Analysis of Dinoflagellate Species Distribution in the Puget Sound and their Environmental Conditions from 2015-2022

Elizabeth Dale

University of Washington, Seattle, WA

School of Oceanography

email: ed18@uw.edu

10/28/21

Abstract

Marine dinoflagellates live in conditions that if changed, can create dangerous environments promoting harmful algae blooms (HABs). This study investigates the drivers of species distribution and bloom peaks using data from the Puget Sound Marine Monitoring Program from 2015-2022. Two datasets were processed using Python coding to produce an analysis of concentration and distribution of different genus of dinoflagellates in the Washington Puget Sound; a dataset for sample collections of dinoflagellates at stations in Puget Sound, and a correlating water conditions dataset. The dinoflagellate dataset was directed through an algorithm to group samples by genus classification of species, minimizing risk of data averaging. Grouping samples by genus found 20 identified taxa in the dataset. The second water quality dataset was parsed for salinity, temperature, chlorophyll-a, nitrate, and dissolved oxygen parameters. Connections were drawn by processing data to determine which stations had the highest biovolume for each genus of dinoflagellate, and then cross referencing with water conditions from the second dataset. It was found that Dockton Park, Jefferson Head, and West Point Outfall stations had the highest concentrations of average biovolume, as well as a distinct correlation with a specific genus. Using the water condition parameters, significant correlations were seen between stations. Dockton Park was found to be the station with the highest number of genus that preferred it, correlating with a September bloom, temperatures at approximately 30˚C, as well as September peaks in chlorophyll-a and salinity. West Point Outfall station had a June peak, and Jefferson Head station had an early spring peak in dinoflagellate biovolume. By looking at how different conditions affect dinoflagellates, and what conditions were present where they are typically found, it is clear that changing ocean conditions and potential impacts of on dinoflagellate taxa are high.

Summary

Microscopic marine life is sensitive to changes in climate. Even slight changes in marine environments, such as change in temperature or salinity of water, can cause an imbalance in ecosystems. As the world experiences global warming, it is important to monitor these small changes, to be able to predict and adjust for changing conditions. In order to understand what effects any changes might have on microscopic organisms and our environment, data from the Puget Sound was taken and analyzed to find significant correlations and trends.

Introduction

Marine dinoflagellates are a subset of phytoplankton, a single-celled primary producer that is known for their harmful algae blooms and bioluminescent blooms. Part of the class Dinophyceae, they can be found in diverse conditions, from the frigid waters of Alaska to the topical waters of Ecuador, in freshwater habitats as well as the ocean (Ribalet et al. 2010). Areas of high diversity and concentration of dinoflagellates are characterized by high ocean circulation, and favorable nutrient conditions. Favorable conditions vary based on species but can be categorized as low salinity as well as moderate temperatures, dissolved oxygen levels and sunlight (Manning et al. 2021). In a study on the dinoflagellate *Cochlodinium polykrikoides* Margalef, specific conditions shown to be favorable included temperatures of about 21.3–26.2°C and salinity of about 27.6–36.7(Kim et. al. 2004). Climate affects phytoplankton through factors of column stratification, resource availability, as well as nutrient and light availability. Changes in these factors can have an impact on production, bloom size, as well as timing and duration of blooms. Size structure and species traits can even be affected

(Winter 1975). To protect our waters, comprehensive data analysis of any change needs to be monitored.

Previous investigations into the change of dinoflagellate blooms have been attributed to climate change. According to a study using sea surface temperature and ocean temperature graphs, the dinoflagellates *Alexandrium fundyense* and *Dinophysis acuminata*, were shown to have an increase in bloom season duration and mean annual growth rates across the North Pacific and North Atlantic Oceans. This increase could potentially mean a rise in harmful algae blooms. Increasing ocean temperature is concluded to be the control for this change shown in Fig. 1 (Gobler et al. 2017).

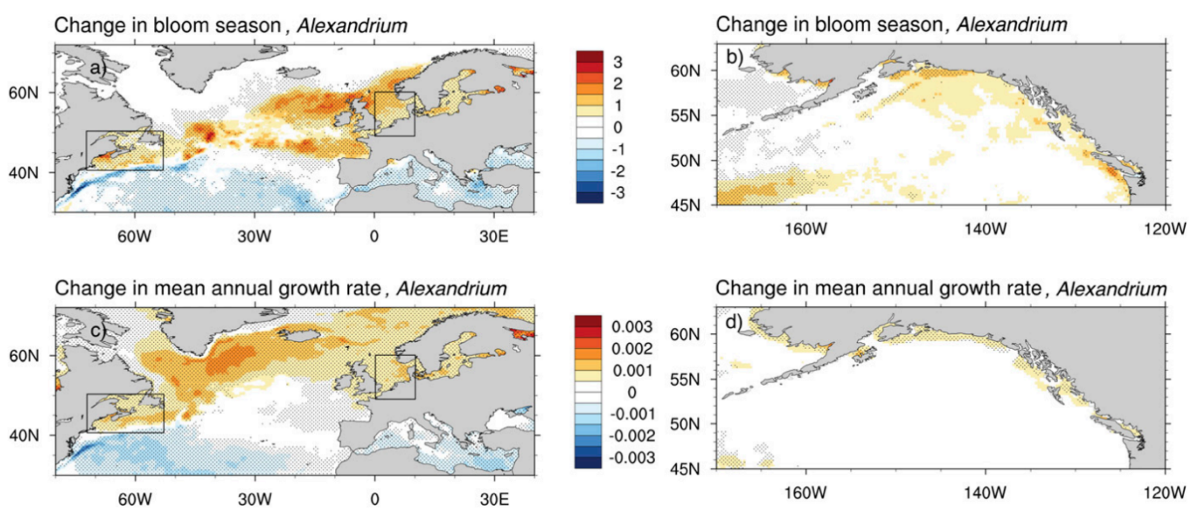

Fig. 1. Modeled trend in bloom season ($d \cdot y^{-1}$) over the period 1982 to 2016 for *A. fundyense* in the North Atlantic (*A*) and North Pacific (*B*). Modeled trend in mean annual growth rate ($d^{-1} \cdot y^{-1}$) over the same time period in the North Atlantic (*C*) and North Pacific (*D*). Stippling indicates regions where trends are statistically significant ($S < 0.05$). Boxes indicate two coastal regions of significantly enhanced temperature, growth rates, bloom season, and record of bloom occurrence: NW Atlantic (40.625°N to 50.325°N; 287.875°W to 307.125°W) and NE Atlantic (49.125°N to 60.125°N; 0.125°E to 10.125°E). *(Gobler et al. 2017)*

Another study conducted in 2016 on the bloom event of the toxic algae bloom *P. australis* across the West coast determined change in bloom behavior was due to an onset of seasonal upwelling, late spring storms and anomalously high surface temperatures (McCabe et al. 2016).

In a study on diversity and distribution of assemblages off Australia, data was taken at two locations of temperate and tropical waters. *Gyrodinium* were found to have the highest presence in cooler waters, while in warm waters *Gymnodiniales sensu stricto* and *Gyrodinium* presence were about equal. Harmful algae bloom assemblages were analyzed by salinity, temperature, dissolved oxygen, and total dissolved solids (Manning 2021). This showed statistically relevant differences in the assemblage of dinoflagellates throughout the sample locations.

In the Puget Sound, phytoplankton production rate in the central basin is about 465 g C m^{-2} $year^{-1}$(Winter 1975). In Washington, recent events of harmful algae blooms required more frequent sampling and monitoring of blooms, specifically in the Puget Sound (Moore 2008). Harmful algae blooms are toxic blooms, that can poison shellfish, a source of food, and income in the Puget Sound area. As mentioned earlier, to protect our waters and our resources, it is important to monitor the effects of climate change on dinoflagellate assemblages.

This study is designed to expand on current data on dinoflagellate conditions in the Puget sound, an estuary connected to the Strait of Juan de Fuca with nutrient influx from the coastal waters (Moore 2008). Functions of the Puget Sound estuary include an input of nutrients from rivers as well as the Pacific Ocean. Within Puget Sound there are five distinct basins, Main Basin, Admiralty Inlet, Southern Puget Sound, Whidbey Basin, and Hood Canal, each with differing habitats, and different circulation patterns (Cannon 1975). With different patterns of circulation, nutrients are distributed in different areas and proportions, a factor in the distribution of dinoflagellates when accounting their nutrient needs.

Coastal waters in Washington are a part of the North Pacific Ocean, one of the most productive marine ecosystems (Ribalet et al. 2010). A recent study done in Puget sound concluded that western coastal waters are the only known location of a specific bioluminescent dinoflagellate, *noctiluca scintillans,* that has lost the cellular function responsible for its bioluminescent properties (Valiadi et al. 2020). With this monumental shift in the *noctiluca scintillan* species, it is cause to wonder if this is a result of climate change, and if so what factors of influence. As Puget Sound experiences global warming, changes in microscopic ecosystems can have a significant impact on the whole ocean ecosystem.

Objectives of the proposed work are to analyze prevalence and location of different dinoflagellate genus, to determine conditions that promote dinoflagellate growth. The study will test the hypothesis that specific water conditions correlate to the location, growth, and prevalence of dinoflagellate blooms in the Puget Sound. Regional sea surface temperatures, salinity, pH, and abundance measurements will make up my data set. With the change in dinoflagellates such as *noctiluca scintillans*, monitoring local waters for any other changes in dinoflagellate species is imperative, as change in the growth and prevalence of harmful algae blooms or other blooms would be disastrous for a marine ecosystem (Ribalet et al. 2010). Prevalence and distribution of dinoflagellate species at stations could potentially describe what conditions are affecting changes such as those seen in the *N. Scintillan* species. Changes in dinoflagellate species are a marker for the conditions of the health of the oceans, and a warning for future changes. Preliminary investigation done in this study may be able to show a trend giving insight to whether conditions have evolved enough that dinoflagellate species and blooms may begin to experience change based off climate change.

Methods

Research Question.

How are dinoflagellate species in Washington distributed, and have there been bloom changes related to climate change?

Location.

The King County Marine Monitoring program collected monthly measurements at eight offshore monitoring stations in the main basin of the Puget Sound (Fig. 2). Locations were chosen based on data availability on phytoplankton in Washington State.

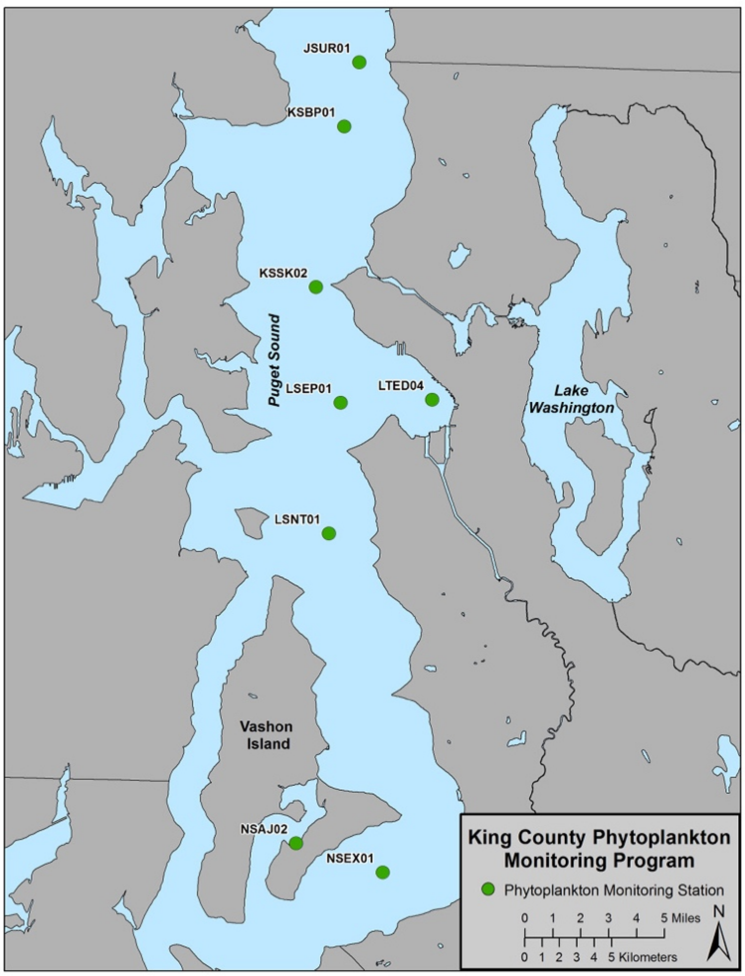

Figure 1 King County Phytoplankton Monitoring Program station locations (King County 2021) https://green2.kingcounty.gov/marine/Content/Images/Sampling/PhytoMap.jpg

Data collection.

King County Phytoplankton Monitoring Program collects monthly water column profiles with a conductivity, temperature, depth (CTD) multi sensor array at offshore monitoring stations. The CTD measures dissolved oxygen, salinity, temperature, density (calculated), transmissivity, photosynthetically active radiation, and fluorescence (as a measure of chlorophyll). The CTD is deployed on a rosette with 12 Niskin sampling bottles, at 16 times a second(16 Hertz), and is lowered through the selected water column, down through the surface to the bottom, and back up to the surface. Measuring instruments included the Seabird SBE 4 Conductivity Sensor, WET Labs WETStar Fluorometer, Seabird SBE 29 Pressure Sensor, and the Seabird SBE 43 Dissolved Oxygen Sensor Seabird SBE 3 Temperature Sensor, and FlowCam. Water samples are collected at each station with either Niskin bottles or a bucket at 1 meter to be analyzed by the FlowCam. FlowCam data is quantitative, using Visual Spreadsheet software to sort images of each sampling event.

Data from three of the eight central basin stations of Puget Sound Marine Monitoring program monitors were highlighted in analysis: West Point Outfall (KSSK02), Jefferson Head (JSUR01), and Dockton Park (NSAJ02). Jefferson Head is a mid-channel location above the busiest parts of Seattle, while West Point Outfall is off local Discovery Park (next to King County's regional wastewater treatment system) and Dockton Park station is in a well-protected shallow bay. Years analyzed were 2015 through 2022. Data was be downloaded from the Puget Sound Marine Monitoring program and organized in Python. Data included site, sample number, collection date, collection depth, biovolume, abundance and species type. In analysis, biovolume and water conditions were used in data visualization for biovolume of each species at each station, and under what conditions. Analysis was pointedly focused on specific genus of potentially harmful taxa, including *Akashiwo* and *Alexandrium* species.

Analysis.

Data from the Puget Sound Marine Monitoring program was imported, “read” into the Python program and parsed to remove columns extraneous to the goals of this study. A function was used to pull the proper parameters from water quality, and sort them into the same box as their corresponding station from the dinoflagellate sample datasheet. Concatenation was used for parameters that had two variable names.

Samples of the class *Dinophyceae* were extracted from the larger dataset of phytoplankton samples, at each site, and a count.values() function was used to determine how many genus were present, and subsequently assign biovolume means of each genus to its own specific variable. Bar plots of each average genus were then generated to determine which station encompassed the respective highest values. From this determination, another function was used to find dates of peak biovolume and displayed in bar graphs of year per genus per station.

Using the preceding information, graphs at each station during peak blooms for each genus were generated. Primarily of focus was biovolume at station comparison with chlorophyll-a, salinity, dissolved oxygen, and temperature. Visual representation of these environmental conditions for each of the prevalent dinoflagellate genus was the primary interpretation method for determining how Puget Sound water conditions affect dinoflagellate species presence and to describe any trends that may be present when looking at the effect of climate change on assemblages.

Results

Average biovolume graphs were used to determine which stations had the highest biovolume measurements, and where each genus had the highest level of biovolume. During data analysis, it was determined that Dockton Park station, West Point Outfall station, and Jefferson Head had the highest average biovolume measurements.

Dockton Park was seen to be the station where genus *prorocentrum, neoceratium, dinophysis, akashiwo, scrippsiella, cochlodinium, alexandrium* and *nematodinium* had the highest average biovolume. Among those, the genus *akishwo* and *alexandrium* both had overall highest biovolume, at about an average of 2.5 mm^3/L and 0.6 mm^3/L respectively (Fig. 3, Fig. 4).

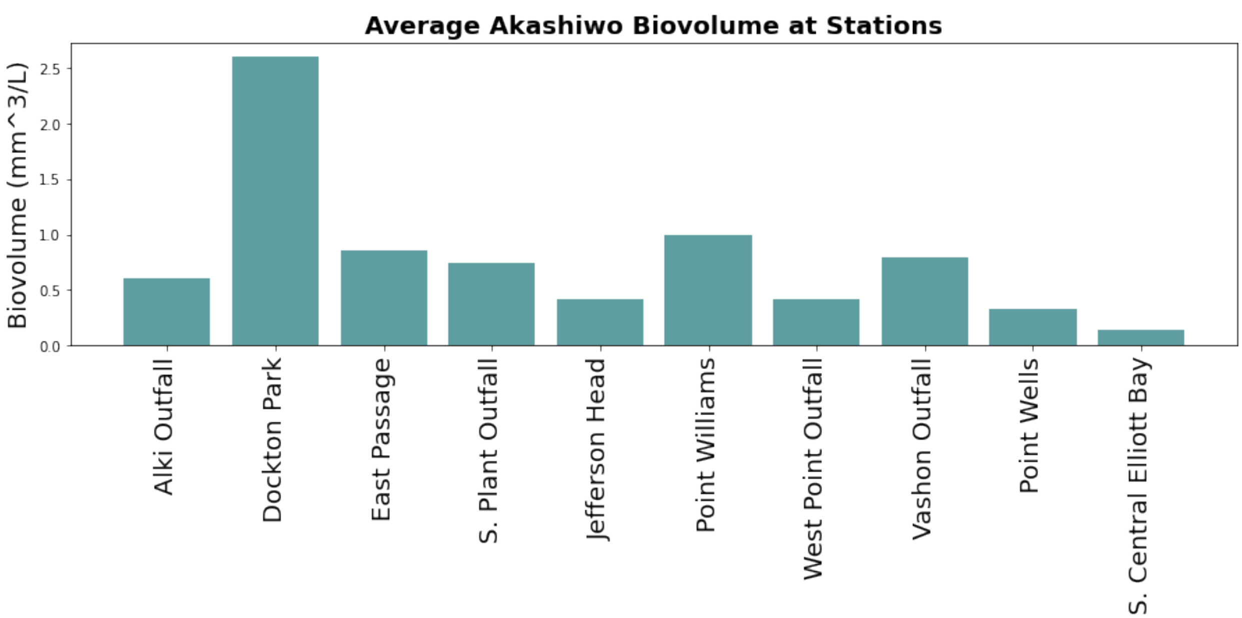

Fig. 3. Average biovolume in mm^3/L of genus *Akashiwo* at each investigated station

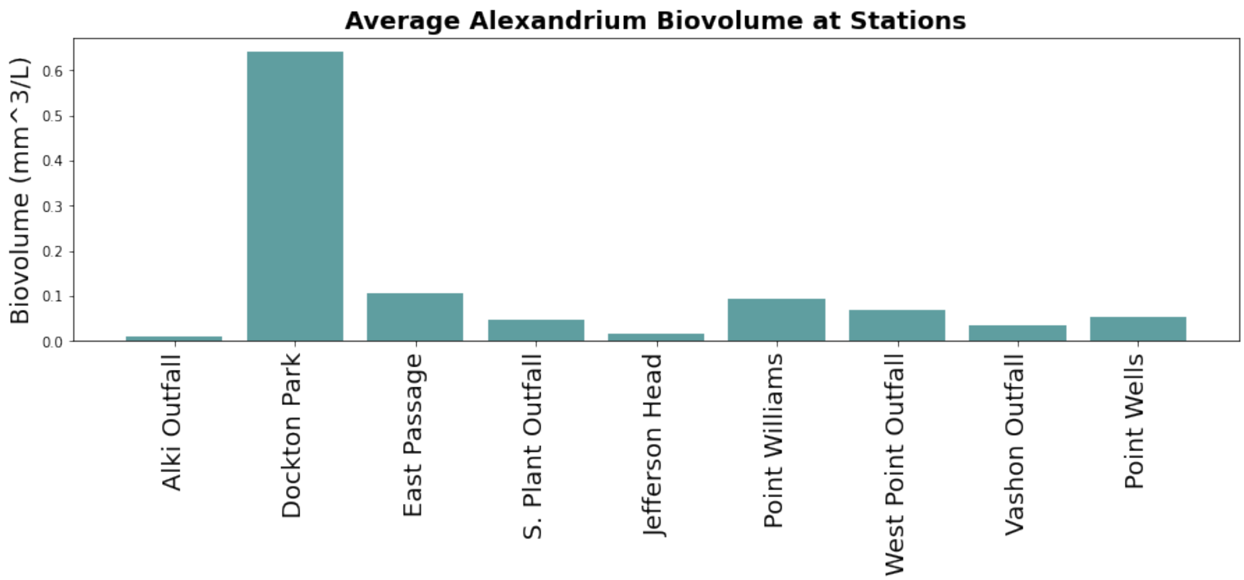

Fig. 4. Average biovolume in mm^3/L of genus *Alexandrium* at each investigated station.

Akashiwo and *alexandrium* on average had a peak bloom in the month of September, however *Akashiwo* had its highest biovolume average peak in 2019, while *alexandrium* had a high in 2020 (Fig. 5). Also of note, *akashiwo* had a much higher value of biovolume maximum peak of about 50 mm^3/L compared to *alexandrium* at of 2.5 mm^3/L.

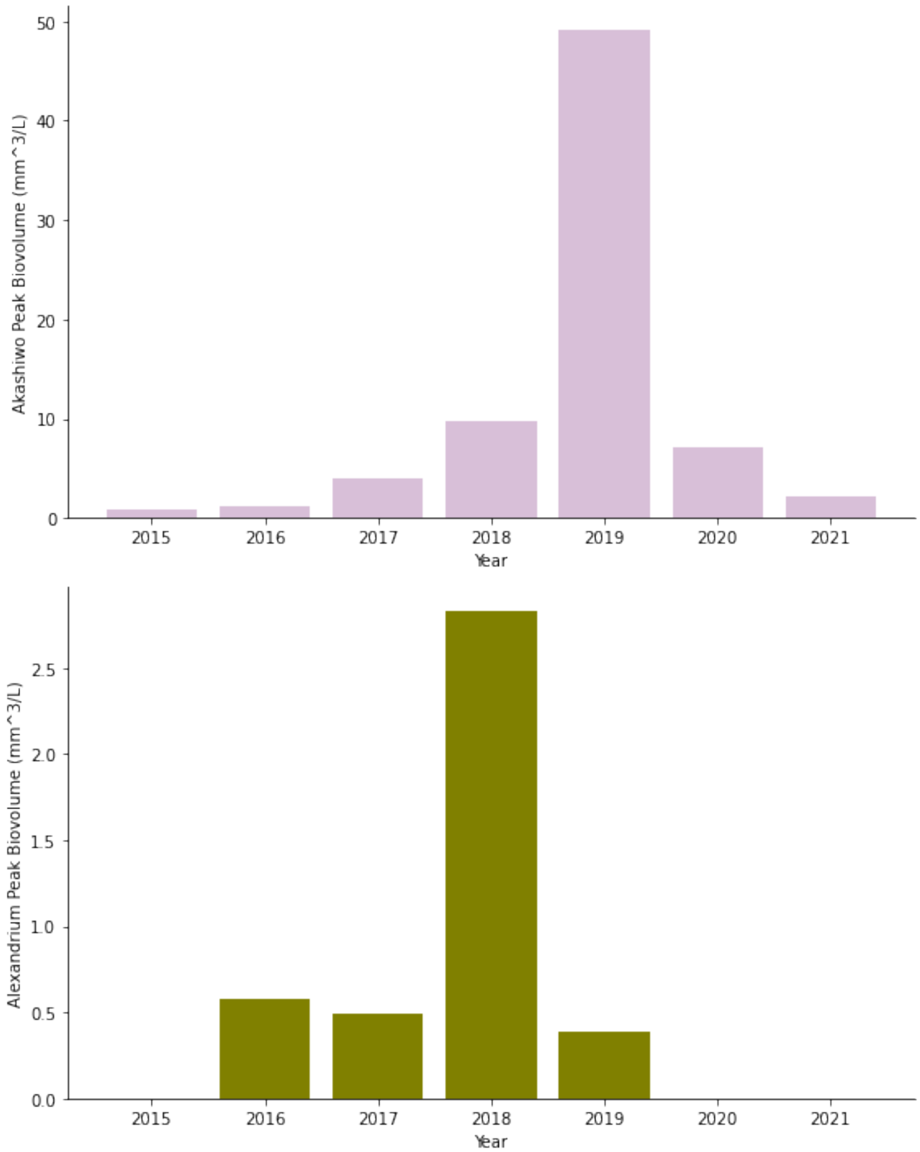

Fig. 5. Dockton Park Station *Akashiwo* and *Alexandrium* genus biovolume, with yearly maximum biovolume peak plotted.

Water quality graphs for Dockton Park (Fig. 6) from the years 2018 – 2021 show a peak in chlorophyll-a measurements september of 2018, as well as a higher than average temperature at the same time of approximately 20˚C. Salinity measurements at Dockton Park had highs during September of 2018 and September of 2019, at around 30.5 PSS. Dissolved oxygen reached a minimum during September of 2018, and a maximum in June of 2018, with a typically annual peak around September. Nitrite concentration decreased from 2018 to 2021, with a typical minimum in the fall.

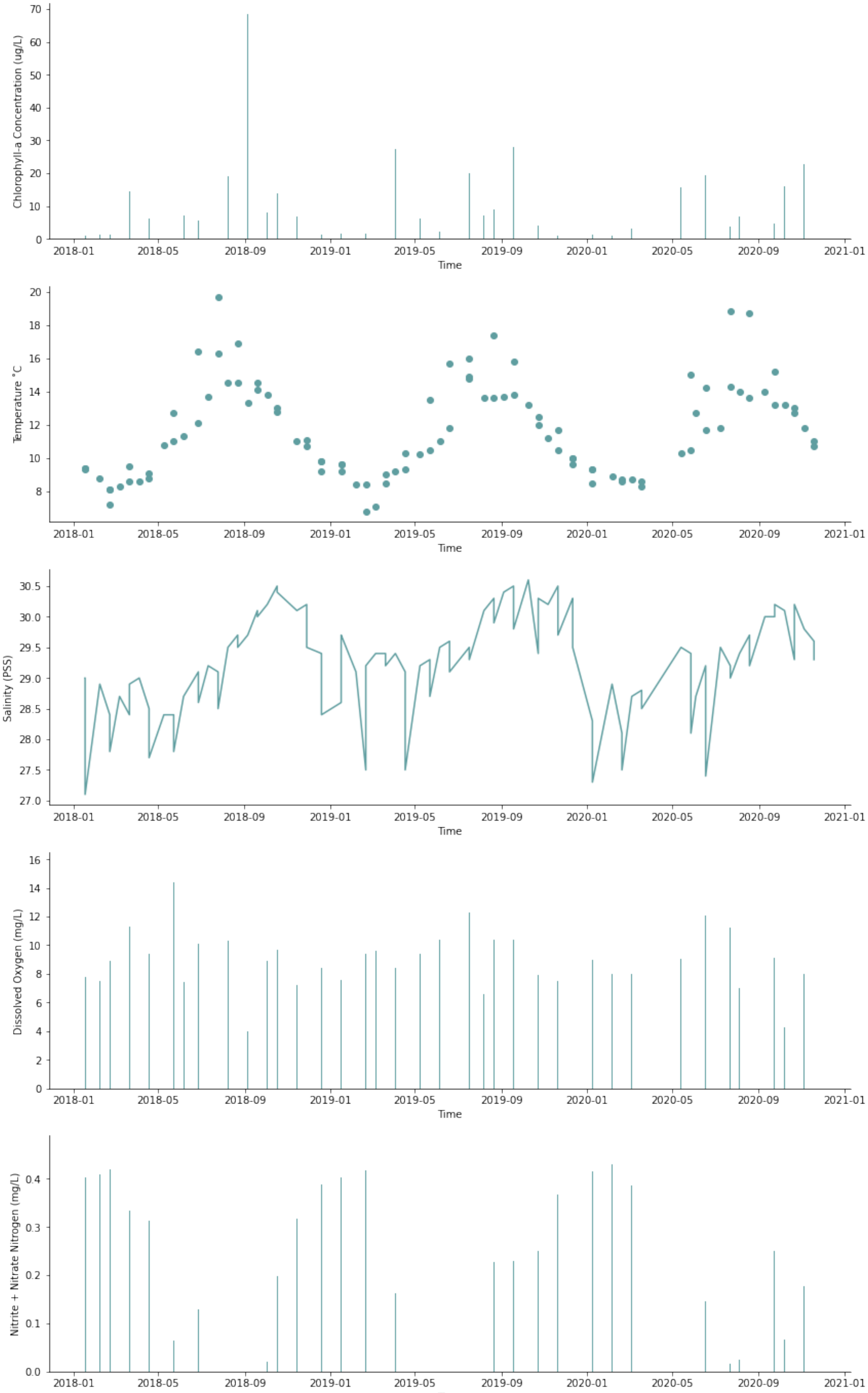

Fig. 6. Dockton Park station with water quality graphs for peak years 2018-2021.

The genus *noctiluca* had the highest average biovolume at each station overall(Fig. 7), with a maximum at West Point Outfall, at an average of around 20 mm^3/L per year. Noctiluca peak biovolume occurs in June of 2020, with a value of about 192.6 mm^3/L, compared to the next highest peak in 2015 with a high of 14.67mm^3/L (Fig. 8). During data analysis it was found that the month *Noctiluca* peaked in was on average June.

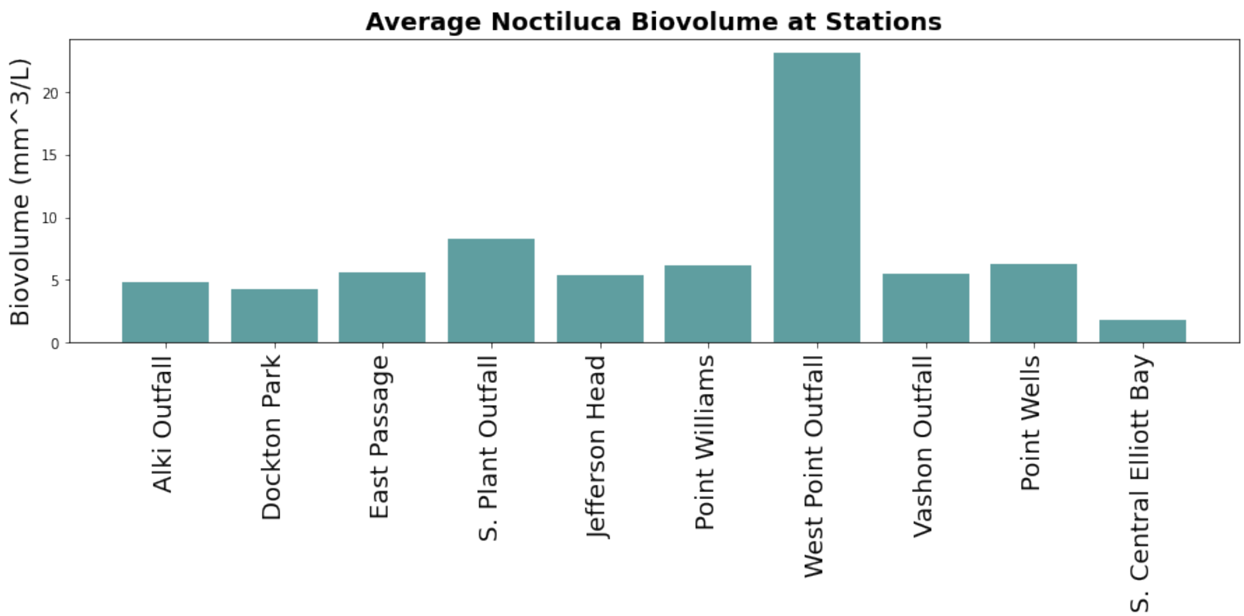

Fig. 7. Average biovolume in mm^3/L of genus *Noctiluca* at each investigated station.

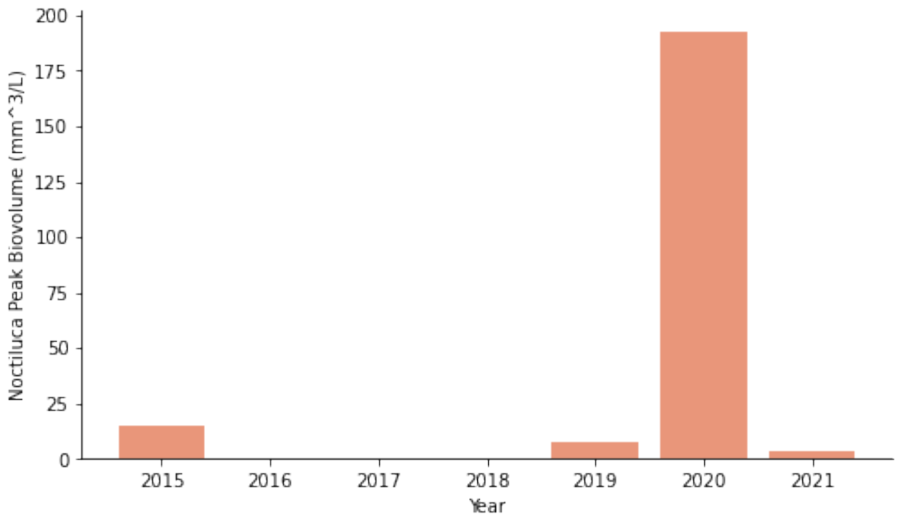

Fig. 8. West Point Outfall station with *Noctiluca* genus biovolume, with yearly maximum biovolume peak plotted.

Water quality graphs for West Point Outfall (Fig. 9) show a maximum chlorophyll-a concentration in 2019, trending downwards overall. Highest water temperatures were recorded in September of 2019 at approximately 15˚C. Salinity at the same time averages steady at about 30PSS, with peaks occurring regularly in September at a slightly higher 30.4 PSS. Dissolved Oxygen measurements peak in June of each year. Nitrite concentration is at a minimum for the same time.

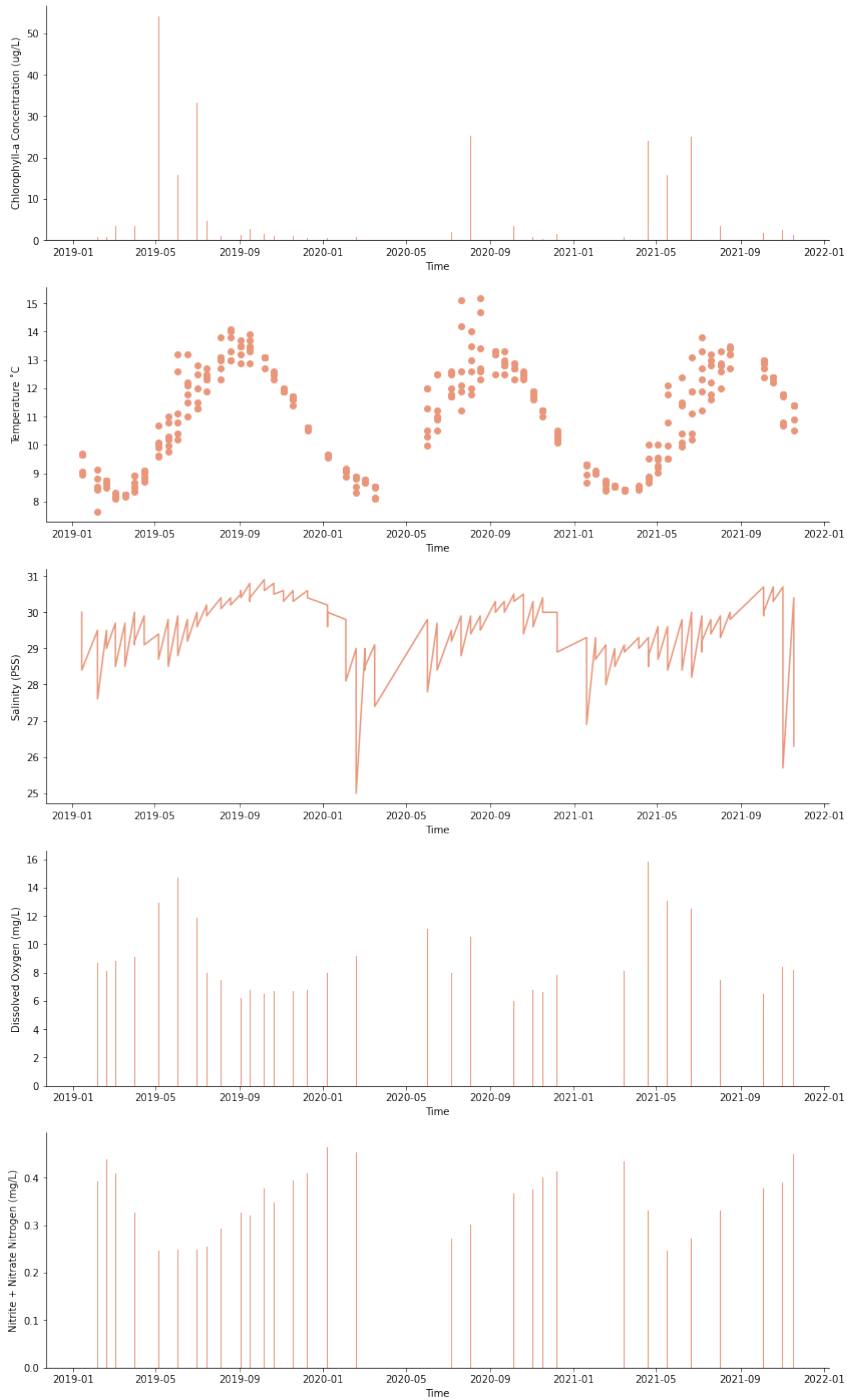

Fig. 9. West Point Outfall station with water quality graphs for peak years 2019-2022.

Jefferson Head station had the third highest amount of average dinoflagellate biovolume, with genus *protoperidinium* having the highest overall at an average of around 2.0 mm^3/L(Fig. 10).

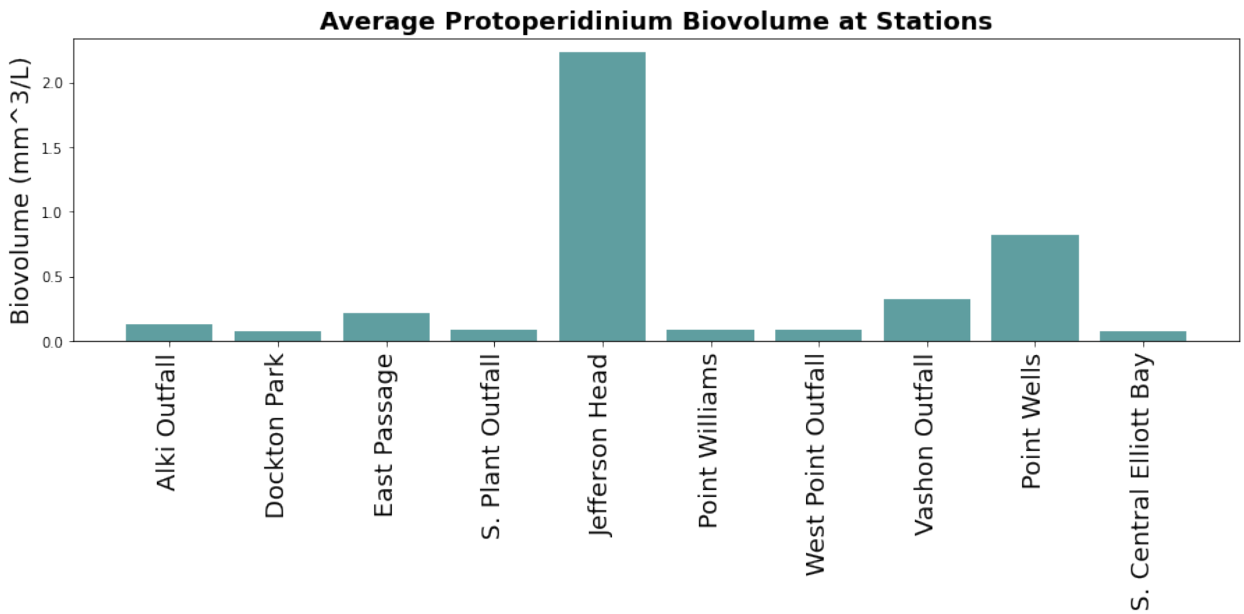

Fig. 10. Average biovolume in mm^3/L of genus *protoperidinium* at each investigated station.

The year *protoperidinium* had the highest biovolume peak was august of 2020, and on average peaks occurred late April and early May(Fig. 11).

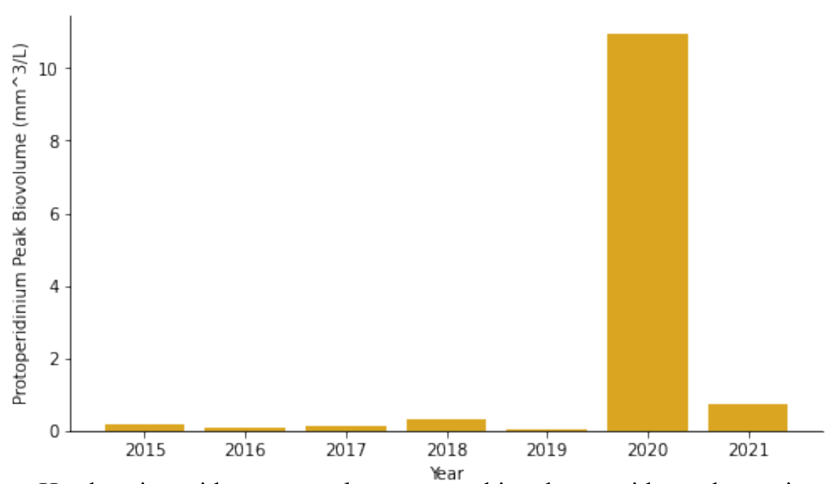

Fig. 11. Jefferson Head station with *protoperidinium* genus biovolume, with yearly maximum biovolume peak plotted.

Water quality graphs for Jefferson Head station show that for chlorophyll-a measurements, august was the peak month in concentration, as well as temperature at about 15˚C. Salinity at Jefferson Head during peak years remained much steadier than previously mentioned stations, at an average of 30.5 PSS. Dissolved oxygen also peaked in August. Nitrite concentration reached a peak during early 2021.

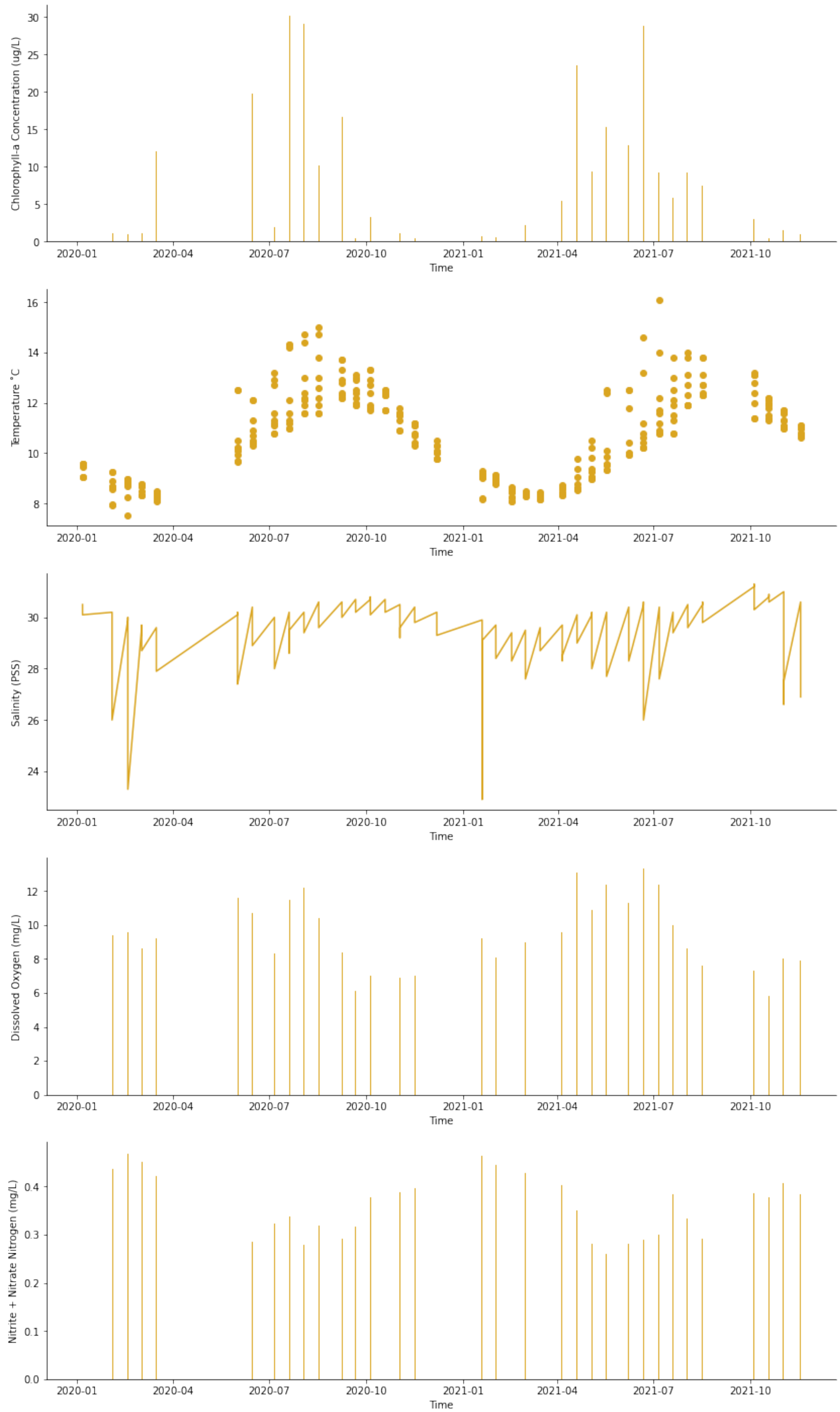

Fig. 12. Jefferson Head station with water quality graphs for peak years 2020-2021.

Discussion

Dockton Park station had the highest number of dinoflagellate blooms that had a high average at the station. This could be due to it being a well protected shallow bay, with higher than average temperature peaks at 30˚C. Peak blooms occurred on average in september, as well as chlorophyll-a concentration, temperature, and salinity measurements. The peaks in biovolume occurring at peaks for the aforementioned parameters support the hypothesis that dinoflagellate genus are dependent on certain conditions for bloom, and high volume. At Dockton Park, high levels of chlorophyll-a, temperature and salinity along with minimum levels of dissolved oxygen and nitrite are the ideal conditions for species that have a high biovolume there.

West Point Outfall is shown to have a June peak in biovolume for *noctiluca*, the genus with highest biovolume at the site. Compared to other stations, a peak biovolume of 192.6 mm^3/L is extreme. Referring to the phenomenon of noctiluca losing bioluminescent properties, this is a curious result. While the genus may be losing some of its original functions, it seems to be thriving in the conditions at West Point Outfall of high chlorophyll-a, and moderate temperatures of 15˚C Celsius during the June peak. Dissolved oxygen measurements peaked during the peak biovolume period of June, with nitrite concentrations at a minimum, indicating that *noctiluca* multiple best with these conditions, holding steady through the demonstrated years of peaks.

Jefferson Head station had yet another period that produced peak biovolume levels, and therefore peak blooms, typically in early spring from April-May. Peaks corresponded with high chlorophyll-a measurements, and again a moderate 15˚C during the peak month of biovolume maximums.

Together, the observations of these three stations can lead to conclusions on preferences of dinoflagellate genus groups. While Dockton Park station is a haven for a plethora of different genus of dinoflagellate, West Point Outfall is a sole winner for *noctiluca*, and Jefferson Head a strong preference of the order peridiniales.

Conclusion

Dinoflagellates are a part of tiny marine ecosystems that thrive on varied conditions. The correlations of bloom during different seasons at different stations are important to note when looking at the health of the Puget Sound as a whole. While this analysis attempted to digest as much data as possible, still more analysis could be done to figure out clearer trends, and potentially dispel questions on why the dinoflagellate order with the highest biovolume has no clear trends relating to peak bloom. Looking at some of the data however, this kind of analysis is important, because where there are trends to see, any variation in documented trends could be cause for concern.

References

Christopher J. Gobler, Owen M. Doherty, Theresa K. Hattenrath-Lehmann, Andrew W. Griffith, Yoonja Kang, R. Wayne Litaker(2017). Ocean warming has expanded niche of toxic algae/ Proceedings of the National Academy of Sciences May 2017, 114 (19) 4975-4980; DOI: 10.1073/pnas.1619575114

Dae-Il Kim, Yukihiko Matsuyama, Sou Nagasoe, Mineo Yamaguchi, Yang-Ho Yoon, Yuji Oshima, Nobuyoshi Imada, Tsuneo Honjo, Effects of temperature, salinity and irradiance on the growth of the harmful red tide dinoflagellate *Cochlodinium polykrikoides* Margalef (Dinophyceae), *Journal of Plankton Research*, Volume 26, Issue 1, January 2004, Pages 61–66, https://doi.org/10.1093/plankt/fbh001

McCabe, R. M., Hickey, B. M., Kudela, R. M., Lefebvre, K. A., Adams, N. G., Bill, B. D., et al. (2016). An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. *Geophys. Res. Lett.* 43, 10366–10376. doi: 10.1002/2016GL070023

Manning T, Thilagaraj AV, Mouradov D, et al. Diversity of dinoflagellate assemblages in coastal temperate and offshore tropical waters of Australia. BMC Ecol Evol. 2021;21(1):27. Published 2021 Feb 15. doi:10.1186/s12862-021-01745-5

Stephanie K. Moore; Nathan J. Mantua; Jonathan P. Kellogg; Jan A. Newton. 2008. Local and large-scale climate forcing of Puget Sound oceanographic properties on seasonal to interdecadal timescales. Limnology and Oceanography. 53(5): 1746-1758.

Ribalet, François & Marchetti, Adrian & Hubbard, Katherine & Brown, Kristina & Durkin, Colleen & Morales, Rhonda & Robert, Marie & Swalwell, Jarred & Tortell, Philippe & Armbrust, E. (2010). Unveiling a phytoplankton hotspot at a narrow boundary between coastal and offshore waters. Proceedings of the National Academy of Sciences of the United States of America. 107. 16571-6. 10.1073/pnas.1005638107.

Valiadi, M., de Rond, T., Amorim, A., Gittins, J. R., Gubili, C., Moore, B. S., Iglesias-Rodriguez, M. D., & Latz, M. I. (2019). Molecular and biochemical basis for the loss of bioluminescence in the dinoflagellate *Noctiluca scintillans* along the west coast of the USA. *Limnology and oceanography*, *64*(6), 2709–2724. https://doi.org/10.1002/lno.11309

Winter, D.F., Banse, K. & Anderson, G.C. The dynamics of phytoplankton blooms in puget sound a fjord in the Northwestern United States. *Mar. Biol.* **29,** 139–176 (1975). https://doi.org/10.1007/BF00388986