatoms, one exception is *Pseudo nitschia* (Wells et al. 2015). The collective impacts of climate change will provide more favorable conditions for harmful algae in Puget Sound. The increase in HABs is already evident in Lummi's main shellfish harvest areas as detailed in this report with increased toxicity, increased harvest closure days, and an extended season of HABs; and HAB events are only predicted to continue to increase under future climate conditions.

Species specific HAB risk

Complicating the current changes in marine environment are drastically different species-specific levels of biotoxins due to differences in the rate of toxin uptake, accumulation, and depuration between species of shellfish and harmful algae. Uptake of toxins depends on algae bloom dynamics, the clearance or feeding rate of the shellfish, and the sensitivity of that species of shellfish to the toxin (some species experience feeding inhibition when highly toxic algae are present) (Shumway et al. 2018). Mussel species for example uptake and depurate biotoxins faster than many other species of shellfish because they are indiscriminant feeders, insensitive to biotoxins, and have high clearance rates, i.e. they eat all types of phytoplankton fast (Shumway et al. 2018; Bricelj et al. 1990). For these reasons, blue mussels (*Mytilus edulis*) are often used as indicator or sentinel species to monitor potential health risks to humans. Some species of shellfish retain high levels of biotoxins for long periods of time. Locally, butter clams (*Saxidomus gigantean*), varnish clams (*Nuttallia obscurata*), and scallops (*Chlamys rubida* and *Chlamys hastate*) are known to retain high levels of PSP for months to years after initial accumulation (Shumway et al. 2018). Butter clams actually preferentially accumulate PSP toxins in the tip of their siphon which is believed to be a defense mechanism (Moore et al 2010; Shumway et al. 2018). Razor clams are slow detoxifiers of domoic acid (ASP) causing them to remain toxic long after a HAB event (Horner et al. 1997; Shumway et al. 2018). The size and age of shellfish can also influence the toxin depuration rate (Moore et al. 2010). Biotoxin levels can vary between species and individual shellfish, complicating harvest closures and communication to the public.

Although filter feeding shellfish are often the primary focus of HABs, other organisms can be affected by HABs via accumulation of biotoxins directly or indirectly, through consumption of toxin-laden organisms. Traditionally, filter feeding bivalves (such as, oysters, clams, and mussels) have been the focus of HAB biotoxin accumulation. Research now shows that many other marine organisms can accumulate toxins including gastropods (snails, limpets, and abalone), cephalopods (squid and octopus), crustaceans (crabs, shrimp, and lobsters), and echinoderms (sea urchins and sea cucumbers) (Shumway et al. 2018). Biotoxins can be transferred up the food chain transferred from one species to another. Some species have a high tolerance and experience minimal to no adverse impacts after the consumption of biotoxins such as many of the bivalve shellfish and crustaceans. Although these species do not experience adverse side effects from the toxins, they can transfer the toxins to organisms that consume them. Biotoxins can affect many species including humans, marine mammals, and birds where consuming high levels of biotoxins can cause severe symptoms and in extreme cases can be lethal (Shumway et al. 2018).

Fishery management implications

Coastal communities that depend on fisheries resources are particularly vulnerable to HAB events. Harvest closures can cause severe social, cultural, and economic disruptions. Closures lead to food insecurity from loss of subsistence harvesting and disruption of cultural practices and loss of community identity tied to resource use (Moore et al. 2019). Restricted access to fishery resources which are central to family gatherings, holidays, or traditions are not recoverable in the same way as economic losses (Moore et al. 2019). Economic loss associated with lost fishery landings can cause financial insecurity for families that rely on fishing income.

Estimating the economic impact of a HAB harvest closure is challenging because there are direct and indirect impacts to the producers (fishers, industries, harvesters) and the consumers (Shumway et al. 2018). It is impossible to quantify, especially in dollars, the lack of safe food available for harvest and the disruption of cultural practices. Despite challenges, attempts at estimating the economic impacts of HAB closures in the United States have ranged from $1 - $117 million dollars (Shumway et al. 2018). Locally, the 2015 West Coast-wide domoic acid event resulted in an estimated loss of $97.5 million in revenue from the commercial Dungeness crab fishery alone (NMFS 2015; Ritszman 2018). These largely focus on the economic loss to commercial fishery practices and rarely attempt to quantify any indirect impacts. For the Lummi Nation, the direct economic loss of a closed commercial fishery impacts both the fishers and tribal buyers.

Currently there are only a couple commercial fisheries Lummi participates in that have been susceptible to HAB closures, but many other fisheries have the potential to be impacted. Commercial fisheries for both Manila and geoduck clams have been limited due to elevated levels of biotins and require monitoring and testing of shellfish for biotoxin levels prior to any commercial harvest. Other fisheries could potentially be impacted by HAB events as well and require testing prior to fishery openings. Of particular concern is the Dungeness crab fishery, which has been the most valuable fishery for Lummi in recent years (Starkhouse 2017). Levels of PSP and domoic acid have been shown to accumulate to dangerous levels in Dungeness crab (Wright et al. 2012; Wekell and Trainer 2002**).** Within Washington State and along the west coast, the commercial Dungeness crab fishery has been significantly impacted by past domoic acid HAB events (Wekell and Trainer 2002; Moore et al. 2019). With the increase and spread of HABs, there is a real concern that harmful algae producing domoic acid could become a threat locally in the future, with serious implications for the Dungeness crab fishery. Additionally, recent research has shown other marine organisms can accumulate biotoxins, including many species that are important in Lummi commercial fisheries such as shrimp, sea urchins, and sea cucumbers (Starkhouse 2017).

Intertidal shellfish harvest implications

Harmful algae have presented a significant threat to human health and have limited safe shellfish harvesting opportunities locally for at least the last four decades. Harvest closures have unquestionably increased in recent years and are predicted to continue to increase with climate change, further reducing harvesting opportunities in the future. Not only will HABs reduce safe shellfish harvesting opportunities, but more frequent severe HAB events might cause declines in shellfish population. Harmful algae blooms can adversely affect the physiology of bivalve shellfish and have major impacts on reproduction, linked to reproductive and recruitment failure (Shumway et al. 2018). Additionally, recent mass shellfish mortality events in Puget Sound are thought to have been caused by a harmful species of phytoplankton that has been shown to be toxic to shellfish (WDFW 2019). Reduced abundance of intertidal shellfish would additionally limit shellfish harvesting opportunities.

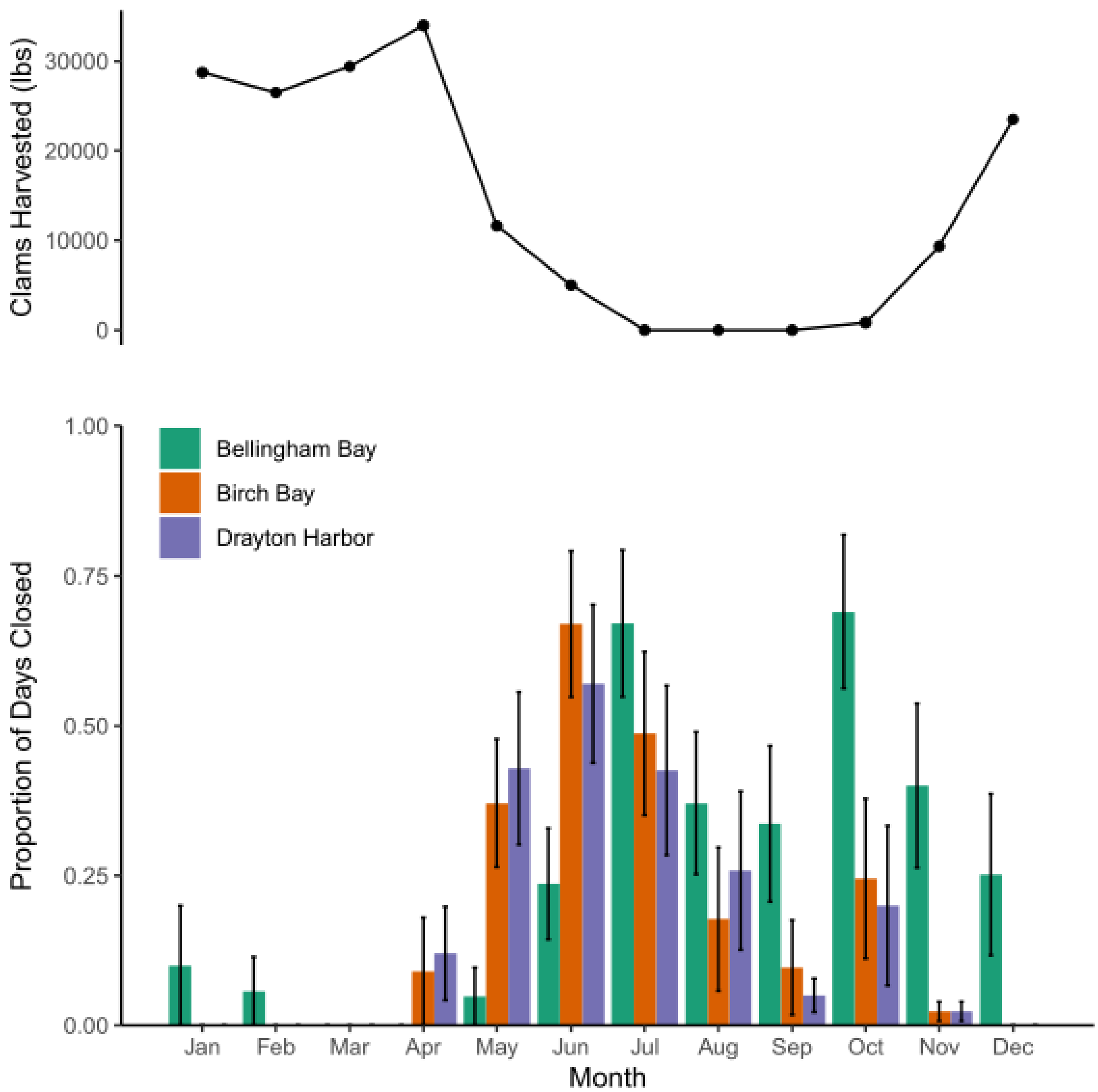

Figure 15. The seasonality of commercial shellfish harvest and biotoxin closures represented as the 10 year average (2009-2018) of commercial Manila clam harvest (landings) by month compared to the average proportion of biotoxin closure days per month.

The change in seasonality and timing of biotoxin closures will influence how the harvest closures impact the Lummi community. Any harvest closure has the potential to limit all shellfish harvesting, but the seasonality dictates which type of harvest is most significantly impacted. Intertidal shellfish are only harvestable during low tides and the time of day of harvestable low tides changes with the seasons. From April-September harvestable low tides occur during daytime making access to shellfish easier, whereas from October-March harvestable low tides occur during the night. The majority of biotoxin harvest closures occur during daytime low tides most significantly impacting Lummi tribal member's ability to safely harvest shellfish from ceremonial and subsistence purposes during easily accessible tides.

Intertidal shellfish resources also support an important commercial fishery of Manila clams. The commercial fishery primarily operates during the winter nighttime tides when HAB risk is low; therefore any biotoxin closure during these months would significantly impact and reduce commercial fishing opportunities. Biotoxin closures in the spring are one of the primary reasons the commercial fishery ends by May (Fig 15), however biotoxin closures have been occurring earlier in the spring which will end the commercial fishing season early. The expanding biotoxin season will shorten the commercial fishery with closures extending into the winter months and occurring earlier in the spring, significantly impacting commercial harvesting opportunities.

This work has highlighted that health risks of harvesting shellfish due to harmful algae have increased and are projected to continue to increase due to climate change. Many local environmental factors control HAB dynamics creating high variability in biotoxin risk annually and spatially. Therefore, it is paramount to regularly sample shellfish from important tidelands for biotoxin levels and close tidelands to shellfish harvest when there is a health risk.

Conclusion

The health risk associated with marine HABs has undeniably increased in Lummi Nation's main shellfish harvesting areas. In recent years, new biotoxins have emerged, biotoxins have increased in toxicity, and biotoxin closures are lasting longer. The increased health risk from biotoxins is limiting safe shellfish harvest opportunities for subsistence, ceremonial, and commercial purposes. New biotoxins with different health risks, along with PSP toxins repeatedly surpassing potentially lethal levels, has redefined the health risks of harvesting shellfish. Shellfish harvesting opportunities have been obstructed 20% of the year on average due to biotoxins from harmful algae. The window of HAB risk has been increasing with closures occurring earlier in the spring and lasting into the winter. The biotoxin closure season extending into the winter months will significantly limit commercial clam harvesting opportunities. The high annual and spatial variability in closures and complex environmental conditions that favor HAB events make predicting future closures impossible. Therefore, it is important to sample important tidelands regularly to protect people from shellfish with high levels of biotoxins and maximize safe shellfish harvesting opportunities.

Acknowledgments

We thank the Washington State Department of Health for providing the shellfish toxicity data. Specifically, we thank Jerry Borchert and Audrey Coyne for compiling the data used in this research and all of the staff throughout the years who have contributed to the sampling of shellfish and testing in the lab. Special thanks to Ben Starkhouse, Karl Muller, and Rachel Dalthorp for providing highly valued comments and feedback. This work was funded by the Unite State Department of Interior Bureau of Indian Affairs, with a 2017 Rights Protection Implementation – Climate Change grant. Additional support was provided by the Salish Sea Research Center at Northwest Indian College.

Cited References

Association of Official Analytical Chemists. 1990. Paralytic shellfish poison biological method. In: Horowitz, W. (Ed.), Official methods of analysis. Association of Official Analytical Chemists, Inc., Washington, D.C., pp. 881–882.

Bricelj VM, Lee JH, Cembella AD, Anderson DM. 1990. Uptake kinetics of paralytic shellfish toxins from the dinoflagellate Alexandrium fundyense in the mussel Mytilus edulis. Marine Ecology progress Series. 63. 177-188. 10.3354/meps063177

US Food and Drug Administration (F.D.A.). Fish and Fishery Products Hazards and Controls Guidance, Appendix 5: FDA and EPA Safety Levels in Regulations and Guidance, Department of Health and Human Services, Public Health Service, Food and Drug Administration, Center for Food Safety and Applied Nutrition, Office of Food Safety, 2019.

Hintz M. 2018. 2018 Lummi Clam Survey Summary. Technical Report. Lummi Natural Resources Department. Bellingham, WA.

Horner RA, Garrison DL, Plumley FG. 1997. Harmful algal blooms and red tide problems on the U.S. west coast. Limnology and Oceanography. 42:1076–1088. doi:10.4319/lo.1997.42.5_part_2.1076.

Kuhlman, K., J. Freimund, and G. Gabrisch. 2016. Lummi Nation Climate Change Mitigation and Adaptation Plan: 2016–2026. Technical report prepared for the Lummi Indian Business Council under USEPA Assistance Agreement No. BG–97042602–4. Pp. 149.

Lewitus AJ, Horner RA, Caron DA, Garcia-Mendoza E, Hickey BM, Hunter M, Huppert DD, Kudela RM, Langlois GW, Largier JL, et al. 2012. Harmful algal blooms along the North American west coast region: History, trends, causes, and impacts. Harmful Algae. 19:133–159. doi:10.1016/j.hal.2012.06.009.

Moore SK, Trainer VL, Mantua NJ, Parker MS, Laws EA, Backer LC, Fleming LE. 2008. Impacts of climate variability and future climate change on harmful algal blooms and human health. Environmental Health. 7(Suppl 2):S4. doi:10.1186/1476-069X-7-S2-S4.

Moore SK, Mantua NJ, Hickey BM, Trainer VL. 2009. Recent trends in paralytic shellfish toxins in Puget Sound, relationships to climate, and capacity for prediction of toxic events. Harmful Algae. 8(3):463–477. doi:10.1016/j.hal.2008.10.003.

Moore SK, Mantua NJ, Hickey BM, Trainer VL. 2010. The relative influences of El Niño-Southern Oscillation and Pacific Decadal Oscillation on paralytic shellfish toxin accumulation in northwest Pacific shellfish. Limnology and Oceanography. 55(6):2262–2274. doi:10.4319/lo.2010.55.6.2262.

Moore SK, Mantua NJ, Salathé EP. 2011. Past trends and future scenarios for environmental conditions favoring the accumulation of paralytic shellfish toxins in Puget Sound shellfish. Harmful Algae. 10(5):521–529. doi:10.1016/j.hal.2011.04.004.

Moore SK, Johnstone JA, Banas NS, Salathé EP. 2015. Present-day and future climate pathways affecting Alexandrium blooms in Puget Sound, WA, USA. Harmful Algae. 48:1–11. doi:10.1016/j.hal.2015.06.008.

Moore SK, Cline MR, Blair K, Klinger T, Varney A, Norman K. 2019. An index of fisheries closures due to harmful algal blooms and a framework for identifying vulnerable fishing communities on the U.S. West Coast. Marine Policy. 110:103543. doi:10.1016/j.marpol.2019.103543.

National Marine Fisheries Service (NMFS). 2016. Fisheries of the United States, 2015. NOAA Current Fishery Statistics No. 2015. Available at: U.S. Department of Commerce. http://www.st.nmfs.noaa.gov/commercial-fisheries/fus/fus15/index.

Wekell JC, Trainer VL. 2002. Harmful algal blooms and their impacts on West Coast Tribes. Red Tides Newsletter, 3rd ed. Autumn 2002.

Ritzman J, Brodbeck A, Brostrom S, McGrew S, Dreyer S, Klinger T, Moore SK. 2018. Economic and sociocultural impacts of fisheries closures in two fishing-dependent communities following the massive 2015 U.S. West Coast harmful algal bloom. Harmful Algae. 80:35–45. doi:10.1016/j.hal.2018.09.002.

Roop HA, Maugerc GC, Morgan H, Snover AK, Krosby M, 2020. "Shifting Snowlines and Shorelines: The Intergovernmental Panel on Climate Change's Special Report on the Ocean and Cryosphere and Implications for Washington State." Briefing paper prepared by the Climate Impacts Group, University of Washington, Seattle. Updated 01/2020.

Shumway SE, Burkholder JM, Morton SL. 2018. Harmful algal blooms: a compendium desk reference. Hoboken, NJ: Wiley Blackwell.

Snover AK, Mauger GS, Whitely Binder LC, Krosby M, Tohver I. 2013. Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle.

Starkhouse, B. 2017. Harvest Management Annual Report. Technical Report. Lummi Natural Resources Department, Bellingham, WA. Pp. 64.

Tatters AO, Flewelling LJ, Fu F, Granholm AA, Hutchins DA. 2013. High CO2 promotes the production of paralytic shellfish poisoning toxins by Alexandrium catenella from Southern California waters. Harmful Algae. 30:37–43. doi:10.1016/j.hal.2013.08.007.

Trainer VL, Eberhart B-TL, Wekell JC, Adams NG, Hanson L, Cox F, Dowell J. Paralytic shellfish toxins in Puget Sound, Washington State. Journal of Shellfish Research. 22(1):213-223

Trainer VL, Moore L, Bill BD, Adams NG, Harrington N, Borchert J, da Silva DAM, Eberhart B-TL. 2013. Diarrhetic Shellfish Toxins and Other Lipophilic Toxins of Human Health Concern in Washington State. Mar Drugs. 11(6):1815–1835. doi:10.3390/md11061815.

[WDFW] The Washington Department of Fish and Wildlife [Internet]. 2019 Aug 19. What's been causing mass shellfish Die-offs around Puget sound? [accessed 2020 Jan 17]. https://wdfw.medium.com/whats-been-causing-mass-shellfish-die-offs-around-puget-sound-1ada7071a242

Wells ML, Trainer VL, Smayda TJ, Karlson BSO, Trick CG, Kudela RM, Ishikawa A, Bernard S, Wulff A, Anderson DM, et al. 2015. Harmful algal blooms and climate change: Learning from the past and present to forecast the future. Harmful Algae. 49:68–93. doi:10.1016/j.hal.2015.07.009.

Wright BA, Donat E, RaLonde, R. 2012. Life-threatening risk from paralytic shellfish poisoning in Dungeness crab in Southeast Alaska. Environment Alaska [Internet]. [accessed 2020 March 1]. http://environmentalaska.us/psp-in-dungeness-crab.html

Appendix A. Biotoxin closure tables

Table A.1. Bellingham Bay approximate biotoxin closures

Year	Start Date	End Date	Length (days)
1999	7/29	8/24	26
2000	8/7	9/19	43
2001	7/10	8/8	29
2001	10/1	10/15	14
2002	10/2	11/13	42
2004	10/5	10/26	21
2005	10/10	11/21	42
2005	12/7	1/4	28
2006	9/25	10/23	28
2008	6/24	7/8	14
2009	9/14	2/16	155
2010	6/21	8/16	56
2011	7/5	7/26	21
2011	10/17	11/7	21
2012	7/3	11/13	133
2013	9/16	12/16	91
2014	6/30	8/26	57
2014	9/22	10/6	14
2014	10/14	11/3	20
2015	6/8	6/22	14
2015	7/6	7/21	15
2016	5/2	5/16	14
2016	6/6	8/8	63
2016	10/11	11/1	21
2017	6/26	7/24	28
2017	7/31	8/15	15
2017	10/2	11/6	35
2018	6/4	6/18	14
2018	7/9	8/14	36
2018	8/27	1/2	128

Table A.2. Birch Bay approximated biotoxin closures

Year	Start Date	End Date	Length (days)
1991	10/23	11/6	14
1992	7/14	7/29	15
1992	10/7	11/4	28
1993	6/29	7/28	29
1994	8/23	9/7	15
1996	8/14	8/28	14
1997	10/29	11/25	27
1999	6/29	8/24	56
2000	5/22	6/15	24
2000	9/5	10/4	29
2001	7/12	8/8	27
2002	5/29	6/26	28
2002	10/2	10/29	27
2005	5/16	7/5	50
2006	6/5	7/5	30
2006	9/25	11/7	43
2007	4/4	4/30	26
2007	5/29	6/25	27
2008	5/21	7/29	69
2009	9/28	11/3	36
2010	6/7	8/24	78
2011	5/17	7/26	70
2012	5/7	7/23	77
2012	7/30	9/24	56
2013	6/3	6/24	21
2013	7/8	7/22	14
2013	9/30	11/4	35
2014	5/19	6/2	14
2014	6/9	7/21	42
2015	5/4	5/18	14
2015	5/26	6/15	20
2016	4/4	5/23	49
2017	6/5	7/31	56
2018	5/14	7/2	49
2018	9/30	10/14	14

Table A.3. Drayton Harbor approximated biotoxin closures

Year	Start Date	End Date	Length (days)
1991	9/25	11/6	42
1992	7/1	7/29	28
1992	10/12	11/4	23
1993	6/16	8/24	69
1997	10/29	11/25	27
1999	6/23	8/24	62
1999	10/20	11/17	28
2000	4/18	5/4	16
2000	5/18	7/12	55
2000	9/5	10/19	44
2001	7/10	7/25	15
2001	10/16	10/31	15
2001	11/15	11/29	14
2002	5/29	7/10	42
2002	10/2	10/29	27
2003	5/20	6/12	23
2004	5/19	6/7	19
2004	10/5	11/23	49
2005	5/12	7/5	54
2006	6/5	7/5	30
2006	9/25	10/23	28
2007	3/19	4/4	16
2007	5/15	6/25	41
2008	5/19	7/29	71
2009	9/29	11/3	35
2010	6/7	9/8	93
2011	5/3	7/11	69
2012	5/7	9/4	120
2013	5/20	6/17	28
2013	6/24	7/8	14
2013	9/30	11/4	35
2014	6/9	8/3	55
2015	4/13	4/27	14
2015	5/4	5/26	22
2016	4/4	4/18	14
2016	4/26	5/16	20
2017	6/5	7/19	44
2017	7/31	8/15	15
2018	4/30	5/28	28
2018	6/4	6/18	14

Appendix B. Annual number of biotoxin monitoring tests in different species of shellfish used in the analysis (year 1953-1993). (1 of 2)

	Blue Mussel	Butter Clam	Pacific Oyster	Manila Clam	Littleneck Clam	Varnish Clam	Dungeness Crab	Cockle	Other
1957	--	2	1	--	--	--	--	1	--
1958	--	--	4	--	--	--	--	--	--
1968	--	2	--	--	--	--	--	2	1
1970	--	2	--	--	--	--	--	--	--
1971	--	2	--	--	--	--	--	1	1
1973	1	8	4	--	2	--	--	--	1
1974	1	31	3	--	2	--	--	1	--
1975	1	45	12	--	1	--	--	--	--
1976	--	52	15	--	3	--	--	--	2
1977	--	28	14	--	2	--	--	2	--
1978	4	59	13	--	5	--	--	1	1
1979	--	54	23	--	1	--	--	1	--
1980	--	76	28	--	3	--	2	1	3
1981	--	46	13	--	4	--	--	--	3
1982	--	23	13	--	2	--	1	--	--
1983	--	15	8	--	6	--	--	--	--
1984	11	17	13	--	9	--	--	--	1
1985	--	14	10	--	13	--	--	--	--
1986	2	20	14	--	16	--	--	1	2
1987	--	11	5	--	10	--	--	--	--
1988	--	13	12	8	22	--	--	--	--
1989	1	18	16	4	6	--	--	--	--
1990	--	7	13	7	18	--	--	--	1
1991	43	7	24	16	13	--	--	--	1
1992	54	6	32	29	14	--	6	--	--
1993	52	3	26	19	12	--	15	--	--

Appendix B. Annual number of biotoxin monitoring tests in different species of shellfish used in the analysis (year 1994-2018). (2 of 2)

	Blue Mussel	Butter Clam	Pacific Oyster	Manila Clam	Littleneck Clam	Varnish Clam	Dungeness Crab	Cockle	Other
1994	51	14	13	28	6	--	--	--	1
1995	53	16	13	25	6	--	--	--	--
1996	46	25	3	27	9	--	--	--	--
1997	47	10	--	18	12	--	--	--	--
1998	70	7	--	15	7	--	--	--	1
1999	86	4	--	9	6	--	--	--	1
2000	84	13	2	25	16	--	--	--	--
2001	87	17	2	15	14	--	--	--	--
2002	83	11	5	19	14	--	--	--	2
2003	84	8	2	20	3	--	--	--	--
2004	82	3	7	13	2	--	--	--	--
2005	92	9	15	17	4	--	--	3	--
2006	89	5	9	15	1	--	--	--	1
2007	89	5	8	10	--	--	--	--	--
2008	95	5	3	12	--	--	--	--	2
2009	95	5	9	15	1	--	--	1	2
2010	122	21	5	23	5	5	--	3	3
2011	116	14	11	19	2	61	--	--	1
2012	133	16	19	16	3	19	--	--	5
2013	136	6	13	10	6	15	--	2	1
2014	129	6	21	10	--	8	--	--	--
2015	132	1	24	17	--	--	--	1	1
2016	140	--	19	25	--	3	--	--	1
2017	120	5	18	10	2	3	--	--	--
2018	171	2	14	10	1	--	--	--	1
ALL	**170**	**561**	**316**	**83**	**164**	**0**	**24**	**11**	**17**