

Clayoquot Sound Harmful Algal Blooms Investigation of Tofino Inlet – 2019

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Major:	Environmental Science
Abstract:	The University of Washington Tacoma has conducted yearly summer research expeditions to Clayoquot Sound along the west coast of Vancouver Island, British Columbia since in 2000. Data collected in the region examined the changing conditions in water properties at 86 different sites in Clayoquot Sound every summer. This research focused on the data collected from Tofino Inlet in 2019 and was compared to the Tofino Inlet data from 2014. Data was analyzed using GIS maps of nutrient distribution and contour profile plots to determine if rising temperatures from “the Blob”, a warm water anomaly, created more favorable conditions for harmful algal blooms. The 2014 data had some stations with higher surface nutrients than 2019, while 2019 had some stations with higher bottom nutrients when compared to 2014. There was also an overall pattern in Tofino Inlet of warmer temperatures in 2019 than in 2014.
Key Words:	Clayoquot Sound, Tofino Inlet, harmful algal blooms, HABs, nutrients, water properties, the Blob
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This analysis is part of a larger project known as the Clayoquot Sound Harmful Algal Bloom Project that has been ongoing since 2000. Dr. Cheryl Greengrove and Julie Masura have been leading several research teams yearly to study this area to include undergraduates, graduates, middle & high school students, and research scientists. This work began in partnership with Dr. Richard Keil from UW Oceanography and has since led to additional partnerships including Dr. Laura Loucks of the Clayoquot Sound Biosphere Trust and the Raincoast Education Society to name a couple. Please contact Cheryl Greengrove at cgreen@uw.edu or Julie Masura at jmasura@uw.edu with any questions concerning this work.

Introduction

The yearly summer research expeditions to the West coast of Vancouver Island, British Columbia collected data to examine the changing water conditions and determine how these changes affect harmful algal bloom development in the region. This research is important because there are commercial and recreational fisheries and small local populations that are directly affected when harmful algal blooms occur. Data was collected at 86 different sites in Clayoquot Sound every summer since 2000. These expeditions measured temperature, salinity, density, dissolved oxygen, fluorescence, transmissivity, nutrients, phytoplankton, sediments, and microplastics. This study is unique because there has not been this extent of data collected in the region to identify if changes in the ocean bring about conditions that would promote the occurrence of harmful algal blooms.

This study examined data collected at 14 stations in Tofino Inlet, the southernmost inlet of Clayoquot Sound on September 9, 2019 (figure 1). This inlet is 38,892 meters long from the head to the mouth with a mean width of 1,389 meters. This glacially carved fjord has two freshwater heads, Tranquil Creek and Tofino Creek, with a maximum depth of 150 meters and has shallow glacial sills as little as 12 meters deep. In addition to the two headwaters, Kennedy River is another freshwater source into the inlet entering near station 55.

The 2019 data from Tofino Inlet was compared with the 2014 data to see if there were changes in the water properties, both of which experienced effects of the warm water anomaly. The purpose of this study was to test the hypothesis that warmer water conditions created environments that were more favorable for increased productivity, which potentially lead to harmful algal blooms.

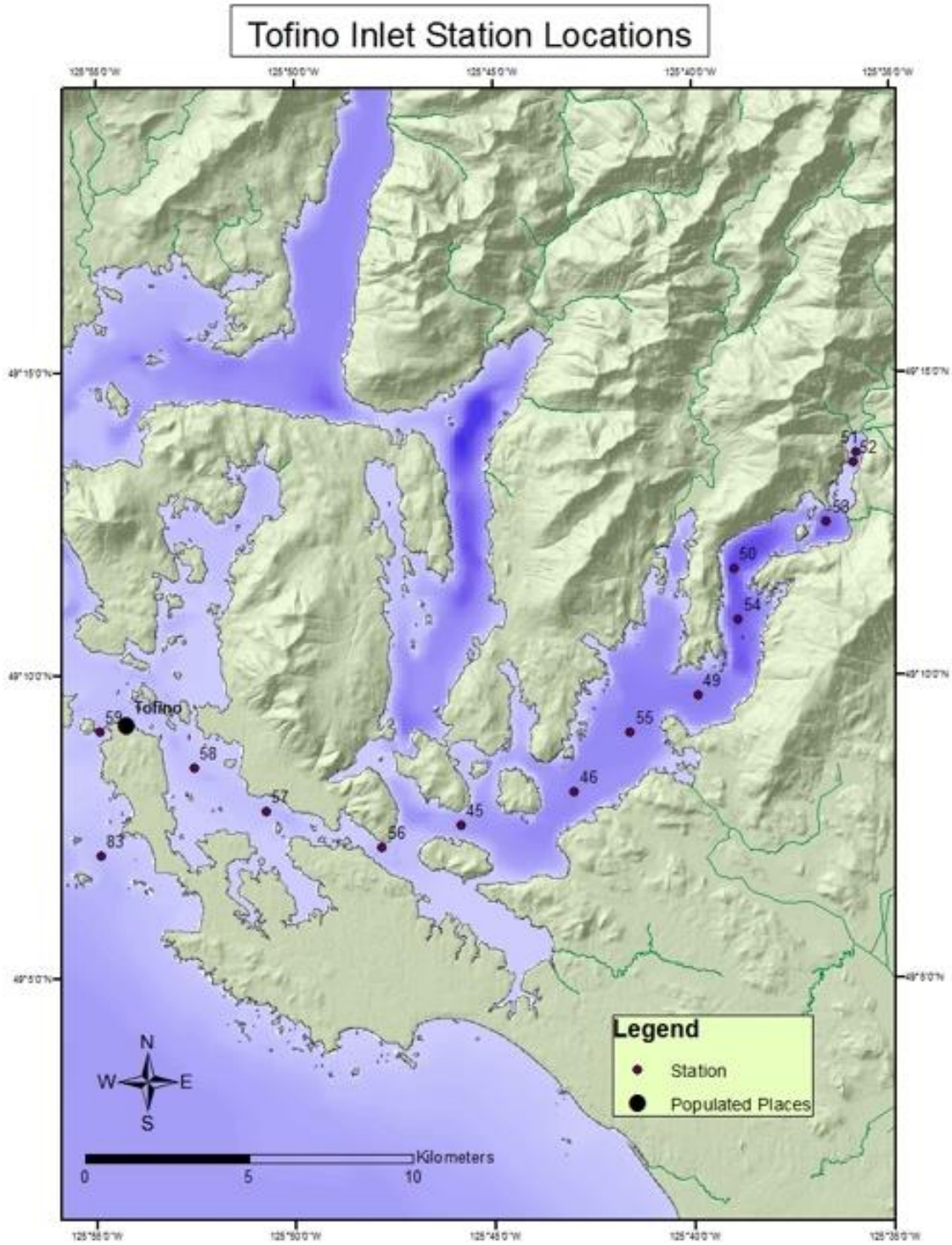


Figure 1. 2019 Tofino Inlet stations sampled in order from mouth to head of inlet: 59, 58, 57, 56, 45, 46, 55, 49, 54, 50, 53, 52 and 51.

Review of Literature

The University of Washington Tacoma has been collecting oceanographic data in Clayoquot Sound's fjords along the west coast of Vancouver Island, British Columbia since 2000. Previous to this work, the fjords were studied by G.L. Pickard in the summer and spring from 1959 to 1962 (Pickard 1963). The ongoing study of the inlets will help to connect changes in global oceanic temperatures to local changes in temperature, salinity, and dissolved oxygen in areas where freshwater and saltwater mix along these coasts.

Pickard's work was the first published research about the temperature, salinity, and dissolved oxygen of the inlets in Clayoquot Sound. In Tofino Inlet, there was a drastic change in surface salinity between two of collection stations located near station 45 (figure 1). An increase in surface temperature of about 4° C was also observed in the middle section of Tofino Inlet, between station 56 and station 45. One of the more unusual observations in Tofino Inlet was that the water temperature began to increase at 30 m from 9.6° C to 15.4° C at 85 m depth, with conditions remaining at 15.4° C to the bottom at 125 m (Pickard 1963). This early research in Clayoquot Sound was a helpful benchmark to compare with the ongoing work in the area.

Understanding the changes in the water conditions of Clayoquot Sound's inlets is important for determining if rising sea surface temperatures can be correlated with an increasing number of yearly algal blooms, because warming conditions may be more conducive to algal bloom development. In October 2013, a warm water mass (+3° C seasonal average) was observed in the North Pacific Ocean that moved eastward over a year-long period (Dewey 2015). Other abnormalities in sea surface temperature of +2° C were observed in the summer

of 2014 off the coast of Baja California that migrated north into the waters off southern California (Dewey 2015). Also in 2014, an unusual warm mass of seawater developed and persisted for 18 months along the west coast of North America, moving south from the coast of Alaska down to the coast of Washington state (Kintisch 2015). The water was 1-4° C warmer than the usual temperature conditions observed along the west coast of North America and was dubbed “the Blob”. This warm mass of water was considered unusual due to its higher temperatures and for the long duration the water was situated along the coast. Warming ocean temperatures were a growing concern for both scientists and the multi-billion dollar fishing industry in the Pacific Ocean.

Harmful algal blooms, like those associated with the dinoflagellate *Alexandrium catenella*, are important to study because *Alexandrium* blooms produce paralytic shellfish toxins (PST) that can lead to paralytic shellfish poisoning. Harmful algal blooms have been increasing in the Puget Sound, an estuary in the Pacific Northwest, since the 1950’s and blooms are sensitive to warmer weather and climate (Greengrove et al. 2014). Further study on this subject is needed because warmer water conditions, as observed from “the Blob”, have the potential to influence the occurrence and severity of harmful algal blooms in coastal regions. The study looked at data from 2019 from a specific region of the west coast of North America where warmer oceanic temperatures were observed during “the Blob”.

Methods

Sampling and Instrumentation

Samples were collected at 13 locations (figure 1) on the Rock Hopper (figure 2) using a SeaBird-19 CTD instrument and closing bottles for collecting discrete water samples (figures 3 & 4). The CTD was used to collect a data profile using temperature, pressure, conductivity and oxygen sensors, as well as a transmissometer and fluorometer (figure 3). The device was lowered into the water at each station and



Figure 2. The Rock Hopper that was used to collect data in Clayoquot Sound (photo credit: C. Greengrove).

internally recorded the data as it moved vertically through the water column. The data from the CTD was then transferred to a computer to calculate the temperature, salinity, density, dissolved oxygen, fluorescence and transmissivity at each station at different depths. Surface and bottom nutrients were also collected at the stations using closing bottles (figure 4). Samples were retrieved by lowering an open bottle to a desired depth and then closing the



Figure 3. CTD instrument being lowered into the water in for data collection (photo credit: C. Greengrove).



Figure 4. Closing bottle used for taking discrete water samples (photo credit: C. Greengrove).

bottle using a jerk line to secure the sample. Once the bottle was back on the boat, the nozzle was opened to collect the sample and then stored in a cooler. The nutrient samples were frozen and sent to the University of Washington Seattle Oceanography Chemistry Lab for analysis (UWO 2019).

Data Analysis

The data was analyzed using spreadsheets, nutrient concentration maps, and contoured profile plots. Excel was used to create statistical 5-number summaries of nutrient data (tables 1 & 2) and graphs of tidal and meteorological properties (figures 5-9). The tide heights were graphed for the week of data collection. Meteorological graphs (air temperature, air pressure, wind speed and wind direction) were created from 5 a.m. to 5 p.m. on September 9, 2019. Choropleth maps of nutrient concentrations were created in ArcGIS for the surface and bottom nutrient data of nitrate (NO_3), silicate ($\text{Si}(\text{OH})_4$) and phosphate (PO_4) (figures 10-12). Surfer was used to create contour profile plots for temperature, salinity, density, dissolved oxygen, fluorescence and transmissivity to see the spatial variations of each property (figures 13-18).

Results

Tides and Weather

Tofino Inlet was sampled on September 9, 2019, where there was a high tide of about 3.1 meters followed by a low tide of about 0.9 meters (figure 5). The temperature was 14°C at 5:00 am and rose steadily throughout the

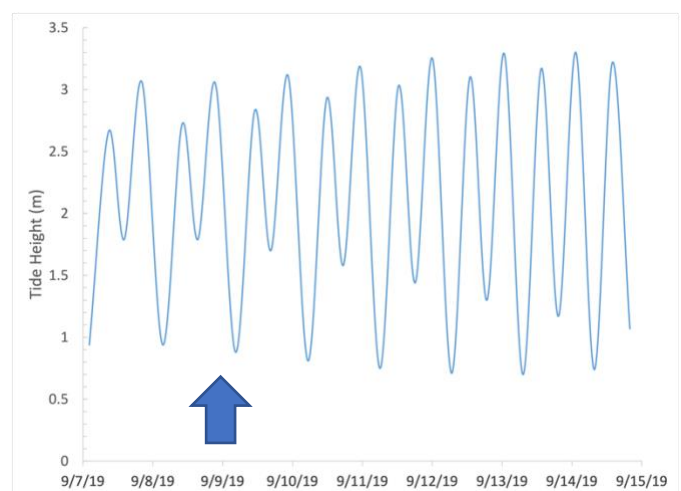


Figure 5. Tide height measured in meters from 9/7/19 to 9/15/19 in Tofino Inlet. Day of sampling was on 9/9/19 with a high tide of about 3.1 meters and a low tide of about 0.9 meters (Mobile Graphics 2019).

Table 1. Five-number summary of surface nutrient data collected from Tofino Inlet in 2019.

Surface Data	PO ₄	Si(OH) ₄	NO ₃	NO ₂	NH ₄
Minimum	0.03	5.33	0.02	0	0
Q1	0.045	6.2925	0.0275	0	0
Q2	0.21	8.26	0.045	0.015	0
Q3	0.6925	11.36	2.64	0.2175	0.68
Q4	1.1	18.02	3.95	0.32	1.89
Mode	0.03	#N/A	0.02	0	0

Table 2. Five-number summary of bottom nutrient data collected from Tofino Inlet in 2019.

Bottom Data	PO ₄	Si(OH) ₄	NO ₃	NO ₂	NH ₄
Minimum	0.61	5.14	0	0.01	0
Q1	1.4225	20.93	3.275	0.0175	0.1875
Q2	1.76	28.41	7.23	0.05	0.965
Q3	2.2625	47.2825	12.43	0.1425	3.805
Q4	7.07	74.91	14.89	0.37	46.6
Mode	#N/A	#N/A	#N/A	0.01	0

day, peaking at 2:00 pm with a temperature of 19.5° C and fell to 17° C by 5:00 pm (figure 6). Air pressure at 5:00 am was 100.73 kPa, increased to the high of 100.824 kPa at 11:30 am, fell sharply to 100.76 kPa from 2:00 pm to 4:00 pm and finally began to increase again to 100.765 kPa at 5:00 pm (figure 7). Wind speed at 5:00 am was 3 km/h, dipped slightly to 2 km/h at 7:00 am, increased throughout the day to 12.5 km/h at 11:00 am, reached the high windspeed of 21 km/h at 3:30 pm, and declined to the final recording of 17 km/h at 5:00 pm (figure 8). The wind was a northeasterly wind for most of the day, varying from the compass direction of 36° in the morning to 19° at 9:00 am and varied from the direction of 20-27° for the remainder of the day (figure 9).

Nutrients

Nutrient distribution data collected in Tofino Inlet was mapped for surface nitrates, silicates, and phosphates at stations 45, 51, 53, 54, 55, 57, 58, and 59 and bottom nutrients at stations 45, 51, 53, 54 and 55 (figures 10-12). Five number summaries were created for the surface and bottom nutrient data to determine the statistical distribution (tables 1 & 2).

The overall trend for nitrate concentration in Tofino Inlet from 2019 was a higher concentration of nitrates at the bottom than at the surface. The surface concentrations of nitrate ranged from 0.02-3.95 μM and the bottom concentrations of nitrate ranged from 0-14.89 μM (tables 1 & 2). The lowest concentration of nitrates at the surface was 0.02 μM at stations 51 and 55 and the lowest concentration of nitrates at the bottom was 0 μM at station 51 (figures 10a, 10b). The highest concentration of nitrate at the surface nitrate was 3.95 μM at station 58 and the highest bottom nitrate was 14.89 μM at station 54.

Overall, the concentration of silicates increased at increased depths in Tofino Inlet. The

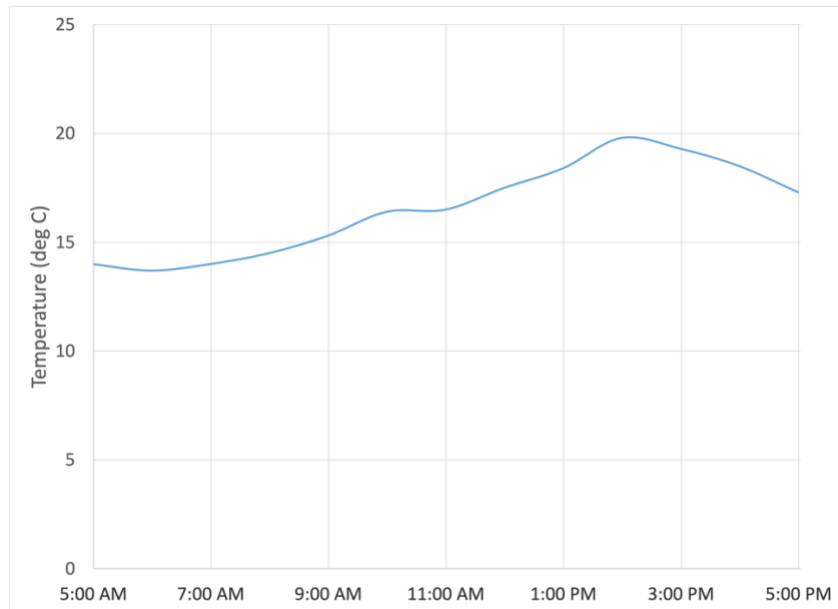


Figure 6. Temperature measured in degree Celsius on 9/9/19 in Tofino Inlet from 5:00 am to 5:00 pm. At 5:00 am the temperature was 14° C, rose steadily to a high of 19.5° C at 2:00 pm, and fell to about 17° C at 5:00 pm (Government of Canada 2019).

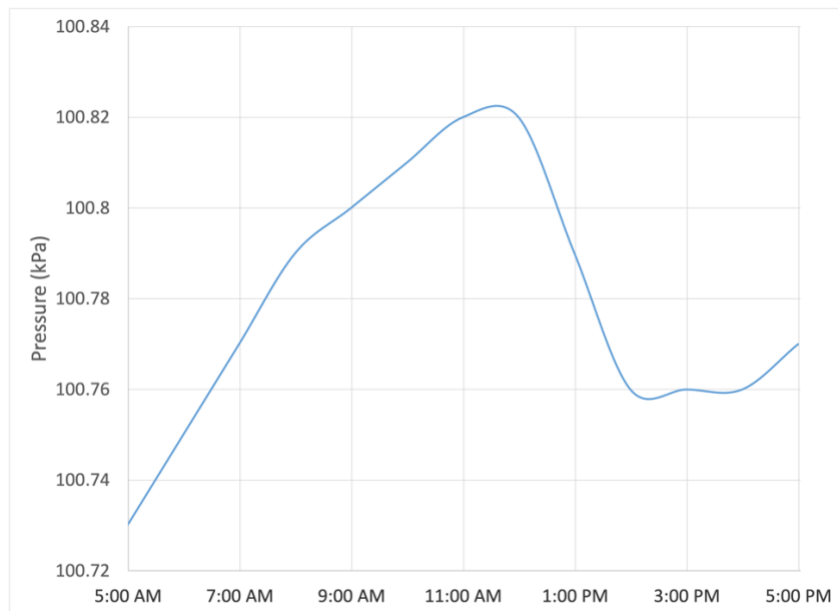


Figure 7. Air pressure measured in kPa on 9/9/19 in Tofino Inlet from 5:00 am to 5:00 pm. At 5:00 am the air pressure was at 100.73 kPa and increased throughout the day to the high of about 100.824 kPa at 11:30 am. The pressure dipped down to 100.76 kPa from 2:00 pm to 4:00 pm, rising to 100.765 kPa at 5:00 pm (Government of Canada 2019).

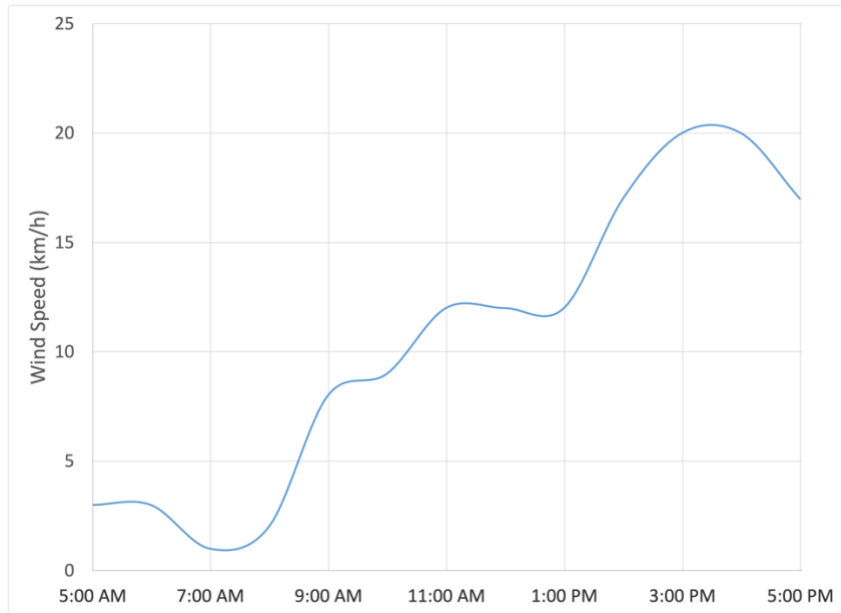


Figure 8. Wind speed measured in km/h on 9/9/19 in Tofino Inlet from 5:00 am to 5:00 pm. At 5:00 am the wind speed was about 3 km/h and dipped slightly to about 2 km/h at 7:00 am. The wind speed then increased to 12.5 km/h at 11:00 am and reached a high of 21 km/h at 3:30 pm before dipping back to about 17 km/h at 5:00 pm (Government of Canada 2019).

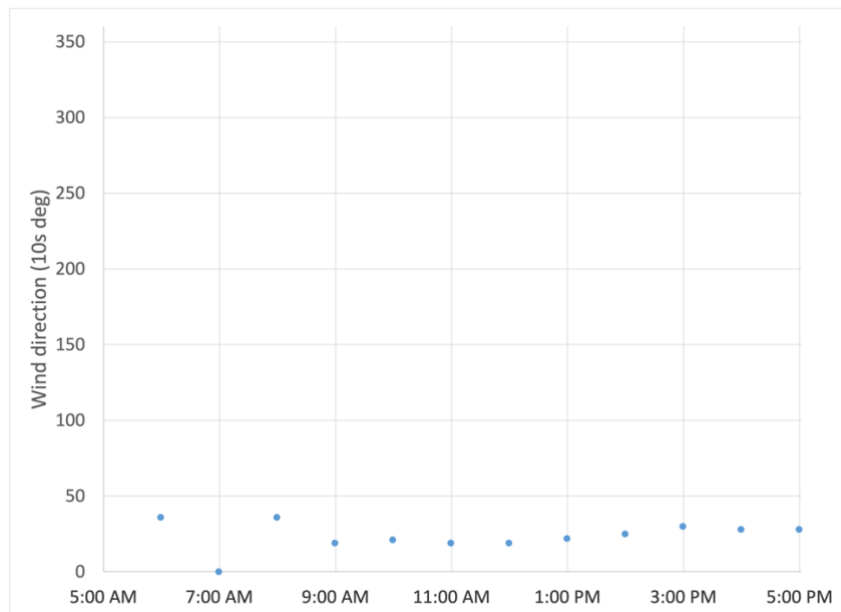


Figure 9. Wind direction measured in 10 second degrees on 9/9/19 in Tofino Inlet from 5:00 am to 5:00 pm. At 5:00 am the wind was at about 36°, indicating a northeasterly wind direction. From 9:00 am to 5:00 pm the wind went from about 20° to 27° (Government of Canada 2019).

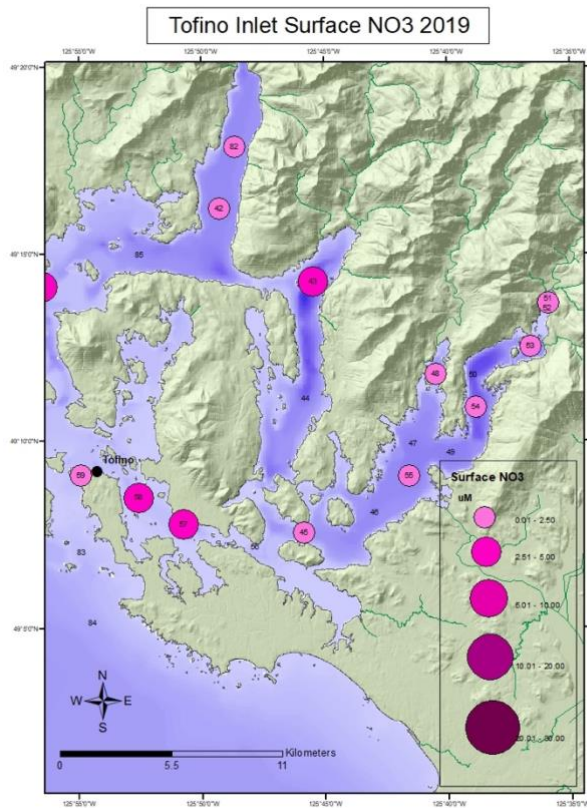
surface concentrations of silicates ranged from 5.33-18.02 μM and the bottom concentrations of silicates ranged from 5.14-74.91 μM (tables 1 & 2). The lowest concentration of silicates at the surface was 5.33 μM at station 59 and the lowest concentration of bottom silicates was 5.14 μM at station 59 (figures 11a, 11b). The highest concentration of surface silicate was 18.02 μM at station 57 and the highest concentration of bottom silicate was 74.91 μM at station 51.

There was a greater concentration of phosphates in Tofino Inlet at the bottom than there was at the surface. The surface concentrations of phosphates ranged from 0.03-1.1 μM and the bottom concentrations of phosphates ranged from 0.61-7.07 μM (tables 1 & 2). The lowest concentration of phosphates at the surface was 0.03 μM at stations 53 and 54 and the lowest concentration of bottom phosphates was 0.61 μM at station 59 (figures 12a, 12b). The highest concentration of surface phosphate was 0.59 μM at station 59 and the highest bottom phosphate was 7.07 μM at station 51.

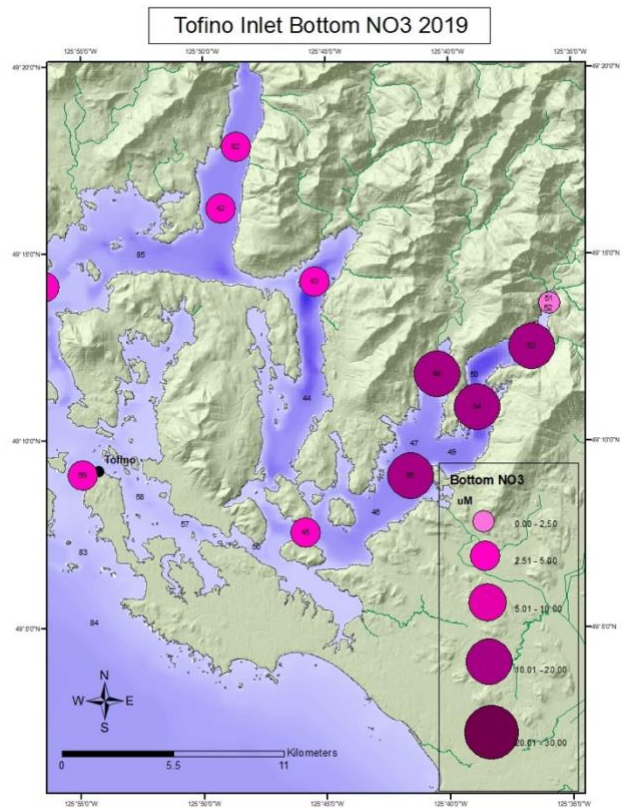
Profile Contour Maps

The water temperature from Tofino Inlet showed the warmest temperature (16° C) spanned almost the entire water column at station 56 (figure 13a). There were also higher temperatures, ranging from 17.5° C to 20° C, along the top 5 meters of the water column from station 45 to station 51. The station closest to the open ocean had a water temperature of 14.5° C. The deepest part of Tofino Inlet was 13° C at 120 m. The coldest temperature recorded in the inlet was 12° C taken 45 meters below the surface at station 51.

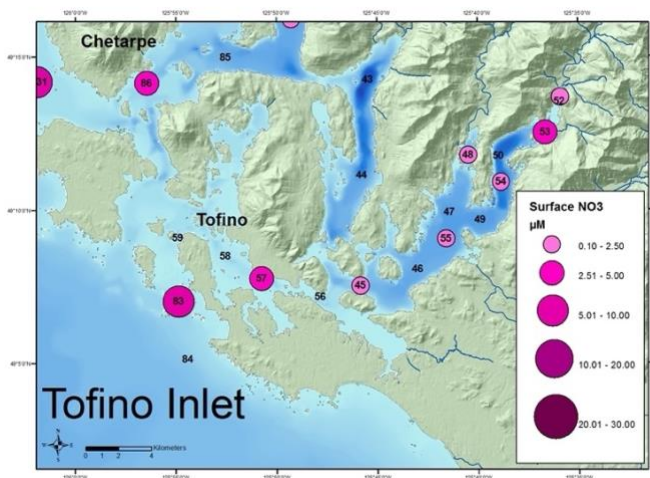
The highest salinity sampled from Tofino Inlet was 31.5 PSU at station 59. The lowest salinity readings were found in the top 1-meter to 5-meter depth from station 56 to the head



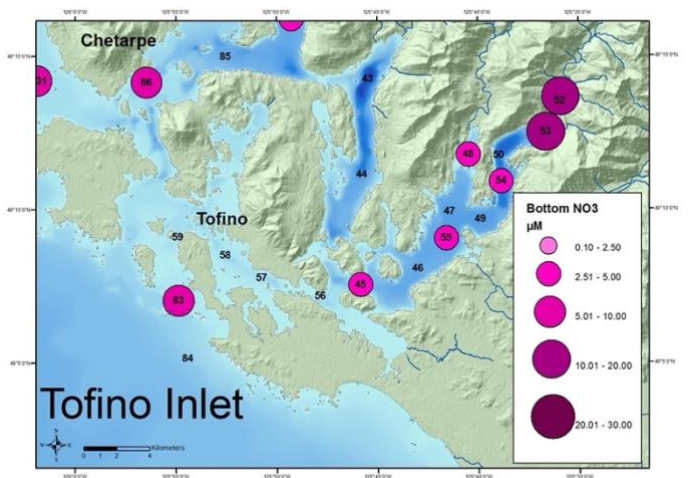
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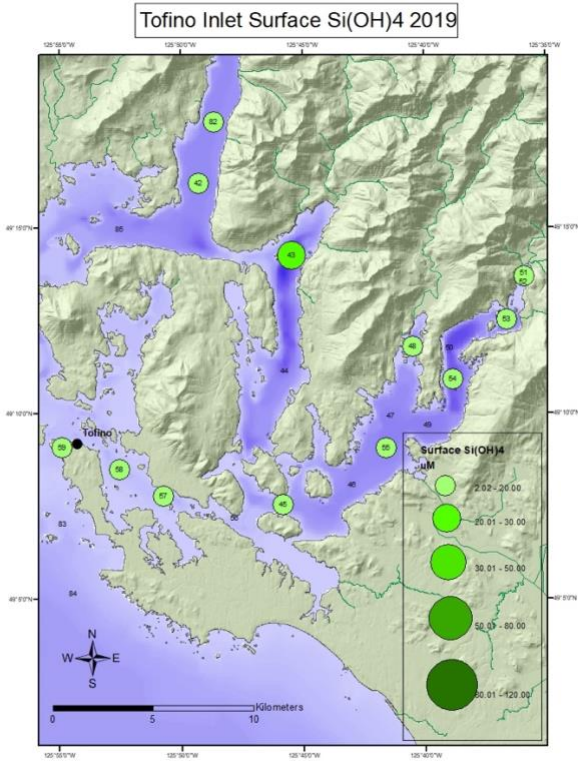


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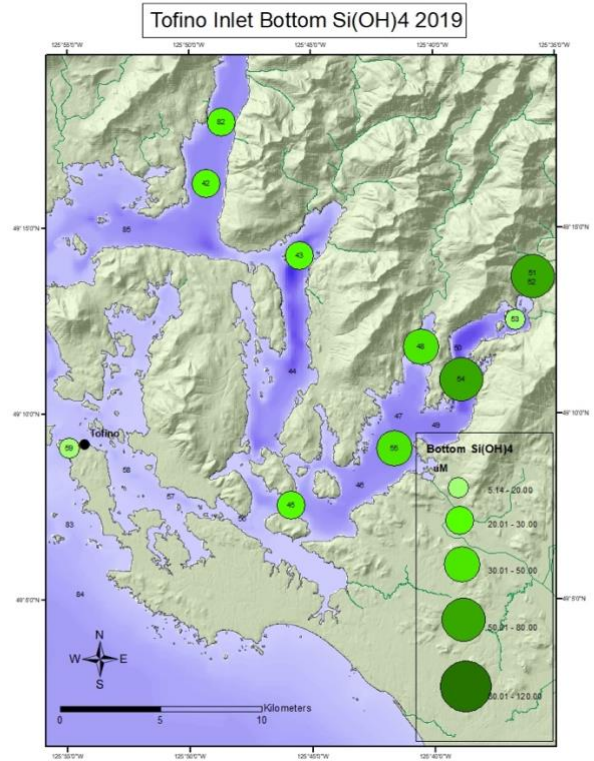


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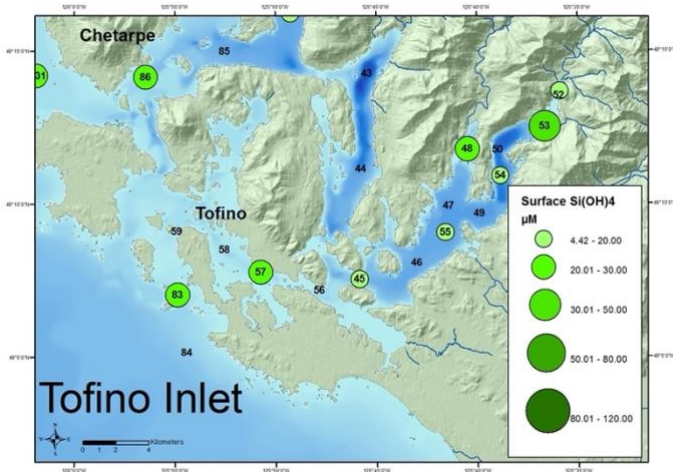
Figure 10. (a) 2019 surface NO_3 measured in μM . The highest surface concentrations of NO_3 were collected at station 58 and station 57 at 2.51-5.00 μM NO_3 . The lowest surface concentrations were collected at stations 45, 51, 53, 54, 55 and 59 with was 0.01-2.50 μM NO_3 . (b) 2019 bottom NO_3 concentrations. The highest bottom concentrations of NO_3 were collected at stations 55, 48, 54 and 53 with 10.01-20.00 μM NO_3 . The lowest bottom concentration was collected at station 51 with 0 μM NO_3 . Bottom nutrients for station 57 and 58 were not collected. (c) 2014 surface concentrations of NO_3 for comparison (Baer 2020). (d) 2014 bottom concentrations of NO_3 for comparison (Baer 2020).



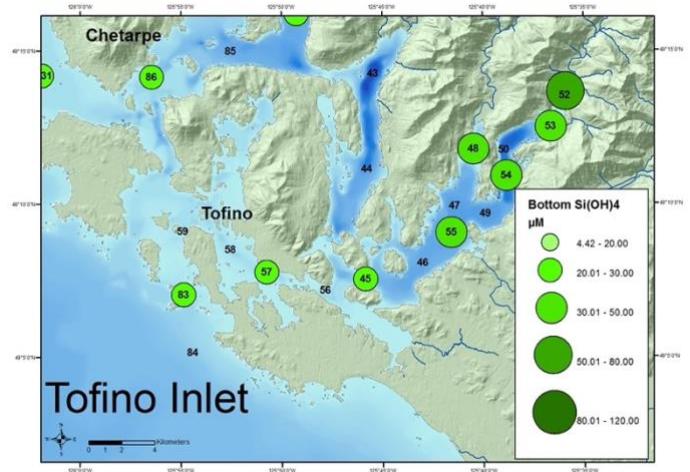
(a)



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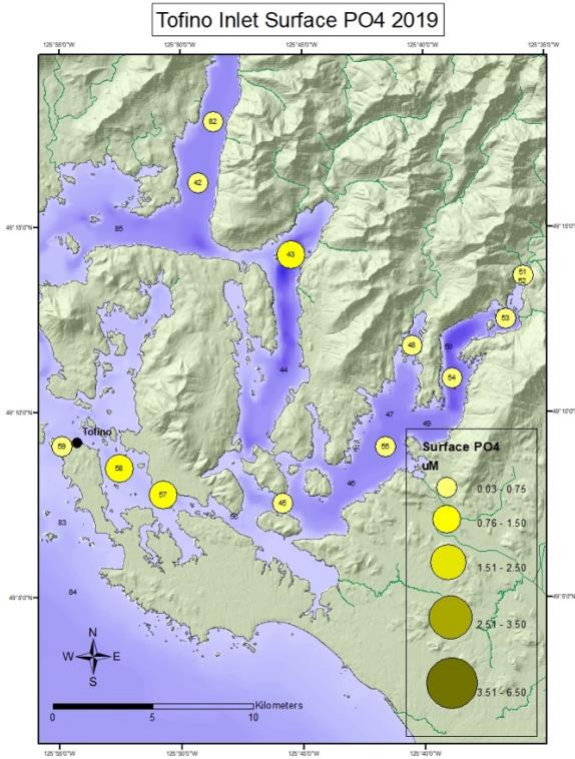


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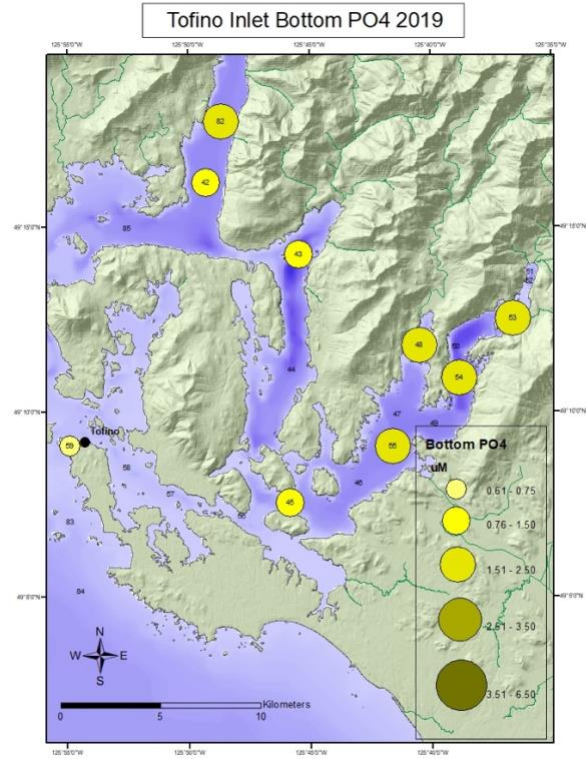


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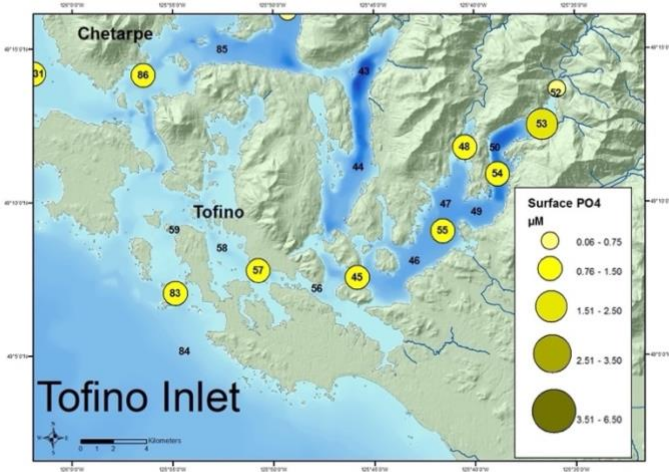
Figure 11. (a) 2019 surface Si(OH)_4 concentrations measured in μM . Stations 59, 58, 57, 45, 55, 54, 53 and 51 all had 2.02-20.00 μM Si(OH)_4 . (b) 2019 bottom Si(OH)_4 concentrations. The highest bottom concentrations of Si(OH)_4 were collected at stations 54 and 51 with 50.01-80.00 μM Si(OH)_4 . The lowest bottom concentrations were collected at station 59 and 53 with 5.14-20.01 μM Si(OH)_4 . Bottom nutrients for station 57 and 58 were not collected. (c) 2014 surface concentrations of Si(OH)_4 for comparison (Baer 2020). (d) 2014 bottom concentrations of Si(OH)_4 for comparison (Baer 2020).



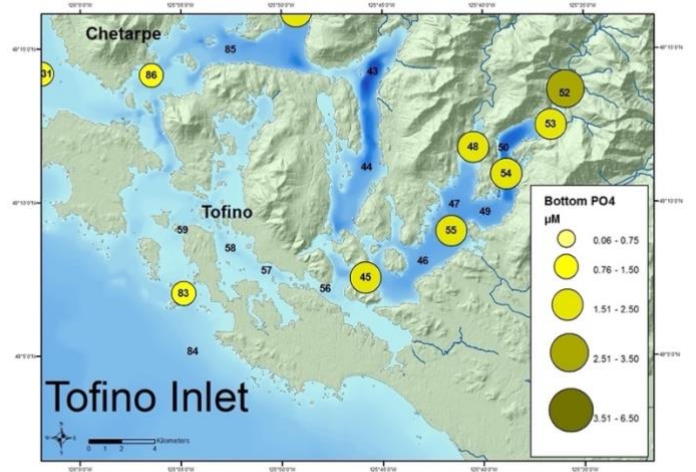
(a)



(b)



(c)



(d)

Figure 12. (a) 2019 surface PO_4 data measured in μM . The highest surface concentration PO_4 were collected at station 58 and 57 at 0.76-1.50 μM PO_4 . The lowest surface concentrations were collected at 45, 51, 53, 54, 55, and 59 with 0.03-0.57 μM PO_4 . (b) 2019 bottom PO_4 concentrations. The highest bottom concentrations of PO_4 were collected with at stations 55, 54 and 53 with 1.51-2.50 μM PO_4 . The lowest bottom concentration was collected at station 59 with 0.61-0.75 μM PO_4 . Bottom nutrients for station 57 and 58 were not collected and station 51 not mapped. (c) 2014 surface concentrations of PO_4 for comparison (Baer 2020). (d) 2014 bottom concentrations of PO_4 for comparison (Baer 2020).

of the inlet at station 51 (figure 14a). Near the bottom of the deepest part of the inlet, at 60 meters, there was a lower salinity layer of 29 PSU separated by two layers of 29.5 PSU.

The highest density in Tofino Inlet from 2019 was near the mouth at stations 59 and 58 ranging from 24 kg/m² to 25 kg/m² (figure 15a). The density decreased toward the head of the inlet. There was a pocket of low-density water below station 59 at about 40 meters with a density of 21.5 kg/m². The deepest region of the inlet, at 120 meters, the density measurement was 22 kg/m². A low-density band of water ranging from 21 kg/m² to 15 kg/m² was recorded at the surface down to about 7 meters, from station 56 to 51.

The dissolved oxygen plots for 2019 in Tofino Inlet showed higher dissolved oxygen near the mouth of the inlet, along the top of the water column, and near the head of the inlet. The dissolved oxygen ranged from 6 mL/L to 7 mL/L near the mouth of the inlet at station 59 from 5 meters to 25 meters (figure 16a). From station 58 to station 45 there was a pocket at the top of the water column with a dissolved oxygen content of 0 mL/L to 1.5 mL/L, indicating anoxic conditions. There was another pocket of water with low dissolved oxygen at the bottom of the inlet at stations 52 and 51. At 35 to 40 meters at these two stations there was near hypoxic conditions with dissolved oxygen content of 2 mL/L to 3 mL/L.

The 2019 data for Tofino Inlet showed mostly 0 mg/m³ fluorescence throughout the mouth of the inlet and at the deepest sections. The concentration of fluorescence started to increase toward the opening of the inlet to the ocean where there is more productivity, reaching 10-15 mg/m³ near station 59 (figure 17a).

Transmissivity marks the amount of material in the water, that material can include phytoplankton and other solid material in the water. The transmissivity for Tofino Inlet showed

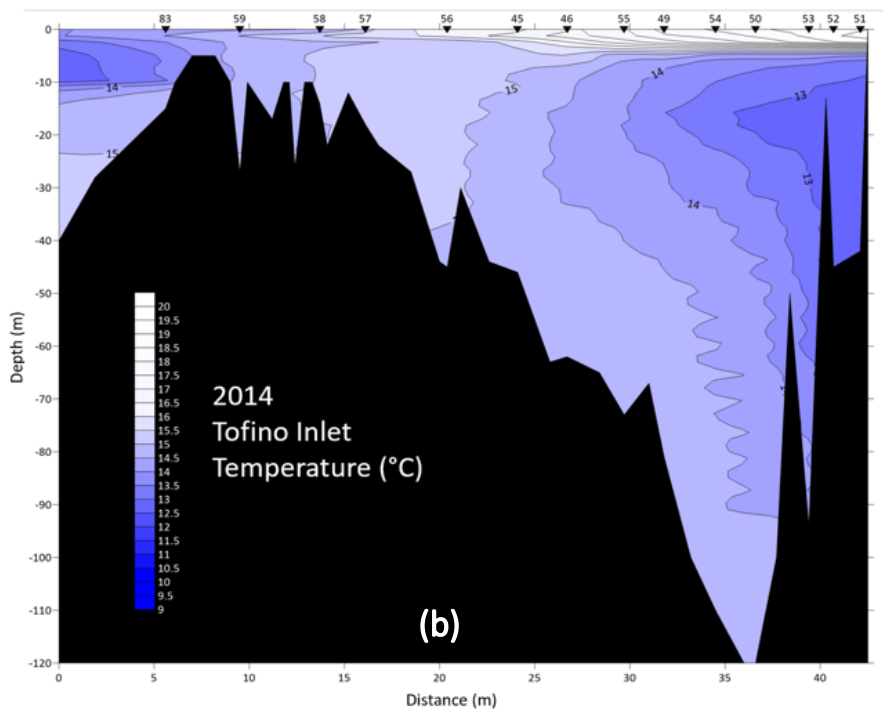
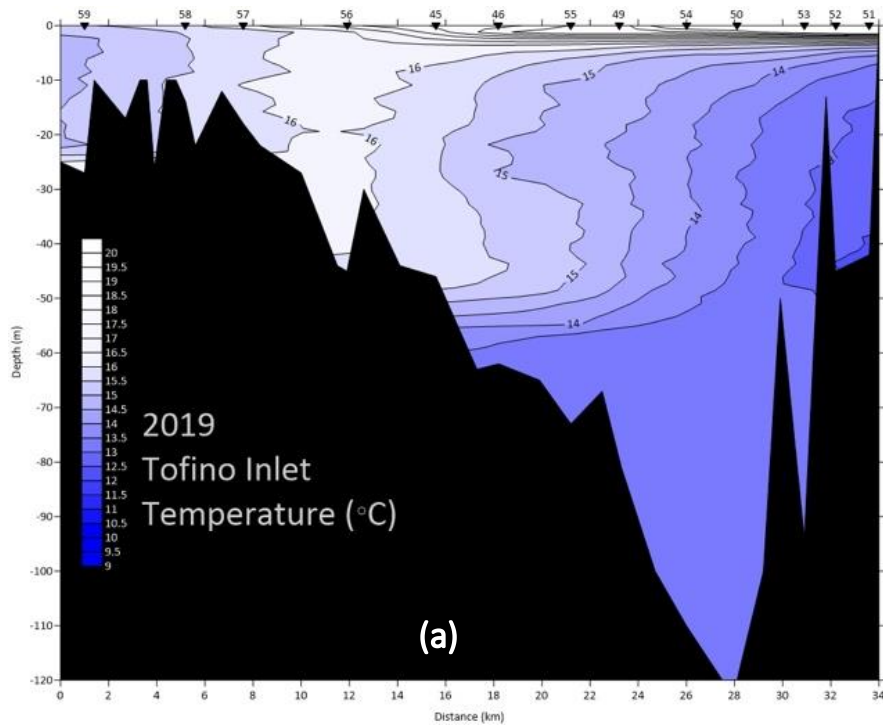


Figure 13. Temperature contour profile plots for Tofino Inlet measure in degrees Celsius. (a) 2019 temperature plot displaying the highest temperatures at station 56 and along the top of the water column from the head of the inlet to station 57. Lowest temperatures were in the deepest part of the inlet below station 50 and at the bottom of the mouth of the inlet at station 51. (b) 2014 temperature plot showing the highest temperature along the top 5 meters of water from the head of the inlet to station 56. The coldest temperatures were at the mouth of the inlet nearest the ocean and at the bottom near the head of the inlet at station 51. Note that the distance measurements on the x-axis should be in kilometers (Baer 2020).

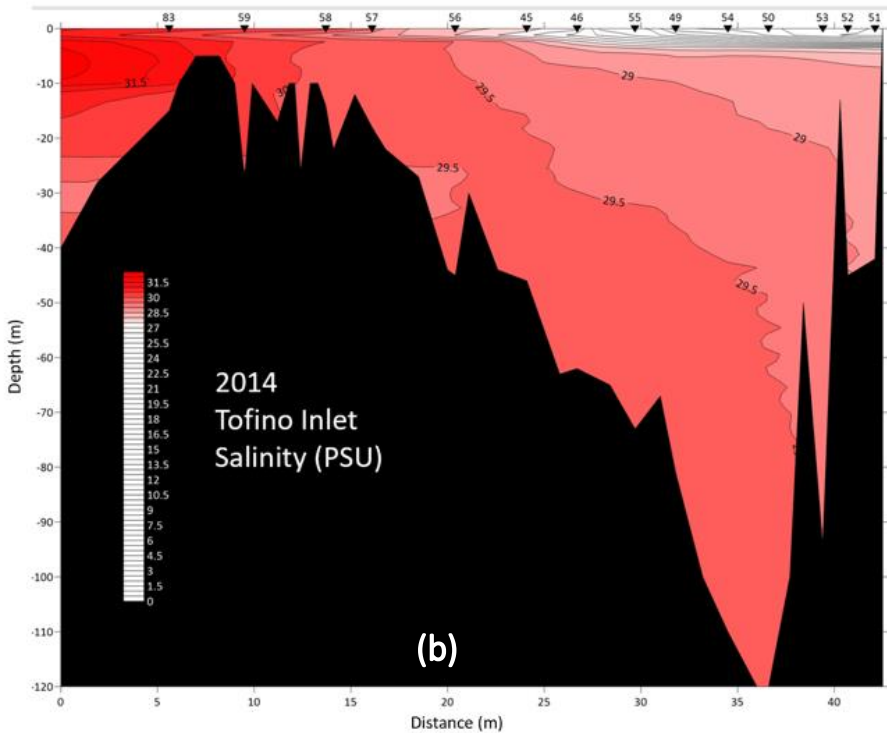
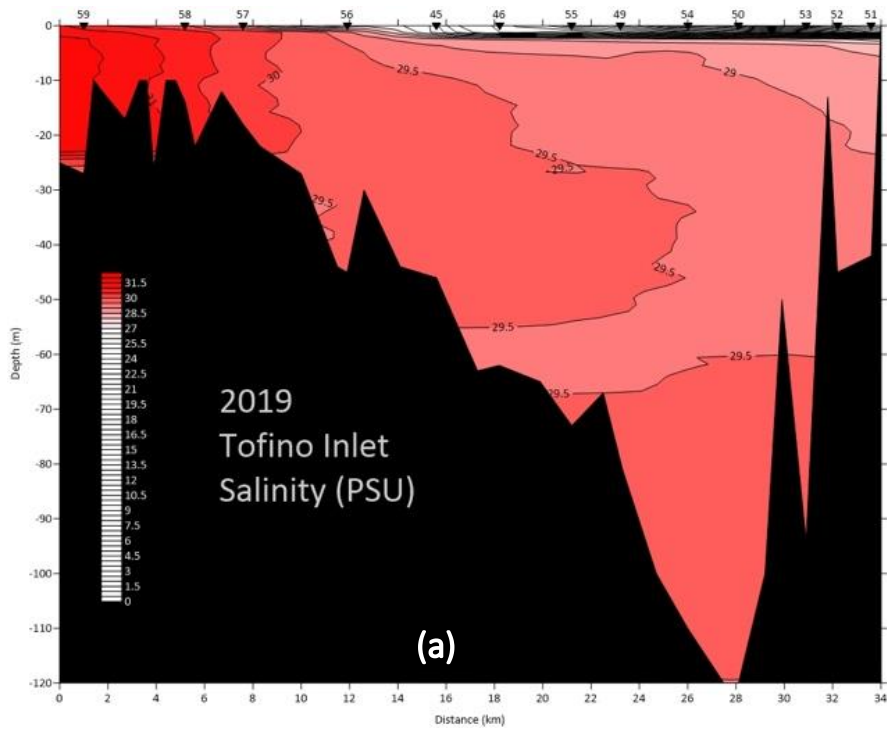


Figure 14. Salinity contour profile plots for Tofino Inlet measured in PSU. (a) 2019 salinity plot displaying the highest salinity at station 59 at the mouth of inlet to the ocean. The lowest salinity was recorded in the first 5 meters of the water column from the head of the inlet at station 51 to station 45. (b) 2014 salinity plot showed highest salinity at stations near the ocean (83 and 59). Lowest salinity was observed to be in the first 5 meters of the water column spanning from the head of the inlet at station 51 to station 45. Note that the distance measurements on the x-axis should be in kilometers (Baer 2020).

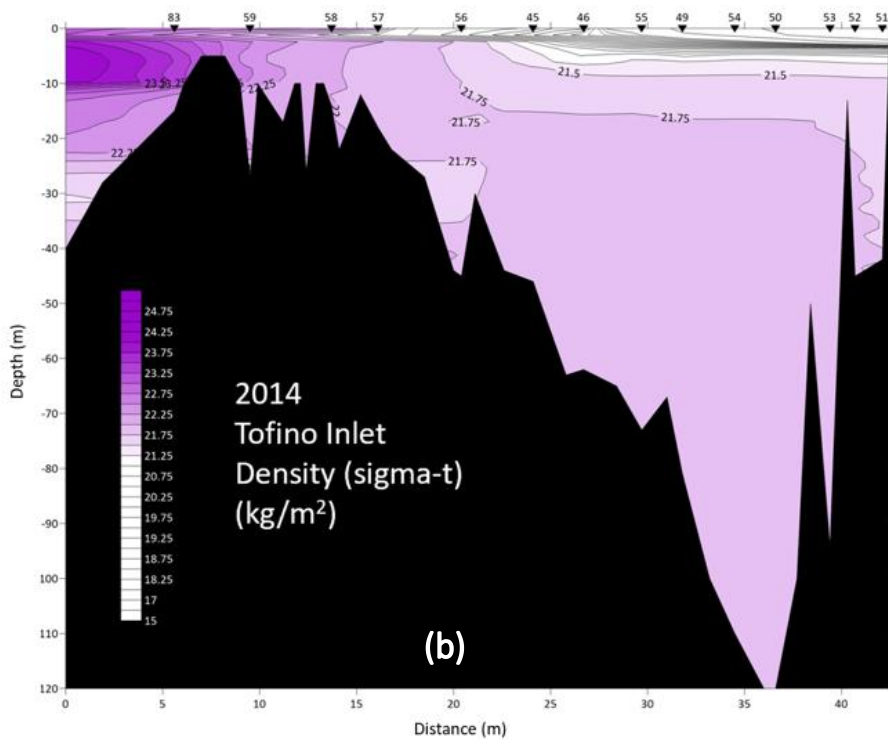
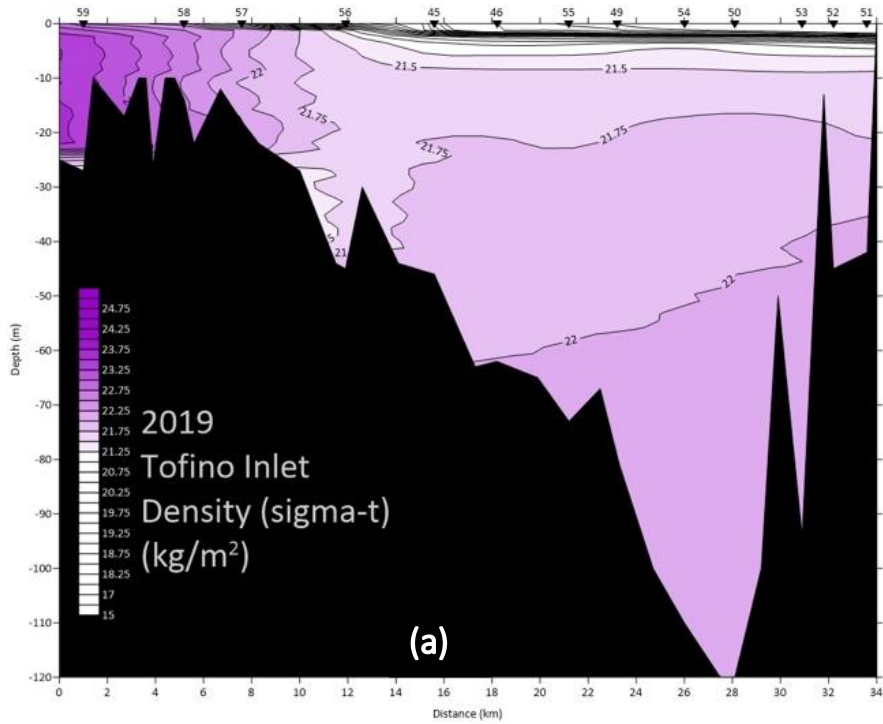


Figure 15. Density contour profile plot for Tofino Inlet measured in kg/m². (a) 2019 density plot displaying the highest density at station 50 at the mouth of the inlet. The lowest densities were observed below the midpoint of station 57 and 58 at 35 meters and long the first 10 meters of the water column from station 56 all the way to station 51. (b) 2014 contour profile plot of density showed the highest density from 0-10 meters at station 83 and the lowest density was along the top of the water column from the head of the inlet to station 57. Note that the distance measurements on the x-axis should be in kilometers (Baer 2020).

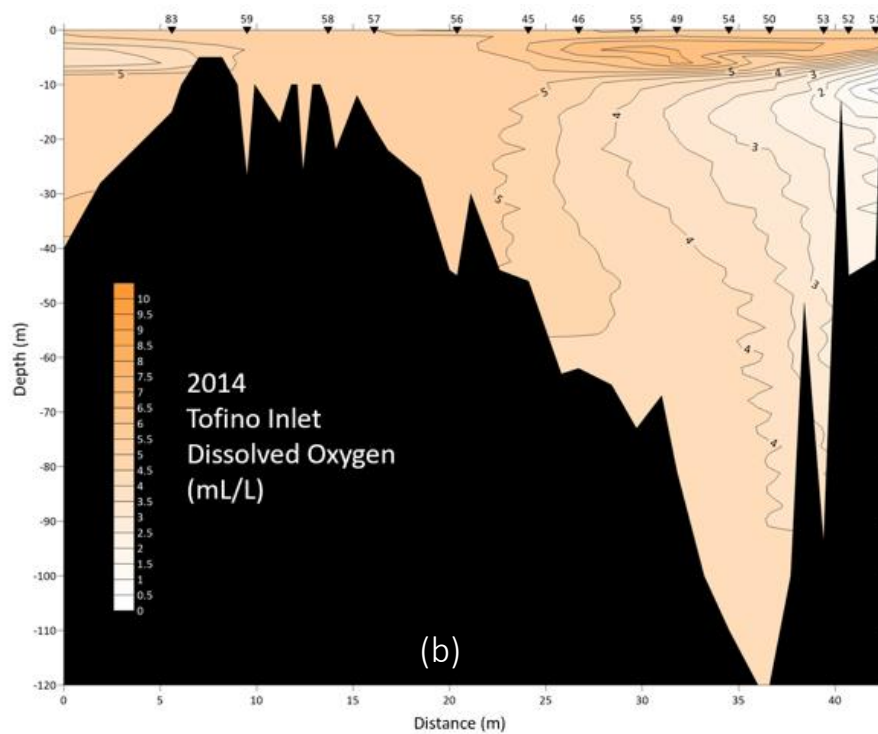
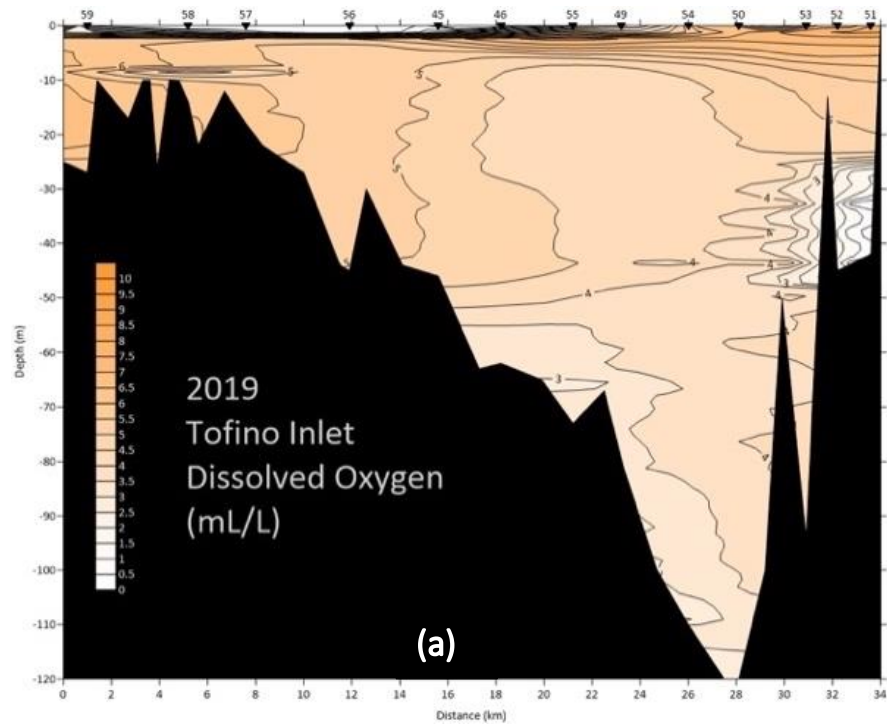


Figure 16. Dissolved oxygen contour profile plots for Tofino Inlet measured in mL/L. (a) 2019 dissolved oxygen content was highest near the head and the mouth of the inlet. The lowest dissolved oxygen was along the top 4 meters of the water column from station 58 up the inlet to station 46. Another pocked of low dissolved oxygen content was measured 30-40 meters below the surface of the water at stations 52 and 51. (b) 2014 dissolved oxygen content from Tofino Inlet. Note that the distance measurements on the x-axis should be in kilometers (Baer 2020).

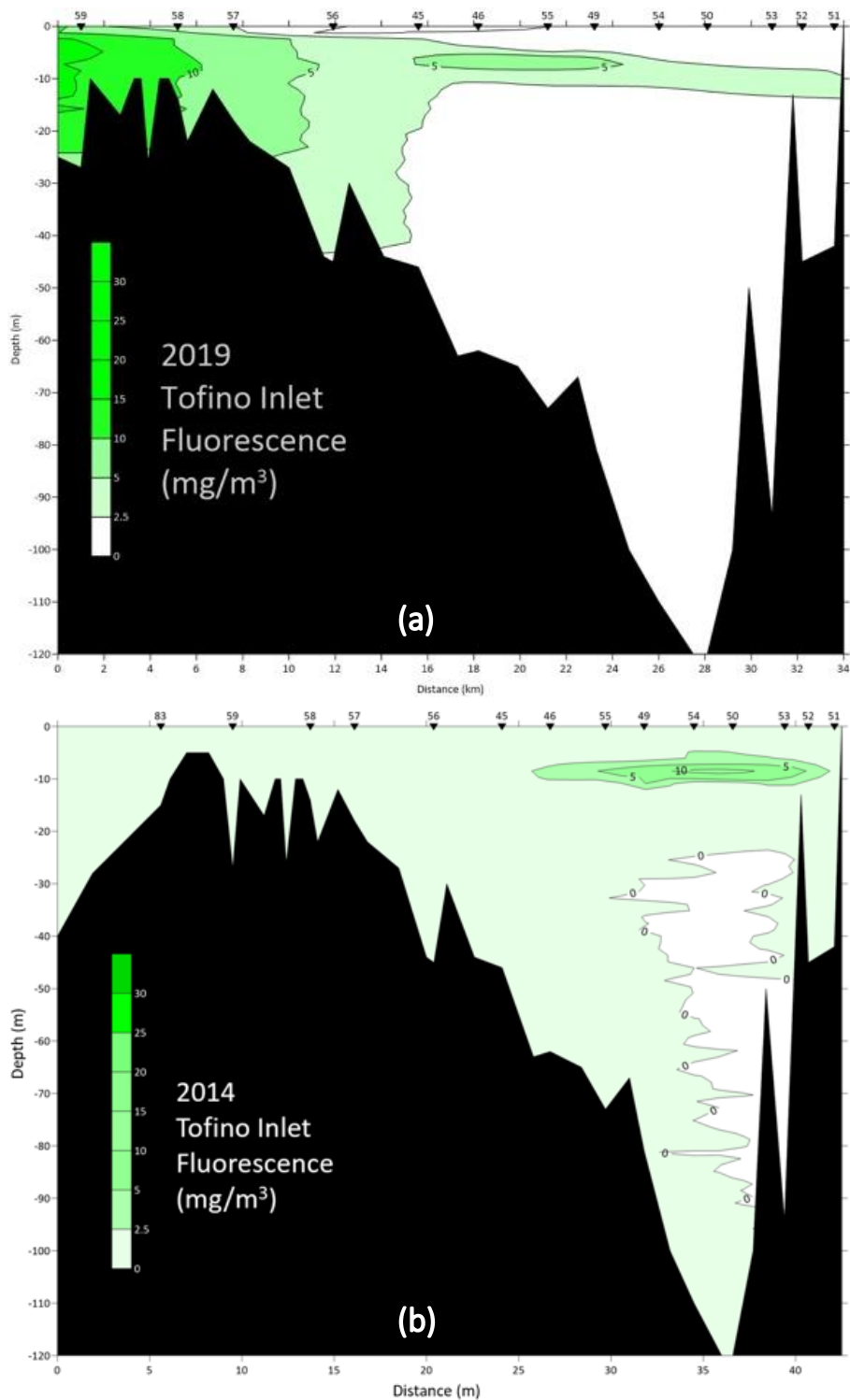


Figure 17. Fluorescence contour profile plots for Tofino inlet measured in mg/m³. (a) 2019 fluorescence data showing the highest measurement of 15 mg/m³ near the mouth of the inlet at station 59. Low fluorescence of 0 mg/m³ was recorded for most of the inlet from starting 10 meters down from stations 46 to station 51. (b) 2014 fluorescence in Tofino Inlet showed a mostly uniform distribution of 2.5 mg/m³ for most of the stations. There was a pocket of higher fluorescence at 10 meters down at station 46 to 52 of 5-10 mg/m³. A pocket of 0 mg/m³ was recorded below station 50 from about 20 meters to 90 meters below the surface. Note that the distance measurements on the x-axis should be in kilometers (Baer 2020).

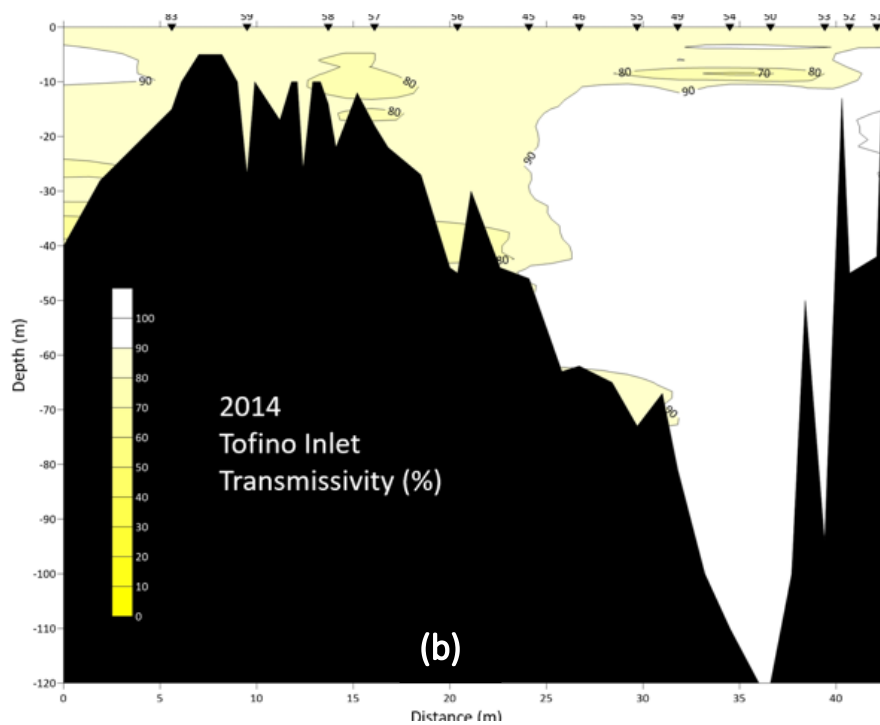
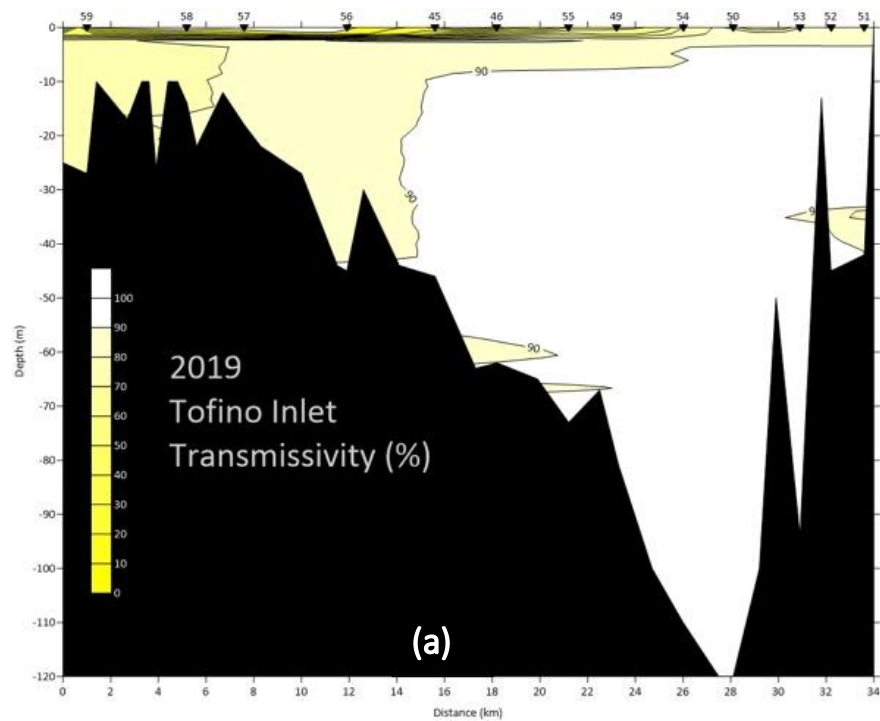


Figure 18. Transmissivity contour profile plots for Tofino Inlet measured in percent transmissivity. (a) 2019 data showed a large section of the inlet with 90%-100% transmissivity from station 45 to 51 starting at about 10 meters. The highest transmissivity was recorded in the first 5 meters of the water column from station 49 all the way to the mouth of the inlet at station 59. (b) 2014 transmissivity plot showed a pocket of 90%-100% transmissivity from 10 meters down the water column spanning stations 46 to station 51. Two pockets had the lowest transmissivity recorded about 10 meters below, one at station 58 and 57 of 70% and another below station 55 to station 53 of 60%-70% transmissivity. Note that the distance measurements on the x-axis should be in kilometers (Baer 2020).

90%-100% transmissivity at the deepest part of the inlet at 120 meters (figure 18a).

Transmissivity decreased towards the surface of the water at all stations ranging from 80% to 20% at 0 to 10 meters depth. The 2019 data also showed a lower transmissivity towards the ocean at stations 58 and 59, with a transmissivity range of 90%-80%.

Discussion

The nutrient maps compiled from the sampling stations in Tofino Inlet showed similar surface nutrients in both years with a few higher concentrations from Tofino Inlet in 2014 compared to the 2019 data. There was an interesting trend of surface nitrate concentrations at station 58 and 57 where there was a high concentration of surface nitrates in 2019 compared to the other stations that year (figure 10). These two stations are located close to the city of Tofino and close to the opening of the inlet to the open ocean to the west. The surface nitrate concentrations for both years were similar for all the stations except for station 53, which was higher in 2014 with a range of 2.51-5.00 μM than 0.01-2.50 μM in 2019. The 2019 results for bottom nitrate concentration showed larger concentrations at the stations further into the inlet at stations 55 and 54 with 10.01-20.00 $\mu\text{M NO}_3$ than in 2014 where these stations had 2.51-5.00 $\mu\text{M NO}_3$ (figure 10b, 10d). Overall, the concentration of surface and bottom nitrates for both years were similar with only a few stations deviating from this pattern.

Most of the data for silicates from 2019 and 2014 had similar concentrations. The surface silicate concentration was higher in 2014 at stations 57 and 53 than in 2019. Station 53 had the largest magnitude of difference in surface silicate concentration with 20.01-30.00 μM in 2014 and 2.02-20.00 μM in 2019. The bottom silicate data was the similar for both years at all stations sampled except for 54 and 53. At station 54 the concentration of bottom silicates

was higher in 2019 (50.01-80.00 μM) than in 2014 (30.01-50.00 μM). At station 53 the silicate concentration at the bottom was higher in 2014 (30.00-50.01 μM) than in 2019 (5.14-20.00 μM).

The phosphate concentrations were similar for both years as the concentration increased in a similar magnitude from the surface to the bottom (figure 12c, 12d). The 2019 data showed lower overall surface phosphate concentrations when compared to 2014. In 2019, stations 45, 55, and 54 had a surface concentration of 0.03-0.75 $\mu\text{M PO}_4$ and in 2014 these stations had a surface concentration of 0.75-1.50 $\mu\text{M PO}_4$. There was an increase in the 2019 concentration of bottom PO_4 at stations 55, 54 and 53 to 1.51-2.50 $\mu\text{M PO}_4$ that was similar to the increase from surface to bottom concentrations in 2014 (figure 12a, 12b). Comparing the 2014 nutrient maps with the 2019 nutrient maps showed evidence that nutrients were overall similar with a few increases and decreases at specific stations.

Temperature, salinity and water density are all linked. Comparing these contour profile plots from 2019 and 2014 were an important metric in determining if there were significant changes that could have been influenced the “the Blob” moving inland. The water temperature distribution in Tofino Inlet from 2014 and 2019 were similar in that the colder temperatures were near the entry to the inlet (near the ocean) and in the deep water near the head of the inlet (figure 13a, 13b). The temperatures in the deep waters near the head of the inlet were 13-12° C in both 2014 and 2019. The temperatures were similar in 2014 and 2019 at station 59, the outer most station for 2019, where the temperature was 15.0-15.5° C (figure 13). The 2019 data had warmer temperatures in the shallow waters of Tofino Inlet below station 56, at about 16° C while the 2014 data the water was cooler below. Warmer water temperatures might

create environments that are more favorable for producing harmful algal blooms and both 2019 and 2014 have temperatures that are optimal at 14° C.

The salinity contour profile plots for 2014 and 2019 were very similar, with the highest salinity near mouth of Tofino Inlet at 31.5 PSU. The freshwater layer was similar in both years and showed that the lowest salinity in Tofino Inlet was where the Kennedy River enters the inlet near station 55. 2019 had a unique salinity pattern near the bottom of the deepest part of the inlet where a lower salinity layer separated the bottom water into two layers (figure 14). The composition of salinity from 2019 indicates that the older water in bottom of the inlet has not been flushed out. The data from 2014 showed a uniform salinity at the deepest section of the inlet where the older water in the inlet had been flushed out.

In the 2019 density plot there was a greater density around stations 58 and 57 than measured in the 2014 data (figure 15). The density of the freshwater layer near the river entering Tofino Inlet was similar in both plots, but in 2019 this layer extended further out of the inlet toward the ocean which indicates further that older intruded water has not mixed yet. Another interesting difference in the two plots was that the 2019 plot showed a greater density layer at the deepest part of inlet than the 2014 data.

Higher levels of dissolved oxygen, fluorescence and transmissivity all imply greater productivity in water systems. The dissolved oxygen plots for 2014 and 2019 had different distribution patterns, with more dissolved oxygen in the upper 25 meters of water in the 2019 data than in the 2014 data. The 2014 data showed more dissolved oxygen in the deepest part of Tofino Inlet at stations 55, 49 and 54 (figure 16). The stations near the head of the inlet, station 52 and 51, exhibited the least amount of dissolved oxygen in both plots at the bottom

where the water is almost anoxic. There were also hypoxic conditions in 2019 near the bottom of Tofino Inlet at stations 50 and 55.

Fluorescence is indicative of productivity which adds to the contribution of dissolved oxygen in the water. The fluorescence plots for 2014 and 2019 were the two contour profile plots with the most differences. The 2014 plots had an overall pattern of most of the water having 2.5-5 mg/m³ fluorescence throughout Tofino Inlet (figure 17b). The only place the 2014 data did not show this uniform distribution was near the head of the inlet and at the deepest section of the inlet, with sections of no fluorescence at the bottom and 5-10 mg/m³ near the top. The 2019 data showed mostly 0 mg/m³ fluorescence throughout the end of the inlet and at the deepest sections (figure 17a). In the 2019 data, the mg/m³ of fluorescence started to increase toward the opening of the inlet to the ocean, reaching 10-15 mg/m³ near station 59.

The transmissivity plots for 2014 and 2019 from Tofino Inlet were similar, with 90%-100% transmissivity at the deepest part of the inlet shown for both years (figure 18). There was also a similar trend where the transmissivity decreased toward the surface of the water and decreased near the ocean to a range of 90%-80%. The 2019 plot showed a much lower transmissivity near the surface and towards the ocean, ranging from 80% to 20% at 0 to 10 meters depth.

The nutrient data and the water property data from 2014 and 2019 had an overall similar distribution throughout the entirety of Tofino Inlet. There was evidence of slightly higher surface phosphates in 2014 but the nutrient data indicated overall similar concentrations from 2014 to 2019. The contoured profile plots demonstrated that in 2014 Tofino Inlet had flushing while the 2019 data showed layers of older water that had not yet undergone flushing.

Further research looking at phytoplankton might produce more definitive results about the productivity levels.

Conclusion

This study used choropleth maps and contoured profile plots to map nutrients, temperature, salinity, water density, dissolved oxygen, fluorescence, and transmissivity in Tofino Inlet from samples taken on September 9, 2019. These maps were compared to maps that were compiled from Tofino Inlet data collected in 2014, to see how the water properties differed and to see if “the Blob” observed off the west coast of North America in 2014 and in 2019 influenced water properties and water productivity. There was higher productivity in 2014 and the overall water properties over both years were similar in overall distribution. Further study of the phytoplankton samples taken during those times is recommended for a more comprehensive analysis into the productivity in Tofino Inlet during 2014 and 2019.

Unusually warm water temperatures in places like the Puget Sound, where “the Blob” was also observed in 2014 and in 2019, can lead to more prolific harmful algal blooms. One such species, *Alexandrium catenella*, has been found in the waters of Clayoquot Sound. *Alexandrium catenella* is currently being studied in the Gulf of Maine, Puget Sound and Gulf of Alaska. Research started in September 2019 is being conducted in hopes of developing a way to forecast the seasonal bloom of *Alexandrium catenella*. Creating a much more rapid method to monitor and predict harmful algal blooms is vital because blooms can impact to the shellfish economy and can cause human health risks (Greengrove et al. 2020).

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