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Tracking Trouble: Spatial and Temporal Distribution of Potentially Harmful Algae Species in Clayoquot Sound, BC

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Tracking Trouble: Spatial and Temporal Distribution of Potentially Harmful Algae Species in Clayoquot Sound, BC

Cover Page Footnote

Special thanks to Dr. Cheryl Greengrove and Julie Masura for mentorship and for providing this opportunity, and Mikayla Mayes for being my class and research buddy over the past four years and throughout this project. Thank you to Clayoquot Biosphere Trust for funding boat time on the R/V Beach Hopper and Captain Toby Theriault for taking us sampling. The UWT Mary Cline award for funding the rental of an SUV that provided transportation to the sampling site in Tofino, BC Canada. The Ahousaht First Nation and the Maaqutusiis Hahoulthee Stewardship Society for allowing us to sample in their territorial waters.

Abstract

Algal species, such as *Alexandrium* spp., *Pseudo-nitzschia* spp. and *Dinophysis* spp., are known to cause harmful blooms (HABs), where toxins accumulate in bivalves and can lead to paralytic, amnesic, and diarrhetic shellfish poisoning, respectively, in humans. These blooms disrupt aquaculture industries and can cause significant economic losses. Additionally, some harmful algae may damage marine animals, including causing fish kills, and disrupt trophic interactions, threatening overall ecosystem stability. Increasing frequency and severity of blooms have been correlated with higher nutrient loads and may also be influenced by changing water properties, such as temperature. Since 2001, researchers at the University of Washington Tacoma have collected late summer/early fall water property data in Clayoquot Sound, with phytoplankton sampling added beginning in 2006. Phytoplankton samples from vertical net tows and discrete water samples collected at 1m and 10m were analyzed taxonomically to quantify species' presence and concentrations. This study investigates the spatial and temporal distribution of select potentially harmful algal species in Clayoquot Sound to assess their prevalence and potential risks to human health, aquaculture, and local economies. We compiled and mapped distribution patterns of the three target species and evaluated changes over the past 18 years, comparing findings with historical data from Department of Fisheries and Oceans Canada. We hypothesize that HABs will become increasingly prevalent as water temperatures rise, as warmer conditions can enhance algal growth rates and extend bloom seasons. The results will support future monitoring and management strategies to mitigate HAB impacts.

Keywords: toxic algae, HABs, phytoplankton, harmful algal blooms, water quality

Introduction

Harmful algal blooms (HABs) can pose serious threats to marine ecosystems, human health, and coastal economies (Glibert et al. 2005; McKenzie et al. 2021). (When some microscopic algae species accumulate, they can be harmful due to their sheer biomass, or some are harmful due to their physical shape that mechanically impacts other organisms, and some are harmful because they produce toxins (Glibert et al. 2005). In British Columbia, Canada, outbreaks of harmful algae have led to significant closures of shellfish harvesting due to the accumulation of biotoxins from toxic algae that cause paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), and diarrhetic shellfish poisoning (DSP) (Taylor and Harrison 2002). These species can impact not only human food safety but also aquaculture infrastructure, fisheries, and the broader food web (McKenzie et al. 2021).

Clayoquot Sound in British Columbia is a glacially carved, fjord-like system with narrow inlets, shallow sills (sea floor barrier that restricts water movement), and estuarine circulation patterns that make it particularly sensitive to bloom formation and retention (Pickard 1963). Since 2001, researchers from the University of Washington Tacoma (UWT) have monitored water column properties in the region, and phytoplankton sampling was added in 2006. This study builds on those efforts by adding the 2023 field season data and analyzing phytoplankton data from 2006-2023 and historical data from Fisheries and Oceans Canada to determine whether specific HAB species have become more frequent and moved over time. This is the first time these data have been used to map the spatial and temporal distribution of HABs in Clayoquot Sound.

The central hypothesis of this study is that rising sea surface temperatures, as a result of climate change, would increase the temporal extent and change the spatial extent of three target harmful algae taxa, *Alexandrium* spp., *Dinophysis* spp., and *Pseudo-nitzschia* spp. in the region. Understanding these dynamics is essential to supporting mitigation strategies for aquaculture operations and community health.

Methods

Since the inception of this project in 2001, water property surveys have been conducted annually in early September in Clayoquot Sound. The region is composed of a complex network of fjord-like inlets and islands, so sampling stations were distributed across all five inlets within Clayoquot Sound (Fig. 1). A subset of these stations was selected to collect discrete water samples for nutrients and phytoplankton. Before 2016, data collection was done off the R/V Barnes, a 65-foot research vessel, and since 2015, sample collection has been done off small boats. Environmental and biological data were collected in early September annually. At each station, vertical profiles of water column conditions were obtained using a Seabird Conductivity-Temperature-Depth (CTD) profiler. The R/V Barnes was equipped with a CTD-Rossette sampling package with multiple Niskin bottles attached to the CTD, and a Seabird 19 CTD and water sample bottles were used to sample off the small boats. The CTD recorded multiple parameters, including conductivity, temperature, depth, salinity, density, dissolved oxygen, fluorescence, and transmissivity. These measurements were used to assess physical and biogeochemical water properties and to help identify stratification layers and thermocline depth. Data analysis required the creation of R code to obtain surface

(0-10m average) temperature information from CTD data collected by UWT researchers from 2013 to 2023, where temperature data were readily available.

Phytoplankton sampling was carried out using two approaches. Vertical 10m net tows were conducted with a 20-micron mesh plankton net to collect qualitative samples of the phytoplankton community. In addition, discrete water samples were collected using a Niskin bottle on a rosette on the R/V Barnes or a Niskin and a Scotty bottle, used for discrete water samples, on a line for small boat work. Three depths were regularly sampled: surface (approximately one meter), thermocline (approximately ten meters), and near-bottom. These discrete water samples were used to take nutrient and phytoplankton samples and were kept cold on ice until back on land to preserve sample integrity.

Once on land, all phytoplankton samples were fixed with formalin to preserve cellular integrity for microscopy. Quantitative phytoplankton analysis was performed using samples collected at the surface and thermocline depths. Cells were counted using a 0.1 mL Palmer-Maloney chamber at 200x magnification under an Olympus BX compound microscope. Species identification was conducted at a minimum to the genus level, and to the species level when identification was certain. Net tow samples were analyzed in the same way; however, since net tow sampling concentrates the phytoplankton, the concentration of phytoplankton cells per liter could not be calculated, so they were used to assess an “inventory” of phytoplankton species present in the first 10m of the water column.

For nutrient analysis, a portion of each discrete water sample was filtered through a 0.45-micron membrane filter. The filtered samples were frozen and

transported to the University of Washington Seattle Marine Chemistry Laboratory for further analysis. Nutrient concentrations were not included in the primary data analysis for this paper but were collected as part of a broader effort to assess environmental conditions influencing bloom development.

Historical data used for temporal comparisons were obtained from the Department of Fisheries and Oceans Canada (DFO) reports covering the years 1999 to 2003. The data was originally archived on microfiche and was available through the University of Washington Seattle library. With assistance from the librarian, files were obtained of the scanned data in portable document format. The PDFs were converted into digital spreadsheets for data analysis using R code. These records included qualitative and quantitative phytoplankton observations from multiple inlets within and near Clayoquot Sound. To ensure consistency, only historical data collected during early September was used for comparative analysis, and the historical locations were matched to the closest available UWT stations. The historic data also included sampling during multiple months through late spring to late fall yearly from 1999-2003. This enabled the addition of analysis of historic seasonal trend data.

Results

Analysis of phytoplankton samples collected from 2006 to 2023 qualitatively revealed varying spatial and temporal patterns for the three target harmful algal taxa: *Alexandrium* spp., *Pseudo-nitzschia* spp., and *Dinophysis* spp. In general, phytoplankton presence and distribution differed across inlets, sampling depths, and years (Table. 1). Patterns were qualitatively compared with surface water temperature

for the period of 2013 to 2023 as well as historical data from DFO surveys conducted between 1999 and 2003.

Alexandrium spp. were detected primarily in Bedwell Sound, Herbert Inlet, and Miller Channel, with comparatively lower abundance in Tofino Inlet. Qualitative analysis of samples from the net tow indicated a persistent but localized presence of *Alexandrium*, especially in regions with limited circulation (Fig. 2). Temporal comparison with historical datasets suggests a modest increase in frequency during 2019 and again in 2023 (Fig. 2).

Pseudo-nitzschia spp. displayed an increase in spatial extent and frequency. Samples from 2023 demonstrated high concentrations of *Pseudo-nitzschia* in southern inlets, particularly Tofino Inlet and Bedwell Sound (Fig. 3). The genus was found at all sampling depths. This observation is consistent with recent studies suggesting an increase in *Pseudo-nitzschia* occurrence and toxicity under conditions of warming and nutrient enrichment (Lundholm et al. 2010; McKenzie et al. 2021). The dataset reveals that in earlier years, *Pseudo-nitzschia* was more commonly observed in northern inlets, such as Shelter and Sydney, indicating a notable southward shift in distribution over time (Fig. 3).

Dinophysis spp. were present in a subset of samples, with the highest frequency recorded in 2007, 2018, and 2023 (Fig. 4). Current detections were most frequent in Bedwell Sound and Tofino Inlet. Overall cell concentrations remained low. Their recurrence over time indicates an episodic yet persistent presence in the region. These findings support prior work noting that *Dinophysis* events in British Columbia are less common but may be increasing in frequency (McKenzie et al. 2021). Additionally,

qualitative visual analysis indicated that *Dinophysis* spp. presence shifted southward over time with decreasing frequency in the northern inlets (Fig. 4).

Environmental data collected concurrently with biological samples indicated some variability in sea surface temperature. Average temperatures in the upper 10 meters ranged between 14.5°C and 15.6°C in 2023 (Figs. 2-4). While this represents a slight increase compared to earlier years, no strong correlation was found between temperature and the abundance of the three target taxa. This is consistent with recent reviews that highlight variability in species-specific responses to warming (Brandenburg et al. 2019a). Notably, regions with higher phytoplankton abundance did not consistently coincide with areas of elevated temperature (Figs. 2-4).

Qualitative analysis of historic DOF data suggests distinct seasonal peaks among the three target taxa. *Dinophysis* spp., *Alexandrium* spp., and *Pseudo-nitzschia* spp. exhibited similar maxima being in the warmer months. However, there were clear variations in magnitude and timing (Figs. 5-10). The timing of the diatom *Pseudo-nitzschia* spp. tends to bloom earlier in the summer (June to August), while the two dinoflagellates, *Dinophysis* spp. and *Alexandrium* spp., peak towards the fall (July to October) as expected since dinoflagellates tend to be more prevalent in fall blooms due to their ability to move vertically in the water column to access deeper nutrients after the surface nutrients are depleted. The highest abundances were generally recorded in 1999 and 2000, followed by a declining trend in the following years (Figs. 5-10).

In the historic data, the sample site in Shelter Inlet near station 80 emerged as the principal hotspot across all three target species and years, exhibiting the highest cell abundances during peak periods. Other locations, including Sydney Inlet (near station

63), Herbert Inlet (near station 36), and Tofino Inlet (near station 45), demonstrated comparatively lower but variable abundances, with sporadic peaks suggesting localized or episodic favorable conditions.

Discussion

The spatial and temporal patterns observed in this study highlight the dynamic nature of harmful algal blooms in coastal fjord systems such as Clayoquot Sound. The central hypothesis of this study is that rising sea surface temperatures would increase the temporal extent and change the spatial extent of three target harmful algae taxa, *Alexandrium* spp., *Dinophysis* spp., and *Pseudo-nitzschia* spp., in the region. Each of the three target taxa exhibited unique distribution characteristics, suggesting that their growth and persistence are driven by a complex set of environmental variables, rather than by a single dominant factor such as temperature.

Pseudo-nitzschia spp. was the most consistently abundant taxon observed across all stations in 2023. The genus has long been associated with amnesic shellfish poisoning (ASP) due to its production of domoic acid. Increases in both frequency and spatial extent over time, as observed in this study, are concerning in the context of climate change and nutrient loading. Similar long-term shifts have been documented in other temperate fjord systems, such as Mariager Fjord in Denmark, where increased nitrogen loading and warming were linked to shifts in *Pseudo-nitzschia* species composition and bloom timing (Lundholm et al. 2010). While nutrient concentrations were not the focus of this study, the expansion of *Pseudo-nitzschia* into southern inlets suggests that either local environmental conditions have changed, or this genus is demonstrating increased physiological tolerance across a wider range of habitats. This

pattern may also reflect the influence of coastal water exchanges. The exchanges are driven by upwelling pulses that bring nutrient-rich offshore waters onto the shelf and into inlet systems, fueling *Pseudo-nitzschia* growth, and can bring blooms that originally formed offshore into the inlets (Du et al. 2016).

In contrast, *Alexandrium* spp. were found to occur more sporadically. Although concentrations were low, it is commonly agreed that a concentration of 200 cells per liter of *Alexandrium* corresponds to the level PSP toxicity can be detected in shellfish (Devred et al. 2018). The persistence of this genus in specific inlets such as Bedwell and Herbert suggests that certain areas may function as localized "hotspots" for cysts to deposit in marine sediments, and where dormant cysts break open and release the active form (excystment). The temporal increase in 2019 and 2023, although modest, is consistent with patterns observed in other regions where warming has been shown to stimulate excystment and be a contributing factor to enhance bloom potential (Moore et al. 2015). While surface temperatures in 2023 were slightly higher than in previous years, the lack of a clear correlation with *Alexandrium* spp. abundance suggests that other factors like sediment characteristics, light availability, movement of offshore blooms into the inlets, or biological interactions may be more or just as important in regulating bloom formation.

Dinophysis spp. were detected less frequently but showed signs of episodic recurrence. Although cell concentrations were low, *Dinophysis* spp. is known to produce diarrhetic shellfish toxins (DST) even at modest abundances. Historical data indicate that such events, while less common than PSP or ASP, have become more frequently reported in Canadian waters in recent decades (McKenzie et al. 2021).

The original hypothesis of this study proposed that harmful algal blooms would become more frequent and intense with increasing sea surface temperatures. However, the data does not support a simple, direct relationship between warming and HAB abundance. While some years with warmer temperatures, such as 2023, did show elevated phytoplankton presence, similar conditions in other years did not. This finding is consistent with broader studies demonstrating that while warming can influence growth rates, its effect on bloom dynamics is highly species and context specific (Brandenburg et al. 2019).

The variability in bloom patterns observed across the inlets of Clayoquot Sound also reflects the physical oceanographic complexity of the region. Shallow sills, restricted flushing, and estuarine circulation create highly localized conditions that can favor or suppress HAB development (Pickard 1963). For example, inlets such as Bedwell and Herbert with limited exchange may promote nutrient recycling and retention, indirectly supporting bloom persistence (Rosen et al. 2022). Inlets that have greater coastal exchange may also have an increase in blooms due to coastal upwelling bringing ocean nutrients into the inlets, causing algae growth or by direct fluid movement transportation of offshore blooms into the inlets (Du et al. 2016). In Clayoquot Sound, the geomorphology of certain inlets may impede the exchange of coastal waters. Some inlet mouths are angled away from the direction of prevailing nearshore currents and cross-shelf flow associated with upwelling, while others are partially sheltered by offshore islands that act as physical barriers to oceanic inflow. These factors together reduce the efficiency of water exchange between the continental shelf and inner inlet systems.

Finally, it is important to note that a change in sampling methodology after 2015 may have contributed to the apparent increase in HAB detection. Earlier surveys were conducted on a larger research vessel where some net samples were able to be counted live onboard with a microscope with lower magnification, and the surveys included a rosette sampler, whose larger Niskin bottles may have been sampling slightly deeper surface waters than the sample bottles on the small boats. These differences underscore the importance of maintaining consistent, high-resolution sampling protocols wherever possible for long-term monitoring. Despite these limitations, the findings of this study contribute to a growing understanding of HAB dynamics in the Pacific Northwest and highlight the need for continued observation, particularly in regions with significant aquaculture activity and cultural reliance on marine resources.

The seasonal cycles in the historic DOF data are consistent with the established phenology of phytoplankton communities, driven primarily by physical and chemical environmental factors such as temperature, daylight, and nutrient fluxes. The high abundance consistently seen in Shelter Inlet near station 80 suggests the area may have ecological significance within the regional phytoplankton community, which may be due to more favorable hydrographic or chemical conditions.

Conclusion

This study contributes to the long-term understanding of harmful algal blooms in Clayoquot Sound by analyzing the spatial and temporal patterns of *Alexandrium*, *Pseudo-nitzschia*, and *Dinophysis* genera over 18 years. While no direct, quantitative correlation was found between rising sea surface temperatures and the abundance of these species, the increased presence of *Pseudo-nitzschia* and continued occurrence of

Alexandrium and *Dinophysis* at key sites indicate that bloom dynamics are shifting. These changes may be driven by a combination of physical, chemical, and biological factors rather than temperature alone.

The observed southward expansion of *Pseudo-nitzschia* and persistent *Alexandrium* detections in Bedwell and Herbert Inlets suggest site-specific conditions that may support future bloom development. The findings reinforce the importance of maintaining long-term, spatially comprehensive monitoring programs, especially as the ecological and economic stakes related to HABs continue to rise. Future efforts should aim to standardize sampling protocols, incorporate toxin quantification, and integrate nutrient and hydrodynamic modeling to improve predictions and support shellfish safety, aquaculture resilience, and coastal ecosystem health. Additionally, further investigation into the decline in maximum cell counts in the historic data following the year 2000 is necessary and may reflect impacts of environmental changes, including climate variability, alterations in nutrient regimes, or anthropogenic impacts.

Taxon	Temporal Pattern	Spatial Pattern	Seasonal Pattern	Correlation with Surface Temp
<i>Alexandrium</i>	Increased in 2019 and 2023	Higher in Bedwell and Herbert, low in Tofino	Peaks in August to September	Weak/moderate
<i>Dinophysis</i>	Peaks in 2007, 2018, and 2023	Southward shift; now mostly southern inlets	Peaks around August in 1999 and 2000 then peaks in September 2001 to 2003.	Episodic, possibly linked to warm years
<i>Pseudo-nitzschia</i>	Steady increase, highest in 2023	Clear southward shift	Peaks around June or July for most years. Early spring bloom in 2001	Moderate/likely

Table 1. Summary of temporal and spatial patterns, seasonal peaks, and correlations with surface temperature for *Alexandrium* spp., *Dinophysis* spp., and *Pseudo-nitzschia* spp.

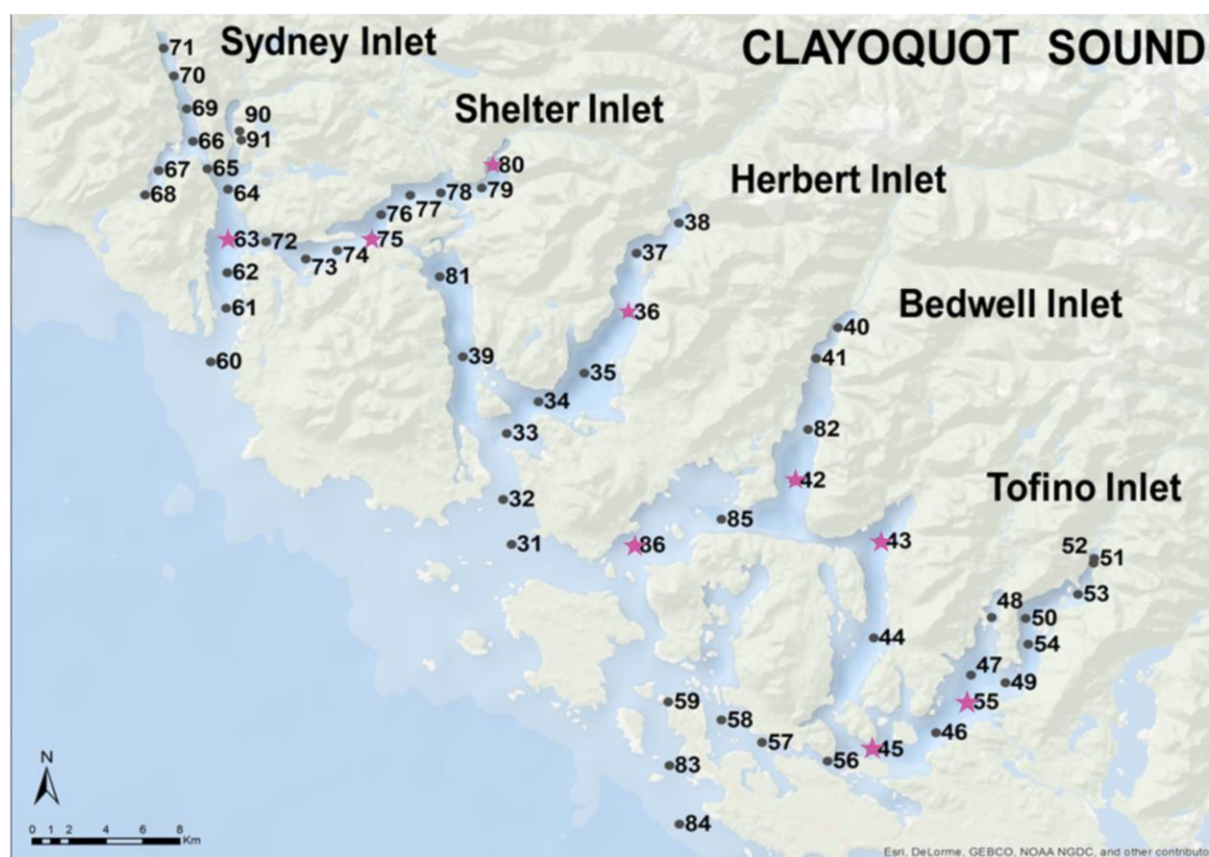


Figure 1. Clayoquot Sound on the west coast of Vancouver Island, BC, Canada. Sample stations are numbered and located throughout all five inlets (Tofino, Bedwell, Herbert, Shelter, and Sydney). Historic data locations matched to present sample stations indicated with a pink star (★).

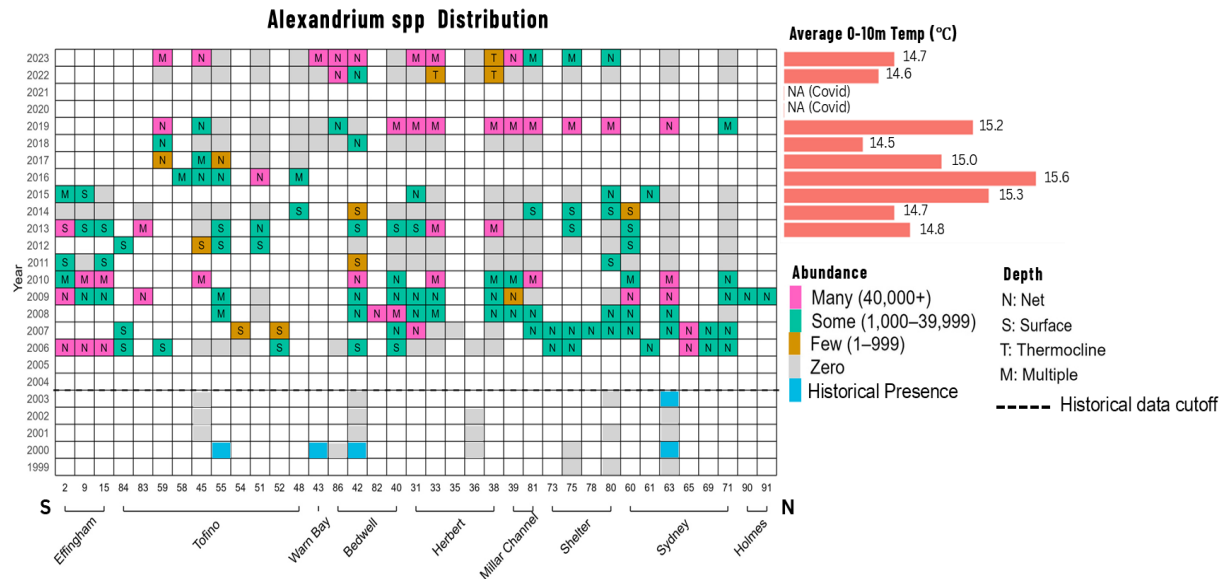


Figure 2. Distribution of *Alexandrium* spp. from 2006 to 2023 across various locations, categorized by abundance (pink: many, teal: some, orange: few, grey: zero) and depth (N: net, S: surface, T: thermocline, M: multiple). Historical presence is indicated by blue squares, and dashed lines denote the cutoff for historical data at 2003. The right panels display the average 0-10m temperature (°C) for 2013 to 2023.

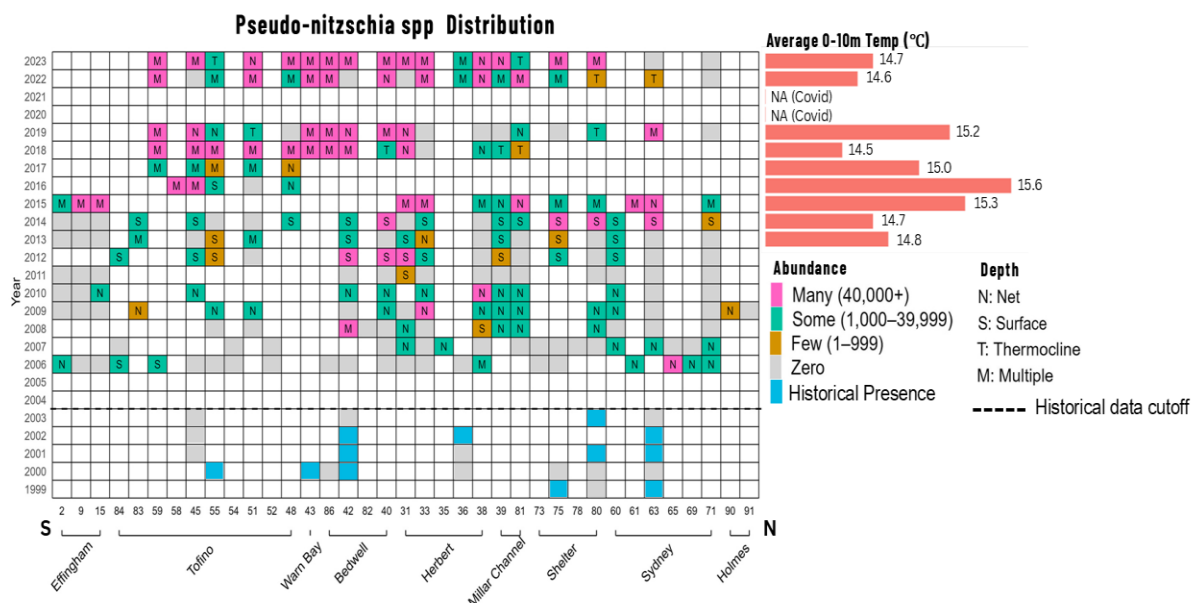


Figure 3. Distribution of *Pseudo-nitzschia* spp. from 2006 to 2023 across various locations, categorized by abundance (pink: many, teal: some, orange: few, grey: zero) and depth (N: net, S: surface, T: thermocline, M: multiple). Historical presence is indicated by blue squares, and dashed lines denote the cutoff for historical data at 2003. The right panels display the average 0-10m temperature (°C) for 2013 to 2023.

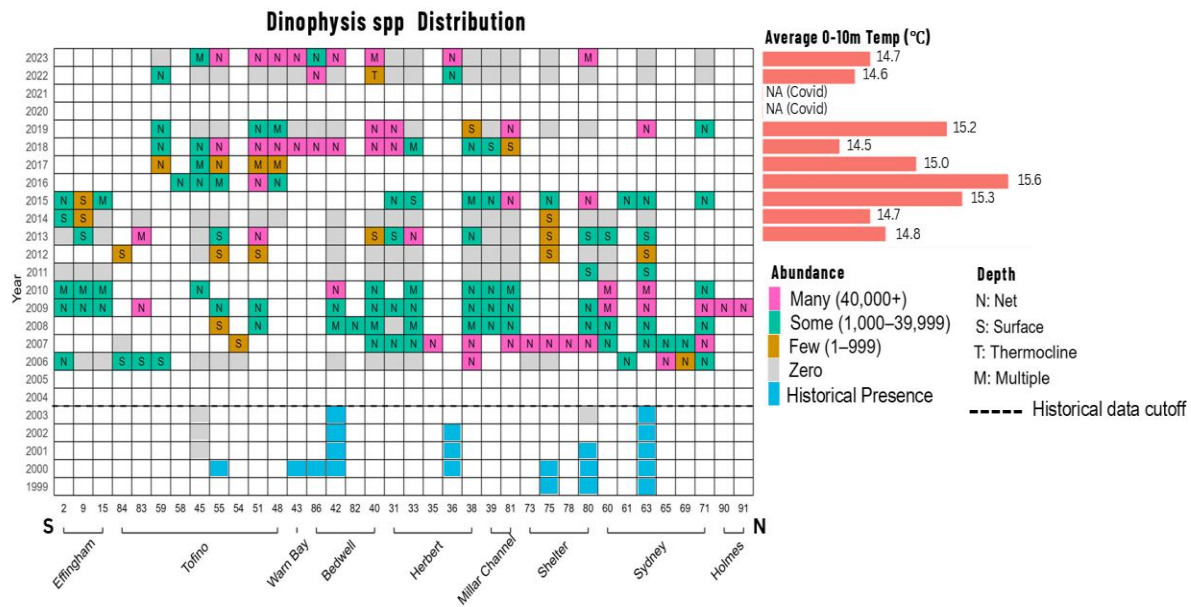


Figure 4. Distribution of *Dinophysis* spp. from 2006 to 2023 across various locations, categorized by abundance (pink: many, teal: some, orange: few, grey: zero) and depth (N: net, S: surface, T: thermocline, M: multiple). Historical presence is indicated by blue squares, and dashed lines denote the cutoff for historical data at 2003. The right panels display the average 0-10m temperature (°C) for 2013 to 2023.

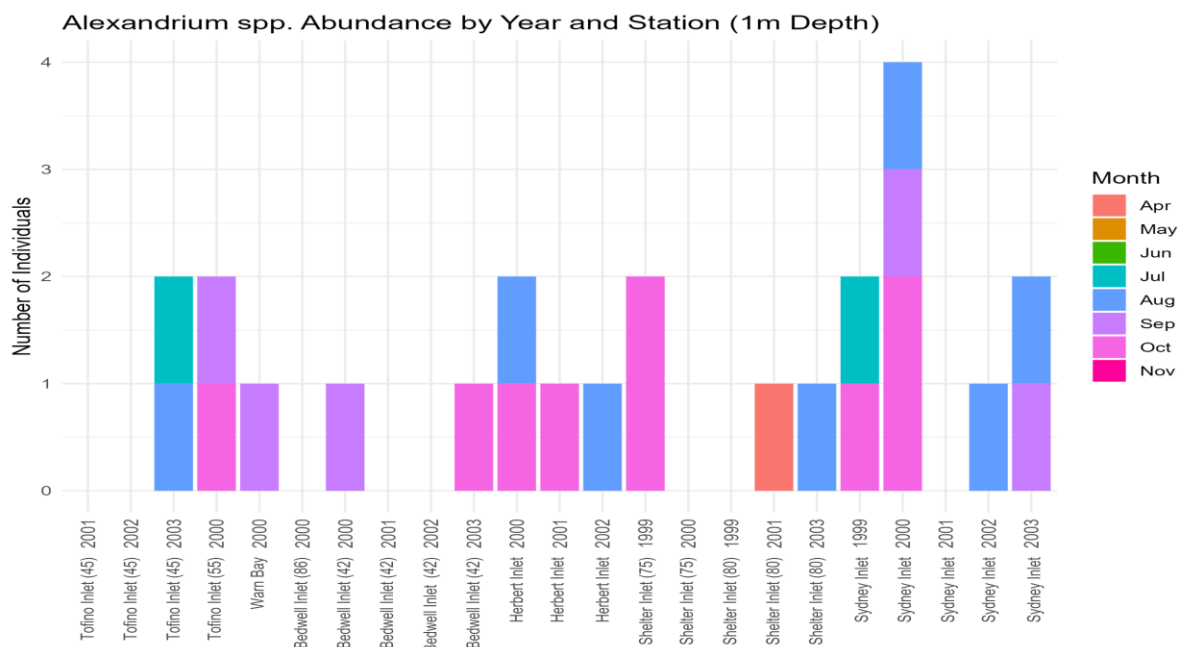


Figure 5. Number of *Alexandrium* spp. individuals observed at different stations from 2001 to 2003, categorized by month and station name. The height of each bar indicates the total count of individuals for that station and year, with individual months represented by colored segments within each bar.

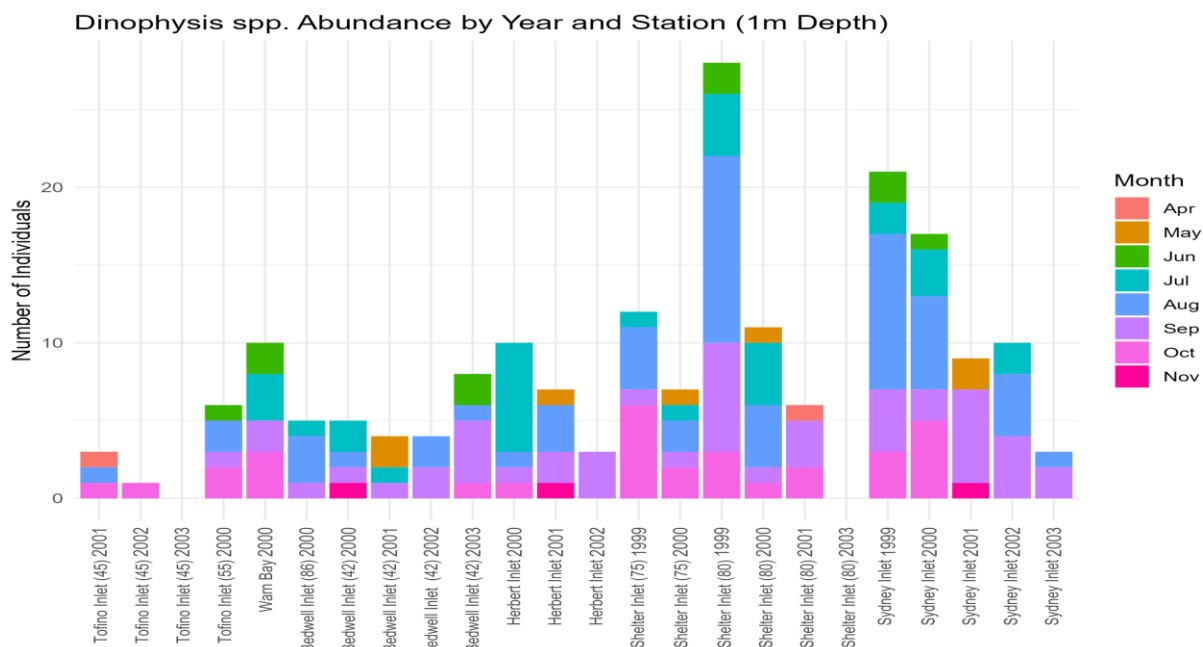


Figure 6. Number of *Dinophysis* spp. individuals observed at different stations from 2001 to 2003, categorized by month and station name. The height of each bar indicates the total count of individuals for that station and year, with individual months represented by colored segments within each bar.

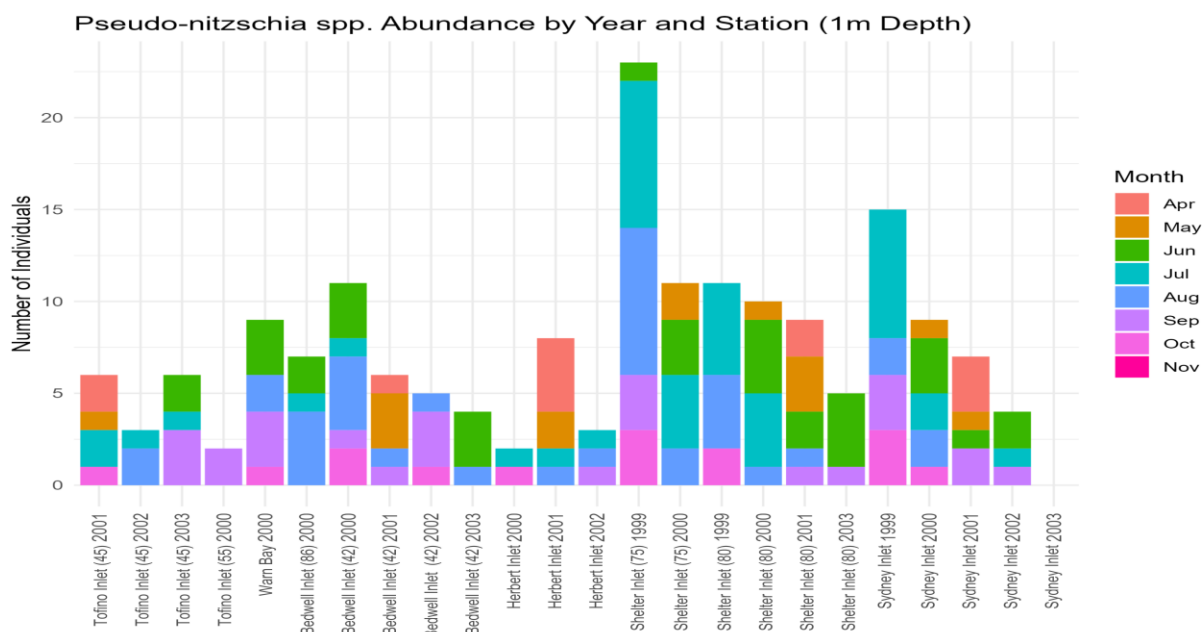


Figure 7: Number of *Pseudo-nitzschia* spp. individuals observed at different stations from 2001 to 2003, categorized by month and station name. The height of each bar indicates the total count of individuals for that station and year, with individual months represented by colored segments within each bar.

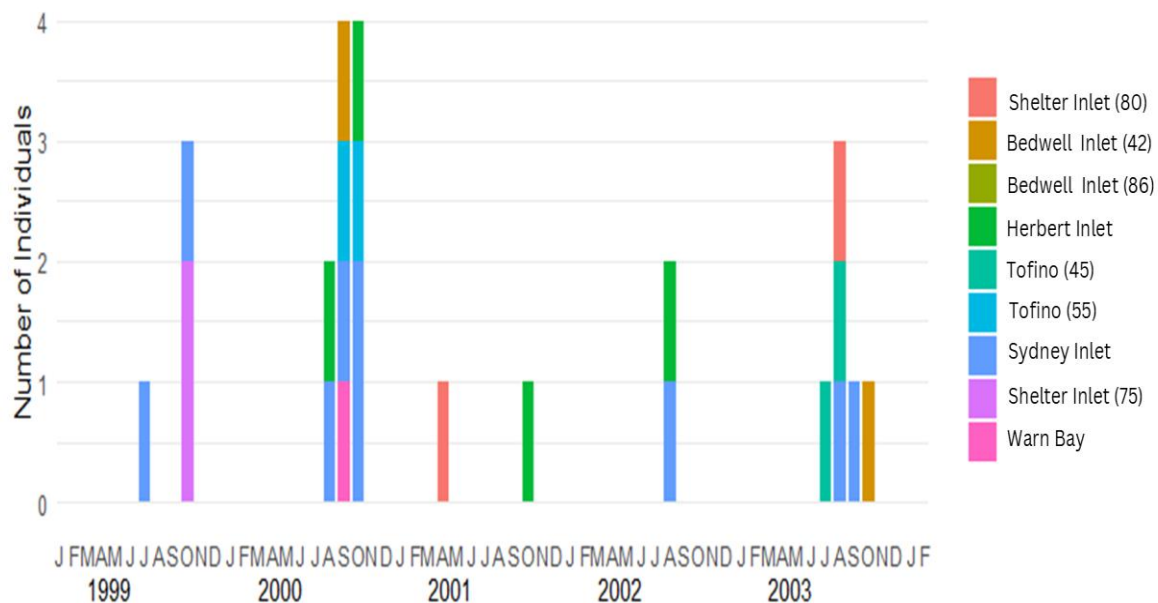


Figure 8: Monthly counts of *Alexandrium* spp. individuals at various sampling sites from 1999 to 2003. Each bar represents the total number of individuals sampled in each month, with different colors indicating specific locations (e.g., Shelter Inlet, Bedwell Inlet, Herbert Inlet, etc.). The height of each segment within a bar corresponds to the number of individuals observed at that site during that month.

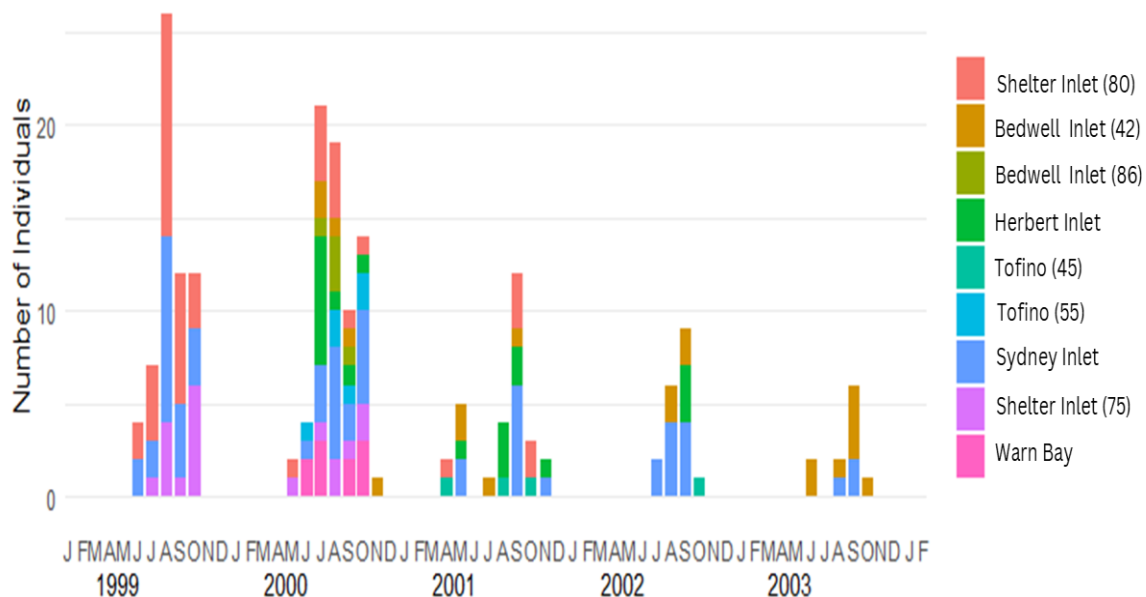


Figure 9: Monthly counts of *Dinophysis* spp. individuals at various sampling sites from 1999 to 2003. Each bar represents the total number of individuals sampled in each month, with different colors indicating specific locations (e.g., Shelter Inlet, Bedwell Inlet, Herbert Inlet, etc.). The height of each segment within a bar corresponds to the number of individuals observed at that site during that month.

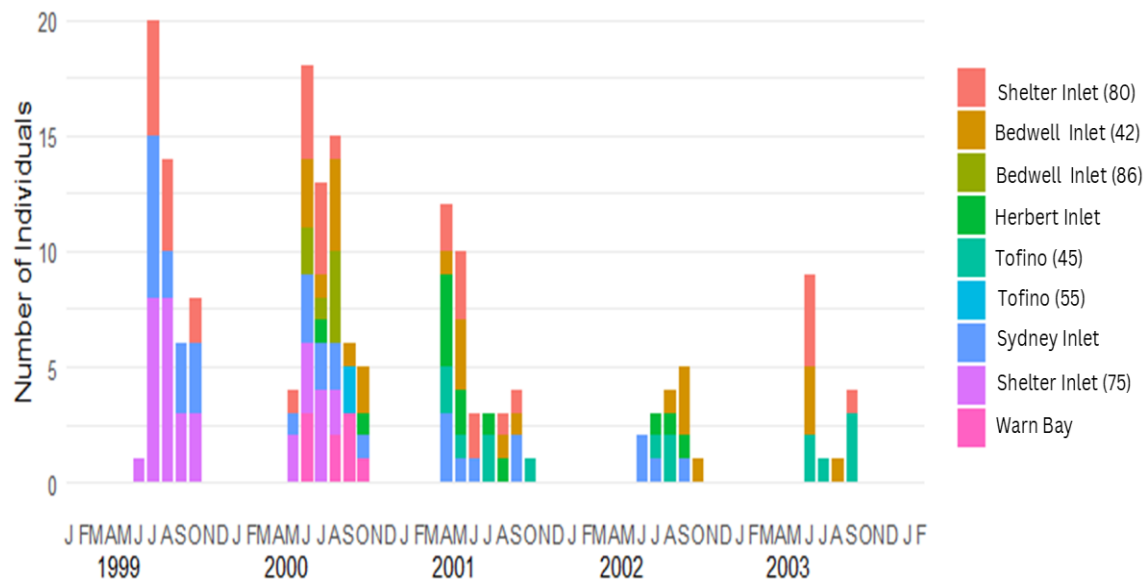


Figure 10: Monthly counts of *Pseudo-nitzschia* spp. individuals at various sampling sites from 1999 to 2003. Each bar represents the total number of individuals sampled in each month, with different colors indicating specific locations (e.g., Shelter Inlet, Bedwell Inlet, Herbert Inlet, etc.). The height of each segment within a bar corresponds to the number of individuals observed at that site during that month.

References

- Brandenburg KM, Velthuis M, Van de Waal DB. 2019. Meta-analysis reveals enhanced growth of marine harmful algae from temperate regions with warming and elevated CO₂ levels. *Glob Change Biol.* 25(8):2607–2618. <https://doi.org/10.1111/gcb.14678>
- Devred E, Martin J, Sathyendranath S, Stuart V, Horne E, Platt T, Forget MH, Smith P. 2018. Development of a conceptual warning system for toxic levels of *Alexandrium fundyense* in the Bay of Fundy based on remote sensing data. *Remote Sens Environ.* 211:413–424. <https://doi.org/10.1016/j.rse.2018.04.022>
- Du X, Peterson W, McCulloch A, Liu G. 2016. Initiation and development of a toxic and persistent *Pseudo-nitzschia* bloom off the Oregon coast in spring/summer 2015. *PLoS One.* 11(10):e0163977. <https://doi.org/10.1371/journal.pone.0163977>
- Glibert PM, Anderson DM, Gentien P, Graneli E, Sellner KG. 2005. The global, complex phenomena of harmful algal blooms. *Oceanography.* 18(2):136–147.
- Haigh N, Esenkulova S. 2014. Economic losses to the British Columbia salmon aquaculture industry due to harmful algal blooms, 2009–2012. *PICES Sci Rep.* 47:2–6.
- Lundholm N, Clarke A, Ellegaard M. 2010. A 100-year record of changing *Pseudo-nitzschia* species in a sill-fjord in Denmark related to nitrogen loading and temperature. *Harmful Algae.* 9(5):449–457. <https://doi.org/10.1016/j.hal.2010.03.001>
- McKenzie CH, Bates SS, Martin JL, Haigh N, Howland KL, Lewis NI, Locke A, Peña A, Poulin M, Rochon A, et al. 2021. Three decades of Canadian marine harmful algal events: Phytoplankton and phycotoxins of concern to human and ecosystem health. *Harmful Algae.* 102:101852. <https://doi.org/10.1016/j.hal.2020.101852>
- Moore SK, Bill BD, Hay LR, Emenegger J, Eldred KC, Greengrove CL, Masura JE, Anderson DM. 2015. Factors regulating excystment of *Alexandrium* in Puget Sound, WA, USA. *Harmful Algae.* 43:103–110. <https://doi.org/10.1016/j.hal.2015.01.005>
- Pickard GL. 1963. Oceanographic characteristics of inlets of Vancouver Island, British Columbia. *Can J Fish Aquat Sci.* 20(5):1109–1144. <https://doi.org/10.1139/f63-080>
- Rosen S, Bianucci L, Jackson JM, Hare A, Greengrove C, Monks R, Bartlett M, Dick J. 2022. Seasonal near-surface hypoxia in a temperate fjord in Clayoquot Sound, British Columbia. *Front Mar Sci.* 9:1000041. <https://doi.org/10.3389/fmars.2022.1000041>
- Taylor FJR, Harrison PJ. 2002. Harmful algal blooms in western Canadian coastal waters. *Univ Br Columbia.* 6(1z4):1–12.