Clayoquot Sound Harmful Algal Blooms Investigation of Herbert Inlet – 2019

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Abstract:	Clayoquot Sound of British Columbia, Canada is a protected biosphere that has been affected by *Alexandrium*, a known toxic dinoflagellate, that when consumed by humans can cause paralytic shellfish poisoning. The "BLOB" events that heated the water in the Pacific Ocean in 2014 and 2019 created favorable conditions for these algae to flourish in this region. This study focused on analyzing and comparing nitrate, phosphate, and silicate levels, oceanic conditions, and water properties like temperature, salinity, density, dissolved oxygen, fluorescence, and transmissivity for Herbert Inlet in 2014 and 2019. Surface and bottom samples were collected and sent to the University of Washington School of Oceanography Marine Chemistry Lab for analysis. Meteorological data was collected from Tofino airport, and the tidal data was observed at Riley Cove. A CTD (Conductivity, Temperature, Depth) instrument was used to record the water properties as it was lowered into the water. For the nutrient data, Microsoft Excel was used to create five number summaries, and box and whisker charts. ArcGIS was used to create station maps and choropleth maps that showed the relative abundance of nutrients at each station. Data from the CTD was plotted and showed significant differences from the previous years. The results showed the nutrient levels in 2019 were lower than 2014, but the temperature in 2019 had increased by 2°C throughout the Inlet, and these warmer waters were starting to make their way into the deeper waters throughout Herbert Inlet.
Key Words:	Clayoquot Sound, *Alexandrium*, harmful algal blooms (HABs), dinoflagellate, The "BLOB", Pacific Ocean, Herbert Inlet, temperature, nutrients, fluorescence
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Byers C. 2020. Clayoquot Sound Harmful Algal Blooms Project: Herbert Inlet - 2019. Environmental Science Undergraduate Thesis.
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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 with partnership with Dr. Richard Keil from UW Oceanography and has since led to additional partnerships including the 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.

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Introduction

Statement of the problem

Clayoquot Sound is on the west coast of Vancouver Island and it is a protected biosphere that is home to organisms like crabs, shellfish, and other marine life (Figure 1). Warmer waters from the Pacific Ocean are impacting the organisms in this area and researchers are trying to determine the environmental conditions that created this warmer water and how the intrusion is affecting marine life. Faculty and students from the University of Washington Tacoma (UWT) have been studying this region since 2000. In this study, the favorable conditions in which harmful algal blooms (HABs) have formed in the Clayoquot Sound will be analyzed and compared. *Alexandrium*, a known toxic dinoflagellate, was found in this region. When these algae are ingested by shellfish, they create a toxin that can cause paralytic shellfish poising when consumed by humans, which provides the need for this work. These inlets are made up of complex bathymetry and topography which makes this a unique research opportunity. As "The BLOB" progresses through these Inlets, it brings the favorable conditions for which harmful algal blooms are likely to occur more often.

Purpose of the Study

The results from this study explored the differences in nutrient levels, oceanic conditions, and inlet water properties that contributed to the favorable conditions for HABs in 2014 and 2019. Research to influence this study in the future could include testing other locations along the Pacific Coast to see the evolving effects of "The BLOB" over the years. There has not been a solution presented for this problem and HABs are occurring more frequently because of climate change. Due to the increase in HABs, there have been monitoring programs set up to examine

Figure 1. Map of Clayoquot Sound, Vancouver Island British Columbia Canada (Baer et al. 2020)

and predict changing patterns. Continuing this study and growing the data throughout the years will improve the understanding of what causes the harmful algal blooms, and how they impact each Inlet differently. The focus of this study included nutrient levels, oceanic conditions, and water properties of stations, locations along a transect bisecting the Inlet. Stations 31 through 38 in Herbert Inlet of the Clayoquot Sound where studied to determine favorable conditions for harmful algal blooms (Figure 2).

Herbert Inlet is in the northwest section of Clayoquot Sound and was formed by glaciers that carved steep valleys with a deep and wide fjord. The depth of the Inlet ranged from 140 to

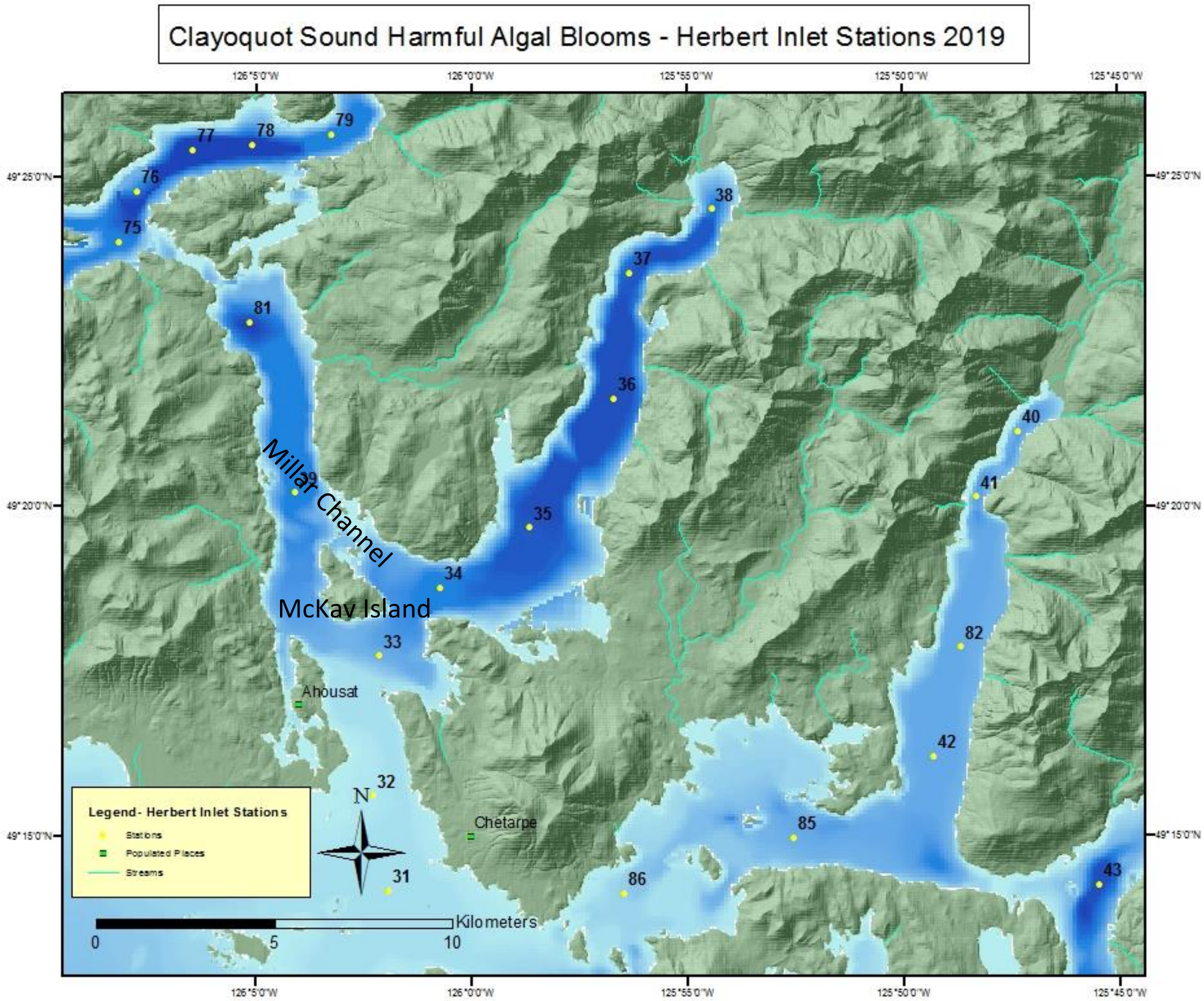


Figure 2. Map of Herbert Inlet Stations

160 meters, with the shallowest sill in Clayoquot Sound, at 5 meters. McKay Island and Millar Channel meet at the mouth of Herbert Inlet, where fish farms are located, and helicopter logging occurs. At the head of the Inlet there is a waterfall from the Moyeha River, which is the main freshwater source for this Inlet (Dewitz 2020). The hypothesis was that when comparing the 2014 data with the 2019 data, there would be an increase in favorable conditions for HABs in 2019 due to the return of warmer waters from “The BLOB”. Through variations in nutrients and

the changing water properties the favorable conditions indicate the possibility that HABs existed in that area. The nutrients nitrates and phosphates are significant because they are necessary for plant growth and development and when there is an overabundance of these two nutrients in the waters, the algae flourish. The algal blooms block the sunlight from reaching the phytoplankton under the surface waters. In a process known as eutrophication, plankton die and decay due to lack of sunlight, and the oxygen is used up due to the decomposing materials, depleting the amount of dissolved oxygen in the water. This is a contributing factor to the devastatingly higher numbers of marine life casualties (NOAA 2019). Nutrients in the water can come from multiple sources, weathering from rocks and soils, run-off from coastal areas and/or from upwelling. Upwelling is the mixing of the cold, deep, nutrient rich waters with the surface waters. As the northern winds push the surface waters out, the cold, nutrient rich water rises and fills in, creating a nutrient rich layer of water (NOAA 2019). The purpose of this study was to compare environmental conditions from different years that "The BLOB" events took place and to determine the impacts on the marine life in the Clayoquot Sound. The methods involved collecting samples at indicated stations, getting recordings from the CTD (Conductivity, Temperature, and Depth) downloading data and uploading it to Microsoft Excel for statistical analysis, using ArcGIS for information mapping and creating station and choropleth maps, and Surfer plots for determining changes in water properties.

Review of Literature

Clayoquot Sound has been a protected biosphere of British Columbia, Canada since 2000 and continues to supply natural benefits for many of the organisms that make this area its home (UNESCO 2015). An increase in sea surface temperatures within the past seven years has created a difficult problem for marine life. In 2013, researchers noticed an increase in sea surface temperatures in the Pacific Ocean, that a University of Washington atmospheric scientist, Nick Bond, called "The BLOB" (Welch 2016). In 2014, the intensity and area of the temperature had reached its maximum and by early 2015, the warm pool was covering the entire west coast of North America (Dewey 2015). The waters along the surface were influenced by atmospheric pressure and surface wind conditions, solar insulated heating, cooling from conduction and evaporation, and buoyancy changes due to precipitation and evaporation (Dewey 2015). "The BLOB" was a patch of warm surface waters that was harming and killing certain organisms as it circulated in the Pacific Ocean before eventually making its way towards the coast, where it warmed the surface waters and created favorable conditions for the harmful algal blooms. In 2016, Nick Bond, said that sea surface temperatures across thousands of miles of the North Pacific and Gulf of Alaska were 3° Celsius warmer than normal (Welch 2016). If the storms that occurred did not do anything to cool the surface temperatures, "The BLOB" was predicted to reappear in that region (Welch 2016). A previous study that investigated the oceanographic characteristics of Vancouver Islands in the 1960s, showed that the surface temperatures were between 10° C and 15° C, and that the majority of the inlet's surface temperature remained within +/- 1° C of the mean value along the length of the inlet (Pickard 1963). With the increased concern for climate change, scientists said that global warming was probably not the major cause of "The BLOB" but others expressed that this could be a preview of what to expect in the future. It appeared to be maintained by cyclical weather patterns that created massive ridges of high atmospheric pressure, that deflect winds that stir up cold deep nutrient rich waters (Kintisch 2015). These cyclical weather patterns included Pacific Decadal Oscillation, which drive up temperatures in the Pacific for up to 30 years, and El Niño/La Niña events, which affect the temperatures in the Pacific more frequently. This information is significant because it creates a belief that the harmful algal blooms will continue to reappear with a stronger more intense presence and that they will remain for longer periods of time.

Methods

Sample Collection

Sampling included taking vertical profiles of water properties with a CTD and collecting discrete water samples at the surface and bottom from designated stations throughout Clayoquot Sound. There were five inlets—Tofino, Bedwell, Herbert, Shelter, and Sydney— and a transect from Warn Bay to Tranquil Inlet that were studied for this project (Figure 3). The data that was collected for this summary was from Herbert Inlet, and included data from station 31, at the mouth of the Inlet, through station 38, at the head of the Inlet. The CTD recorded the water's conductivity, temperature, and pressure by using sensors located on the instrument, with additional sensors to measure dissolved oxygen, fluorescence, and transmissivity (Figure 4). This instrument was lowered into the water at each station and internally recorded vertical profiles of water properties. Discrete samples were collected by hand using closing water bottles, then the samples were frozen and sent to University of Washington School of Oceanography Marine Chemistry Laboratory for analysis.

Instrumentation

The CTD data was downloaded, exported, and uploaded into Microsoft Excel. The nutrient samples were analyzed at the UW Oceanography Marine Chemistry Lab. This state of Washington accredited lab works with universities and oceanographic communities to provide analytical services for freshwater and marine environments. They specialize in the analysis of

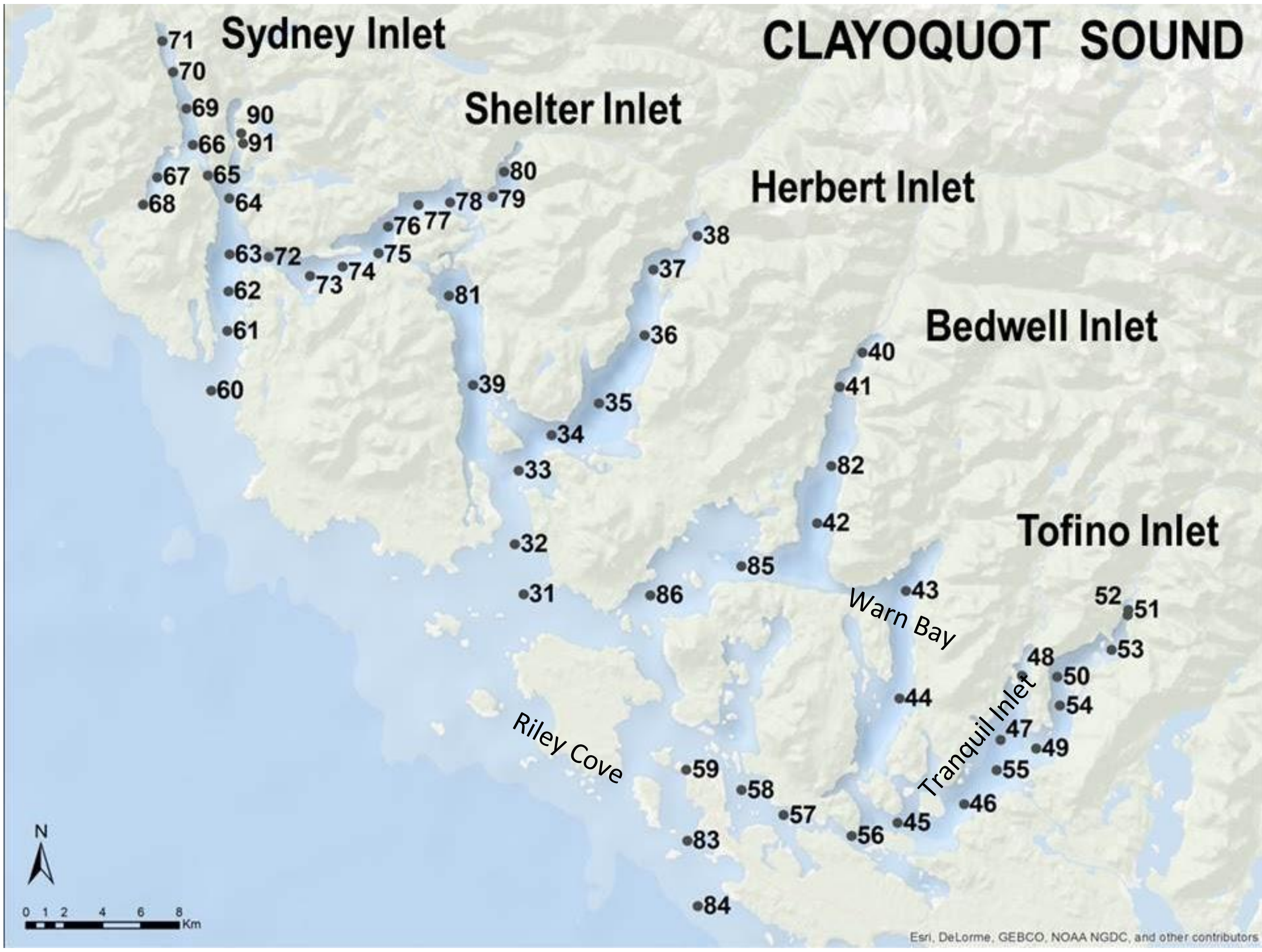


Figure 3. Clayoquot Sound Sampling stations (Baer et al. 2020)

nutrients including the total amount of nitrogen and phosphorus, salinity, chlorophyll, oxygen, and dissolved oxygen (UWSO 2020).

Data Analysis

2019 data was analyzed with Microsoft Excel, ArcGIS, and Surfer. Microsoft Excel was used to create five number summaries and box and whisker plots for the surface and bottom nutrient data (Table 1). These values were imperative for the comparison of the two years because they show the differences in nutrient levels. Excel was also helpful in setting up the data

Figure 4. CTD instrument (Image by M. Baer)

files for the other programs used in this project. ArcGIS, an information mapping system, was used to make station and choropleth maps that showed the relative amount of nutrients in Herbert Inlet. The CTD data was used in the Surfer program to create contoured profile plots to illustrate trends of water properties—temperature, salinity, density, dissolved oxygen, fluorescence, and

Table 1. Statistical analysis of nutrients in Herbert Inlet (Q1-First quartile, Q2-Median, Q3-third quartile)

Surface PO4		Bottom PO4		Surface SiOH4		Bottom SiOH4	
Minimum	0.03	Minimum	0.61	Minimum	2.02	Minimum	5.14
Q1	0.53	Q1	1.535	Q1	9.44	Q1	25.37
Q2	1.075	Q2	2.23	Q2	13.94	Q2	42.57
Q3	2.215	Q3	2.49	Q3	18.28	Q3	51.485
Maximum	7.07	Maximum	7.07	Maximum	23.35	Maximum	84.62
Mode	0.58	Mode	#N/A	Mode	13.63	Mode	#N/A
Surface NO3		Bottom NO3		Surafce NO2		Bottom NO2	
Minimum	0.01	Minimum	0	Minimum	0	Minimum	0.01
Q1	0.03	Q1	5.39	Q1	0.02	Q1	0.095
Q2	0.05	Q2	18.58	Q2	0.02	Q2	0.16
Q3	0.7	Q3	23.46	Q3	0.1	Q3	0.38
Maximum	4.72	Maximum	27.16	Maximum	0.37	Maximum	0.56
Mode	0.03	Mode	#N/A	Mode	0.02	Mode	0.15
Surface NH4		Bottom NH4					
Minimum	0	Minimum	0				
Q1	0	Q1	0				
Q2	0.09	Q2	0.75				
Q3	0.63	Q3	3.055				
Maximum	3.07	Maximum	46.6				
Mode	0	Mode	0				

transmissivity— along a transect of Herbert Inlet in 2019. Once that information was collected, analyzed, mapped, and plotted, results were compared with the results from the last “BLOB” event in 2014.

Results

The results for the Clayoquot Sound Harmful Algal Bloom Project were broken into different Inlets throughout the area. The results that follow were from Herbert Inlet stations 31-38 and include surface and bottom nitrate levels (Figure 5), surface and bottom phosphate levels (Figure 6), and surface and bottom silicate levels (Figure 7). The results from the CTD had plotted data for temperature (Figure 8), salinity (Figure 9), density (Figure 10), dissolved oxygen

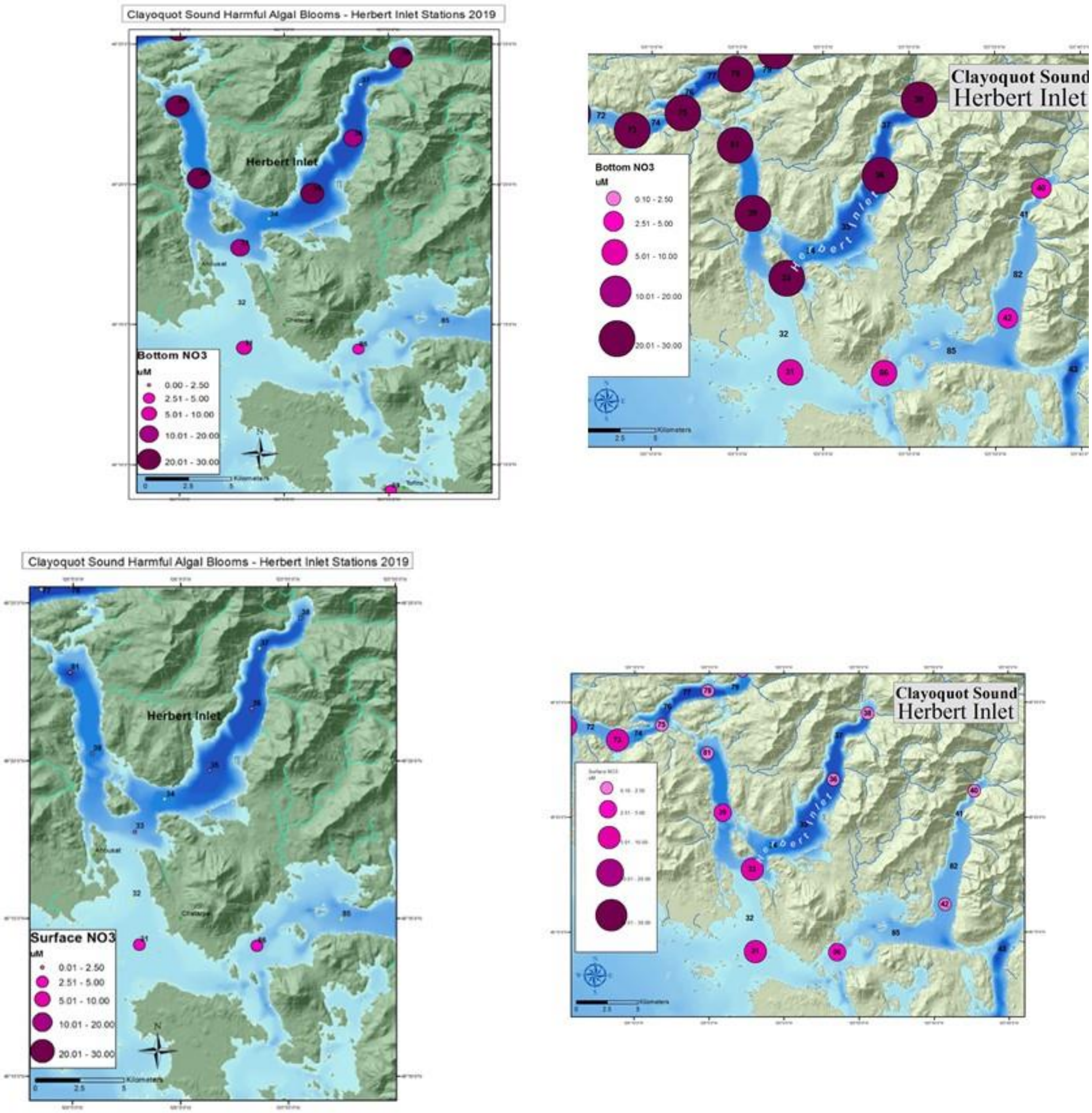


Figure 5. 2019 Surface and Bottom Nitrates of Herbert Inlet (left) 2014 Surface and Bottom Nitrates of Herbert Inlet (right) (Dewitz 2020)

(Figure 11), fluorescence (Figure 12), and transmissivity (Figure 13). Nutrient samples were not taken at every station due to budget restraints. The nutrient data at each station that was collected, will be described by station below.

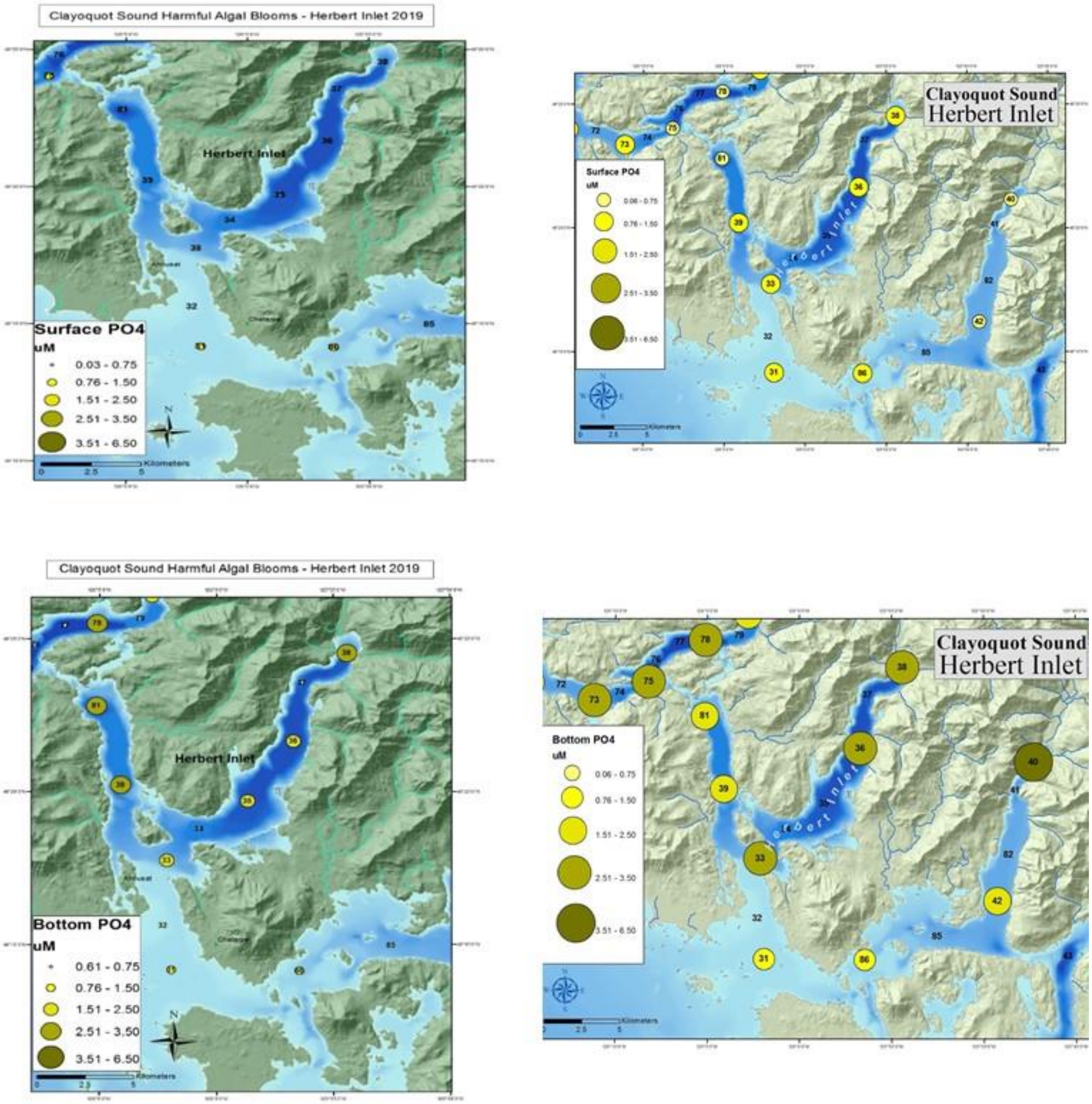


Figure 6. 2019 Surface and Bottom Phosphates of Herbert Inlet (left) 2014 Surface and Bottom Phosphates of Herbert Inlet (right) (Dewitz 2020)

The meteorological data was collected from the Tofino Airport on September 10 and 11, 2019 (GOC 2020) and the tidal data for Herbert Inlet was collected from Riley Cove from September 8 -12, 2019. The air temperature from 5 am to 5 pm on September 10 ranged from 13.1°C at 7 am to 18.9°C at 4 pm. On September 11, the air temperature ranged from 12.9°C at 6

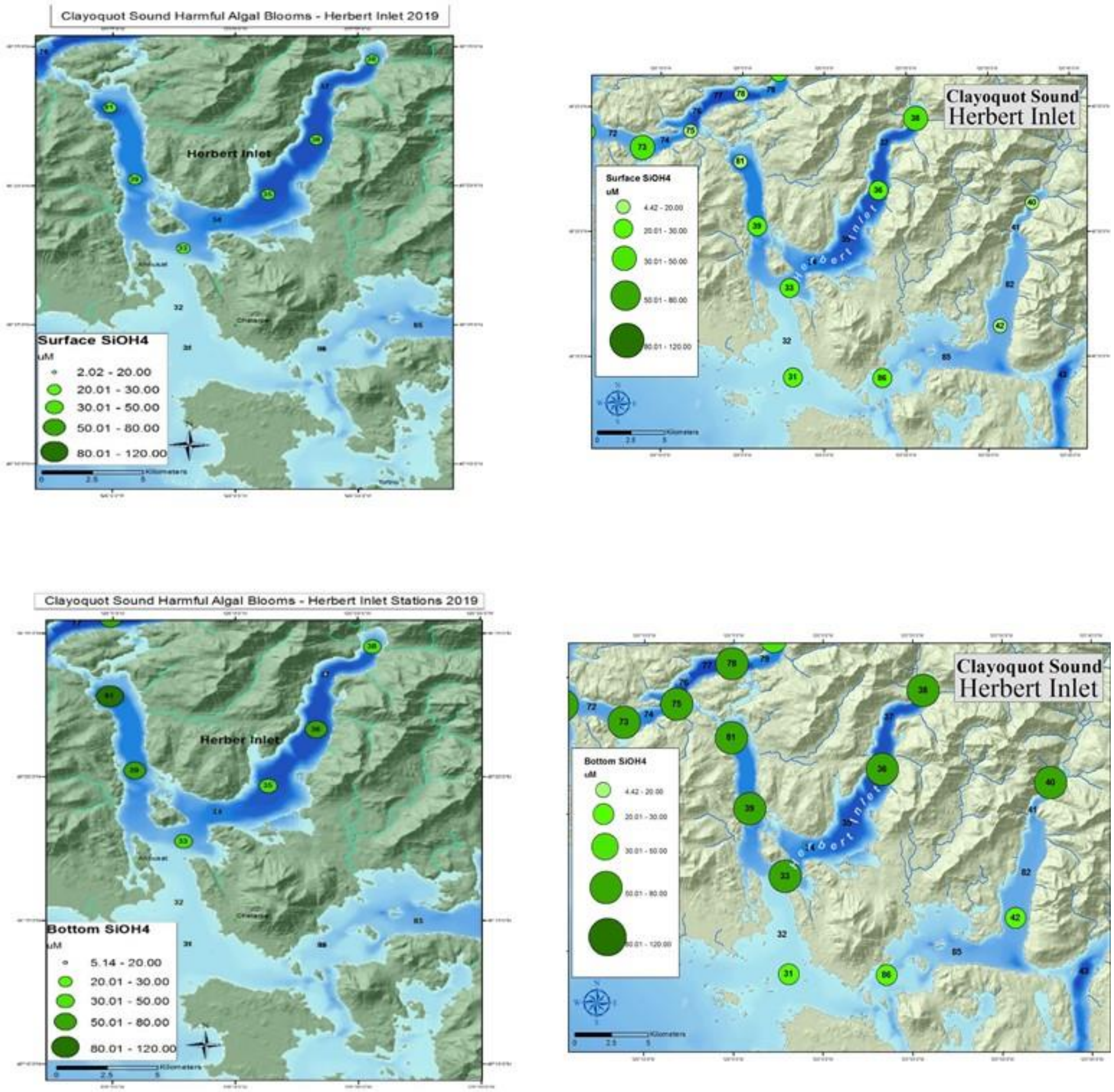


Figure 7. 2019 Surface and Bottom Silicates of Herbert Inlet (left) 2014 Surface and Bottom Silicates of Herbert Inlet (right) (Dewitz 2020)

am to 16.8°C at 2 pm (Figure 14). The wind speed on the 10th ranged from 1 km/hr. at 5am and 7 am to 17 km/hr. at 4 pm. On the 11th the wind speed ranged from 1 km/hr. at 5 am to 21 km/hr. at 3 pm (Figure 15). Air pressure had a minimum value of 100.98 kPa at 5 am on September 10th and a maximum value at 101.17 kPa from 11 am to 1 pm. September 11th had a minimum

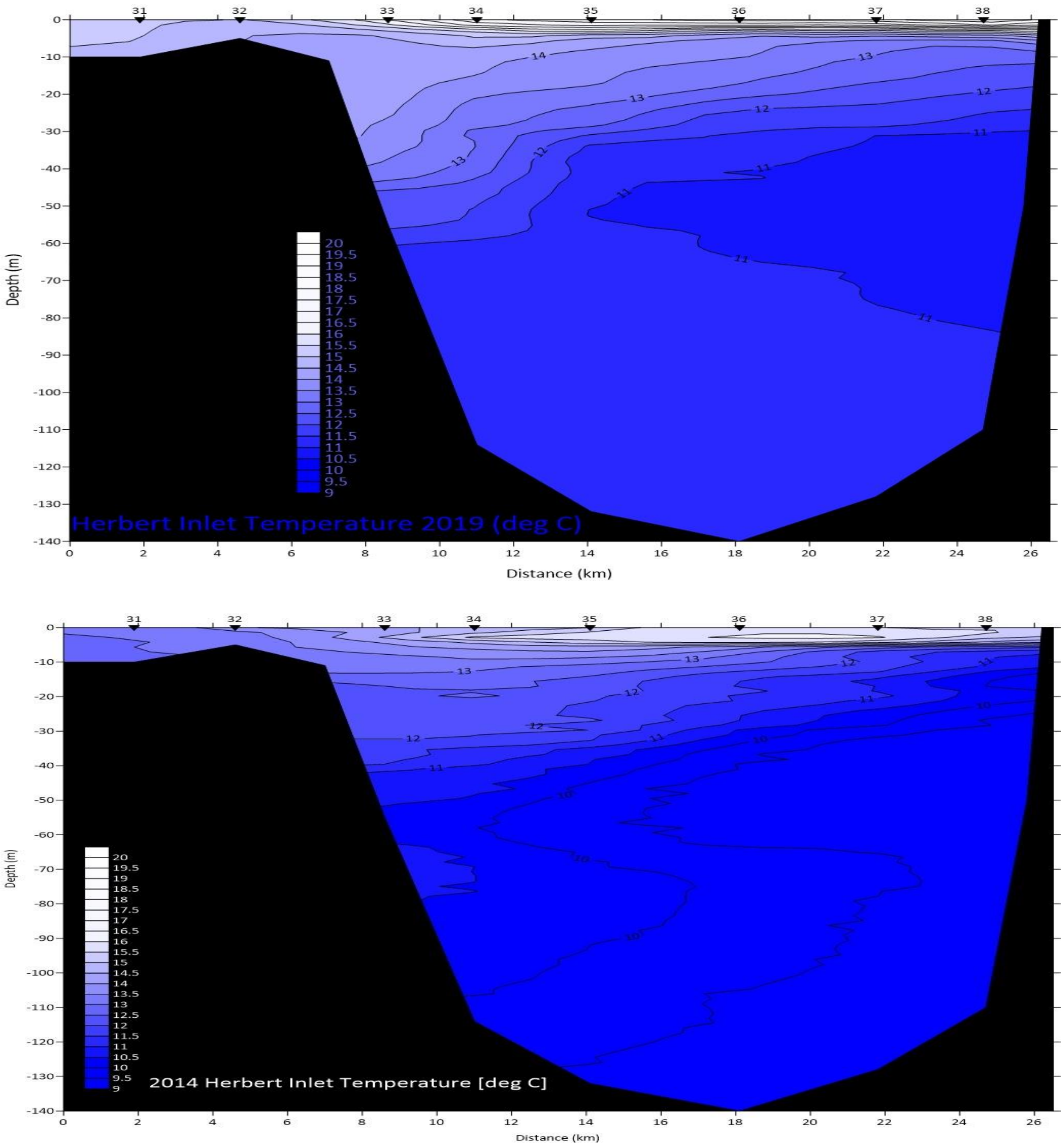


Figure 8. 2019 temperature (°C) of Herbert Inlet (top) 2014 temperature (°C) of Herbert Inlet (bottom) (Dewitz 2020)

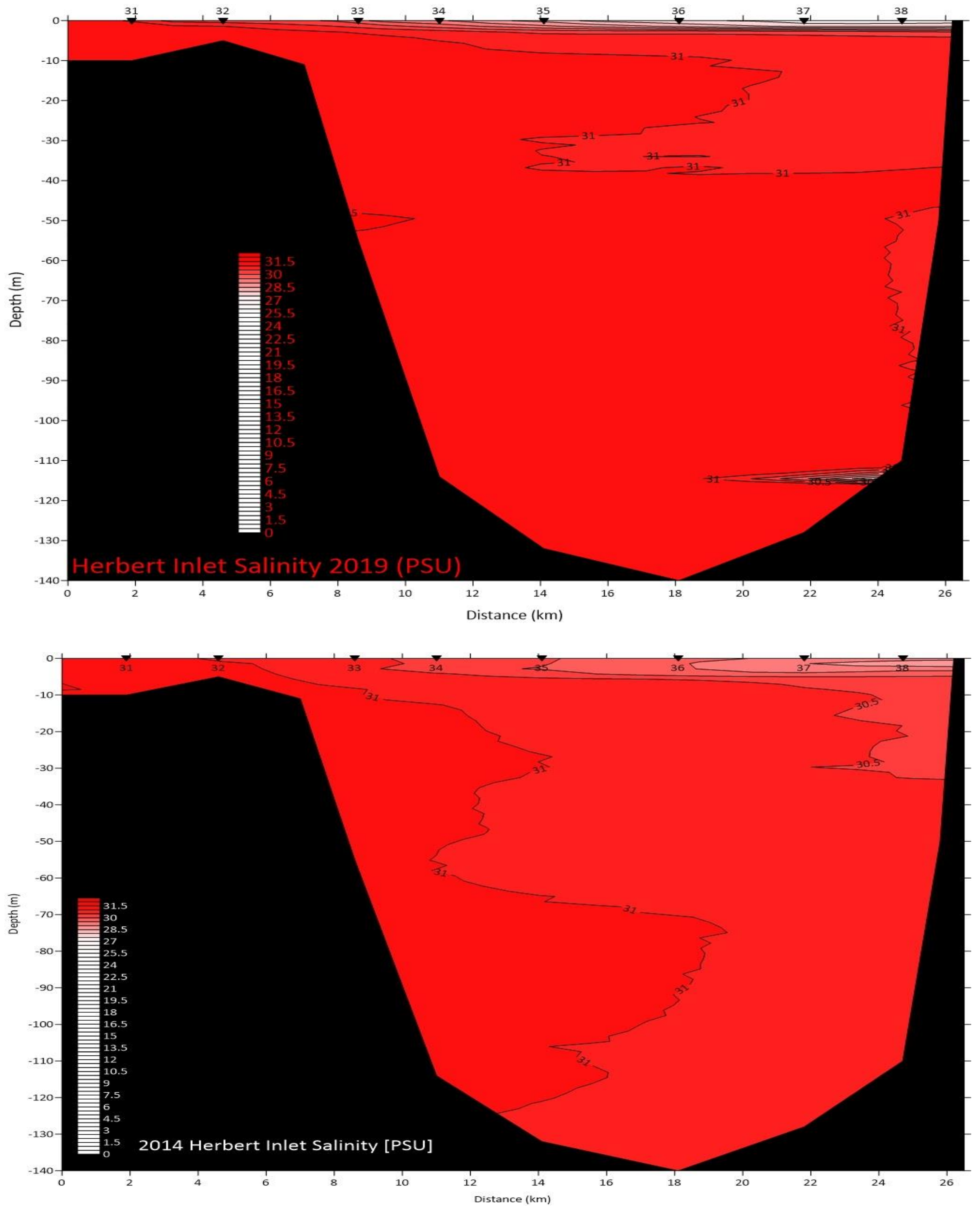


Figure 9. 2019 salinity (PSU) of Herbert Inlet (top) 2014 salinity (PSU) of Herbert Inlet (bottom) (Dewitz 2020)

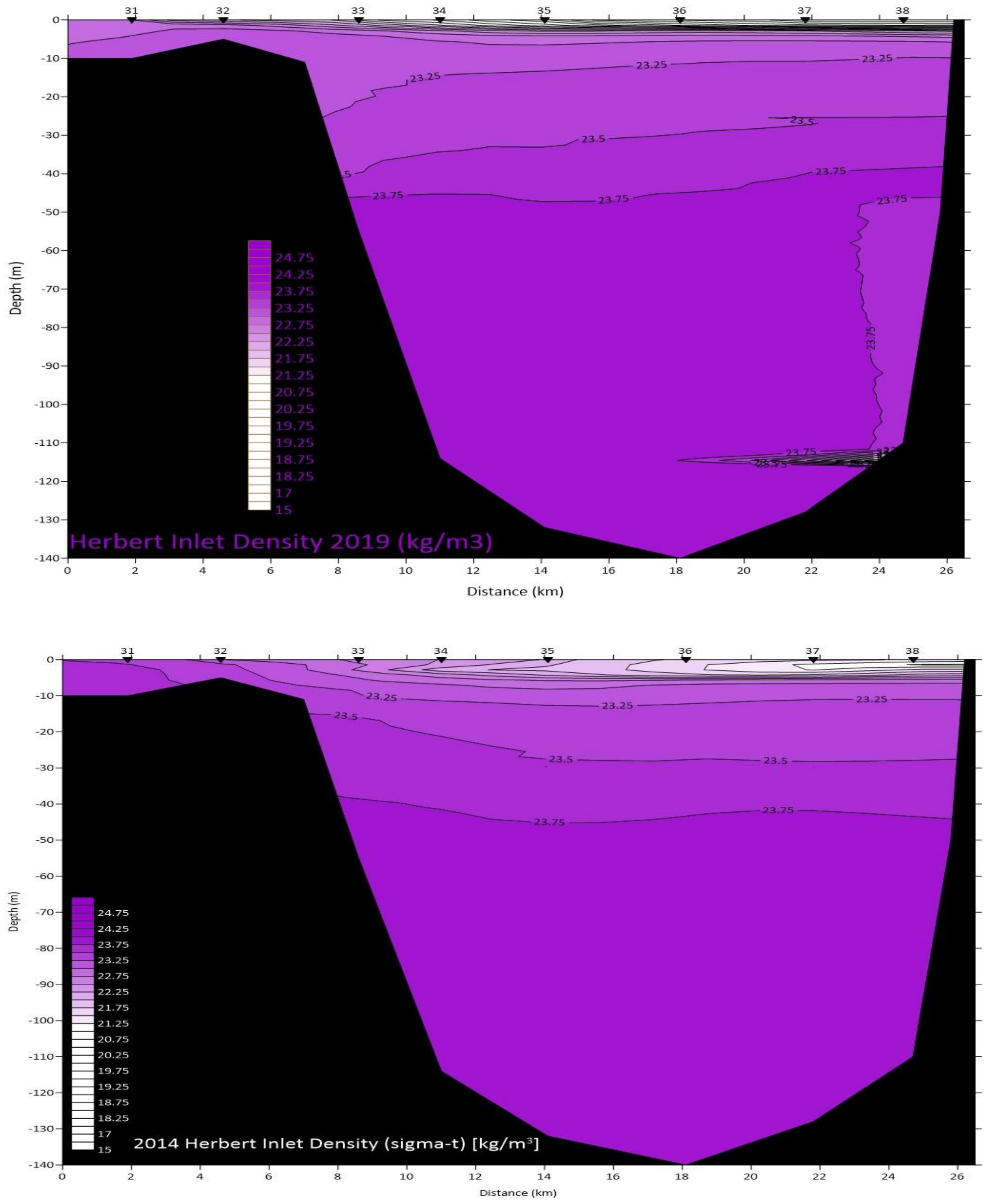
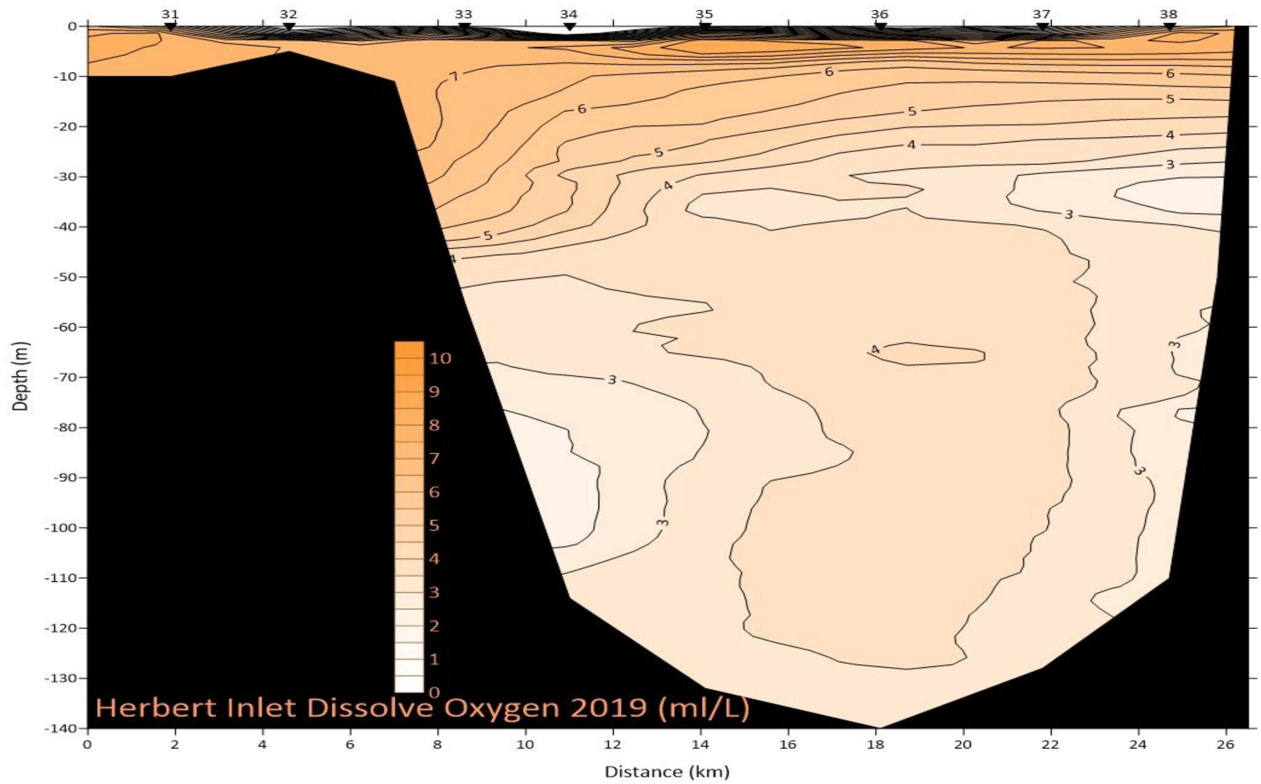


Figure10. 2019 density (kg/m³) of Herbert Inlet (top) 2014 density (kg/m³) of Herbert Inlet (bottom) (Dewitz 2020)



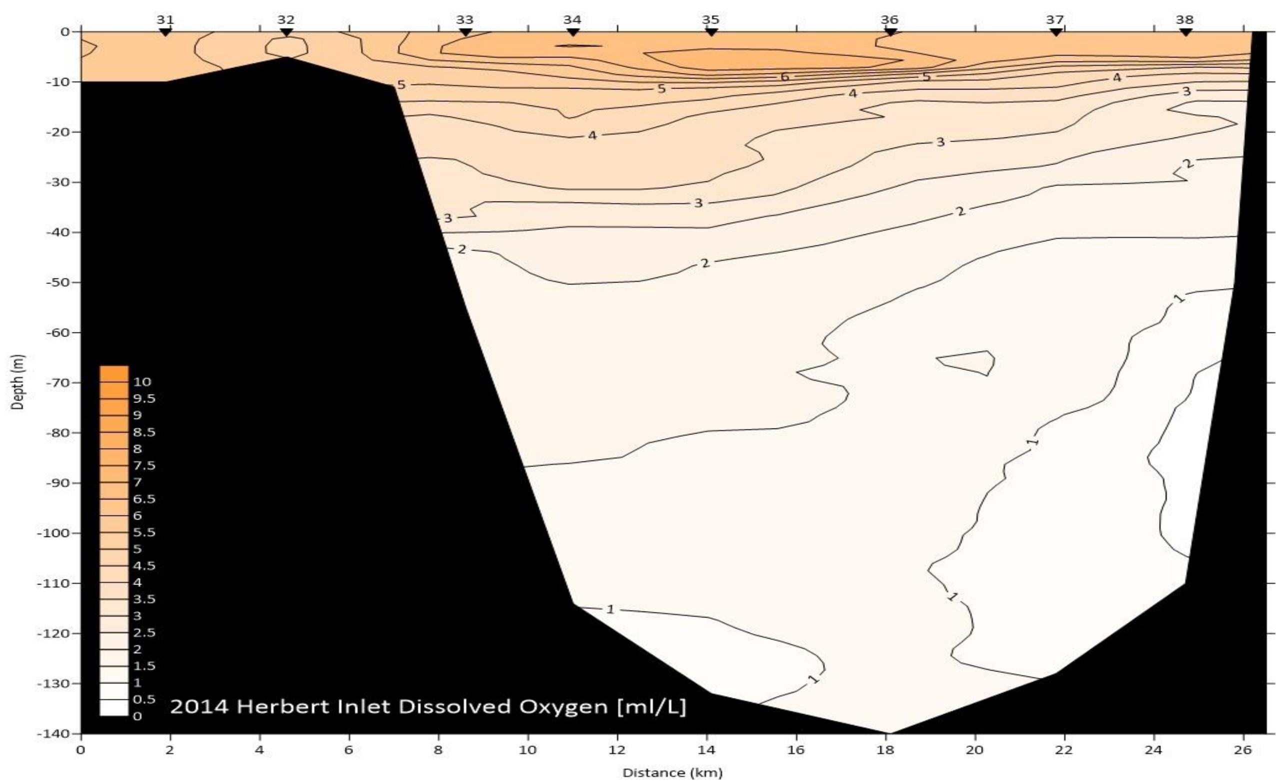


Figure 11. 2019 dissolved oxygen (ml/L) of Herbert Inlet (top) 2014 dissolved oxygen (ml/L) of Herbert Inlet (bottom) (Dewitz 2020)

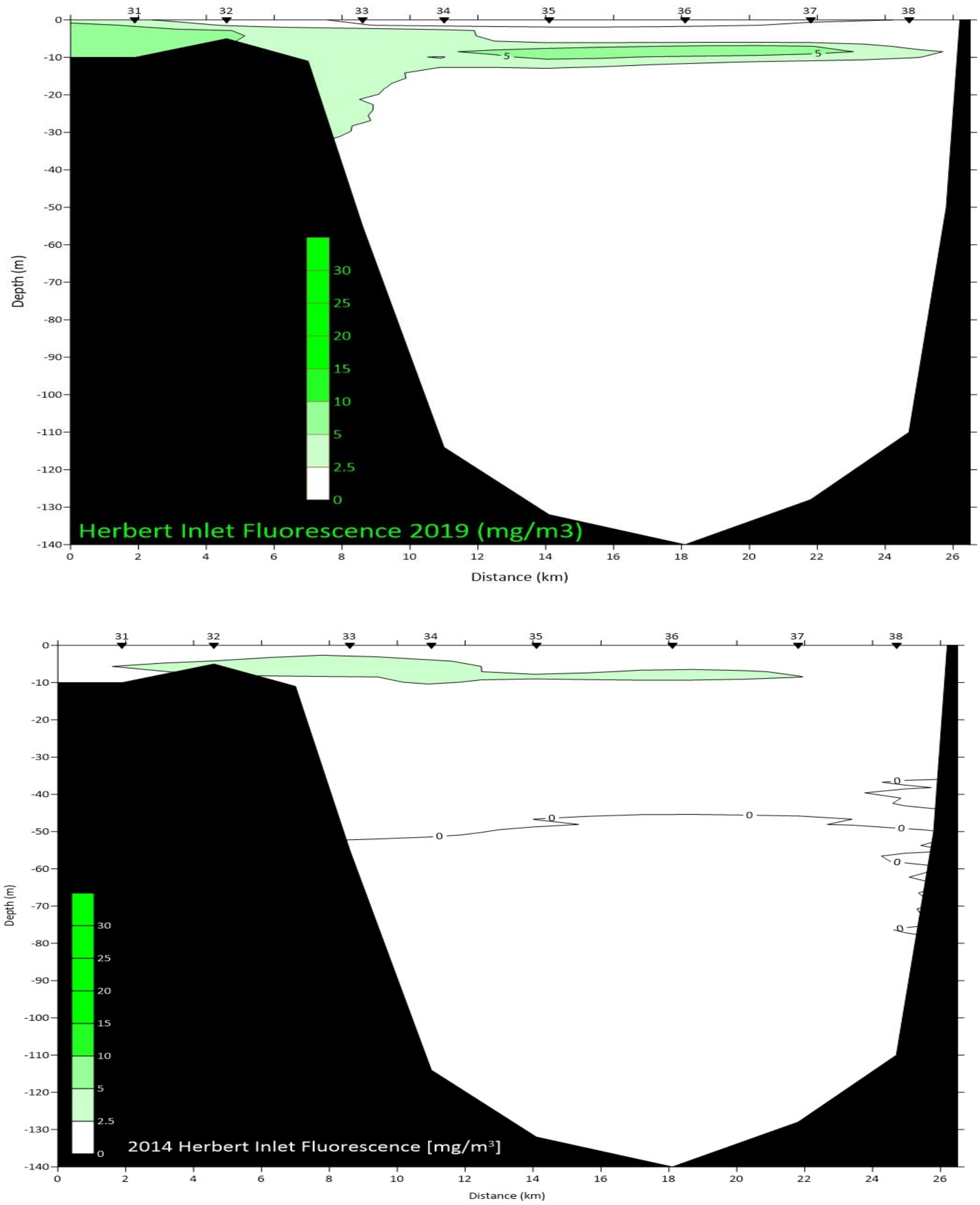
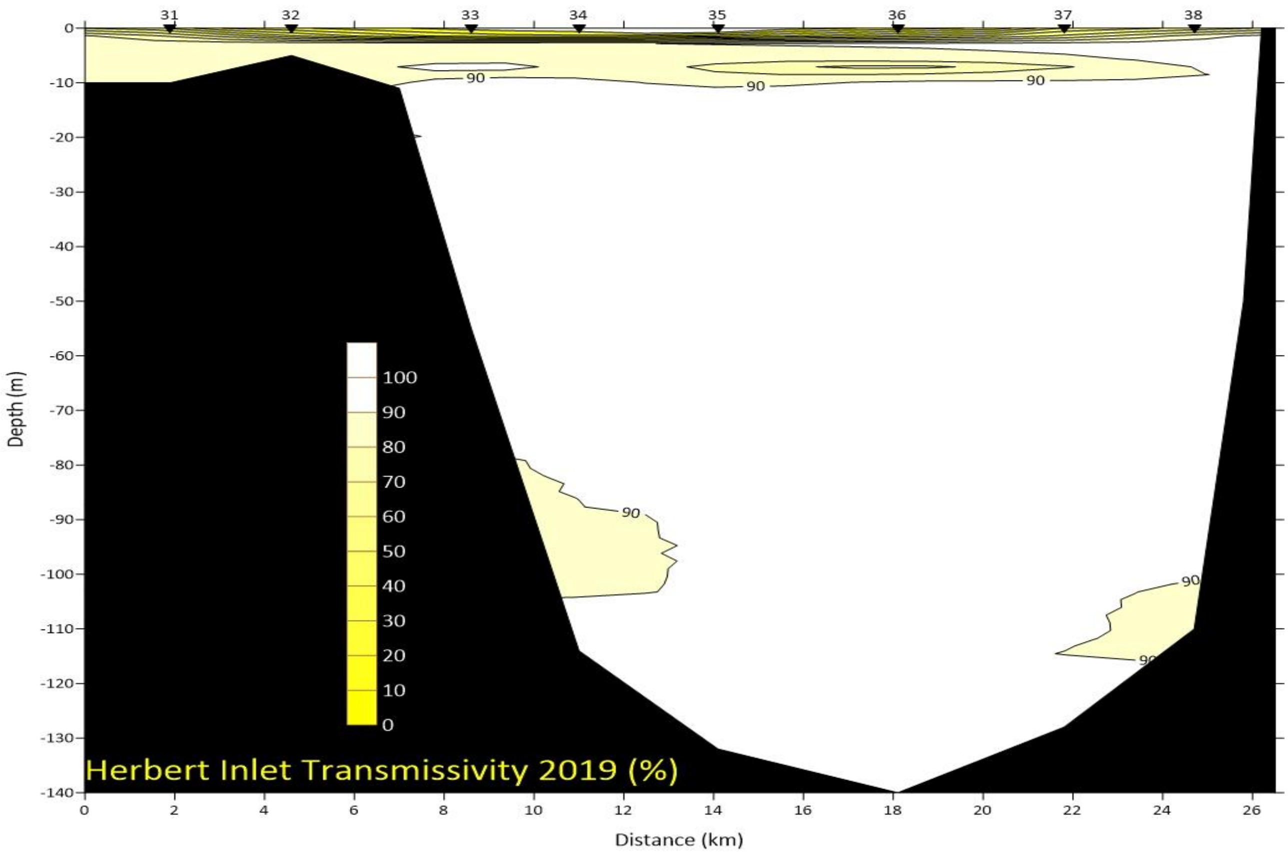


Figure 12. 2019 fluorescence (mg/m³) of Herbert Inlet (top) 2014 fluorescence (mg/m³) of Herbert Inlet (bottom) (Dewitz 2020)



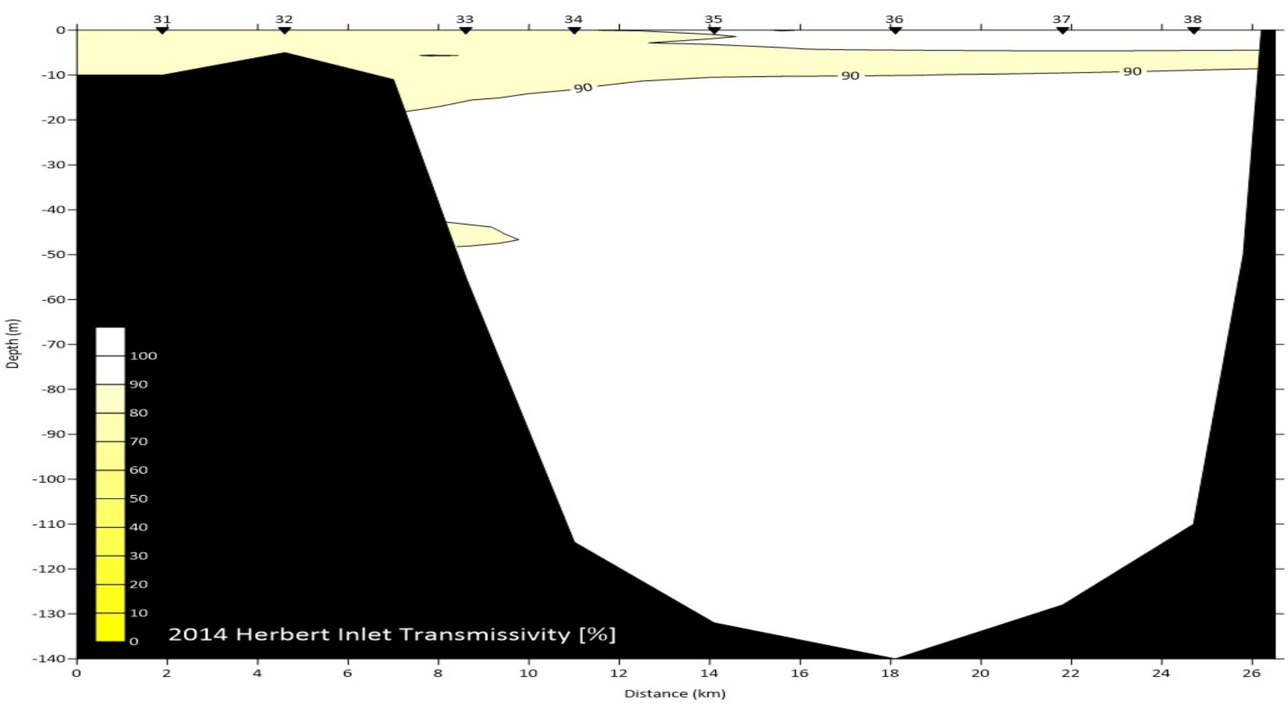


Figure 13. 2019 transmissivity (%) of Herbert Inlet (top) 2014 transmissivity (%) of Herbert Inlet (bottom) (Dewitz 2020)

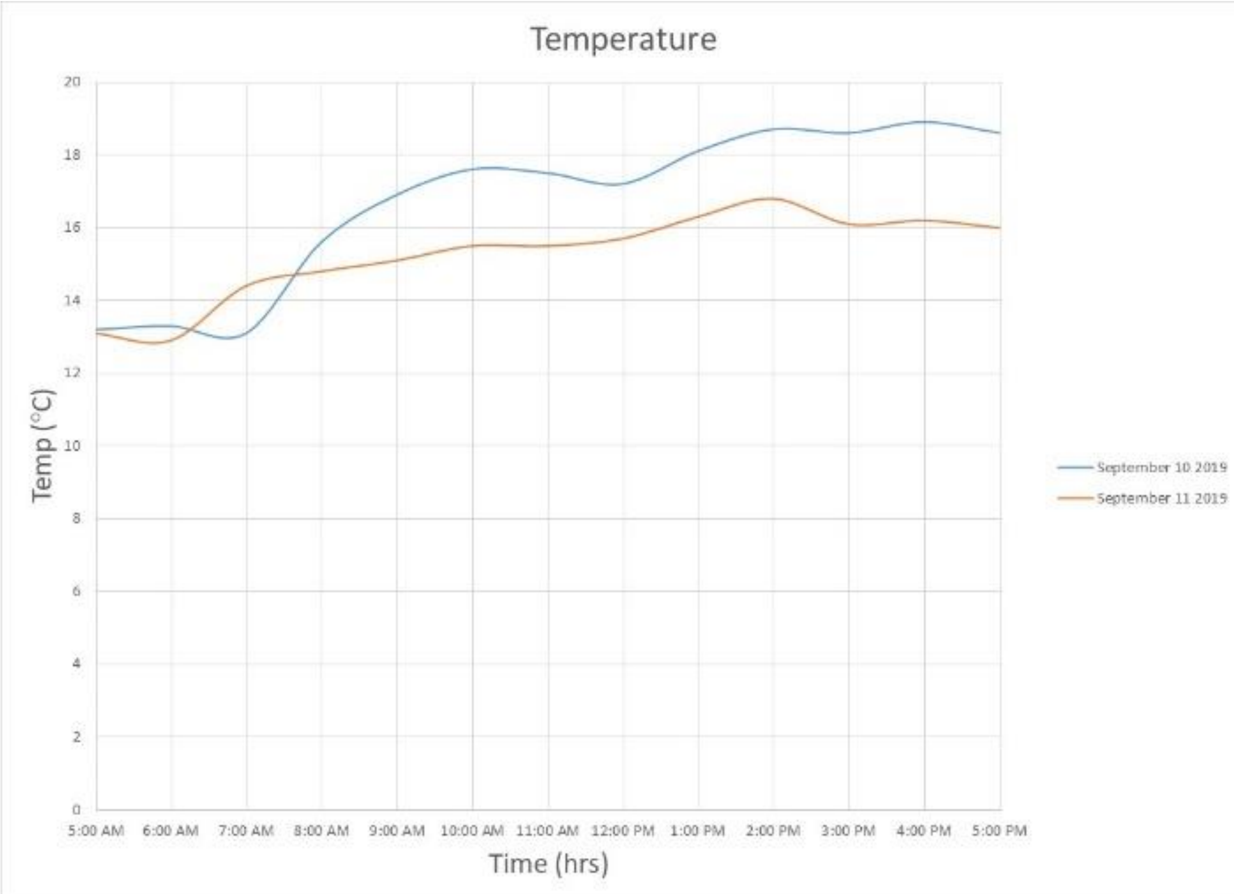


Figure 14. Tofino Airport temperature from September 10 and 11 2019 (GOC 2020)

pressure value of 101.49 at 5 am and a maximum air pressure of 101.8 kPa at 1 pm (Figure 16). The winds were coming from the north on both days, with some northwest winds throughout the days (Figure 17). The tidal data showed a minimum of 2.9 ft on September 11th and a maximum tidal height of 10.8 ft on September 10th (Figure 18).

At station 31 the surface nitrate levels were 5 - 10 µM and the bottom levels were between 5 - 10 µM also (Figure 5). Surface and bottom phosphate levels ranged from 1.51 - 2.50 µM (Figure 6) and silicate levels for the surface were measured at 2.02 - 20.00 µM and the bottom silicate levels ranged from 5.14 - 20.00 µM (Figure 7). The temperature trend at station 31 had warmer waters towards the surface and the colder waters were found at lower depths

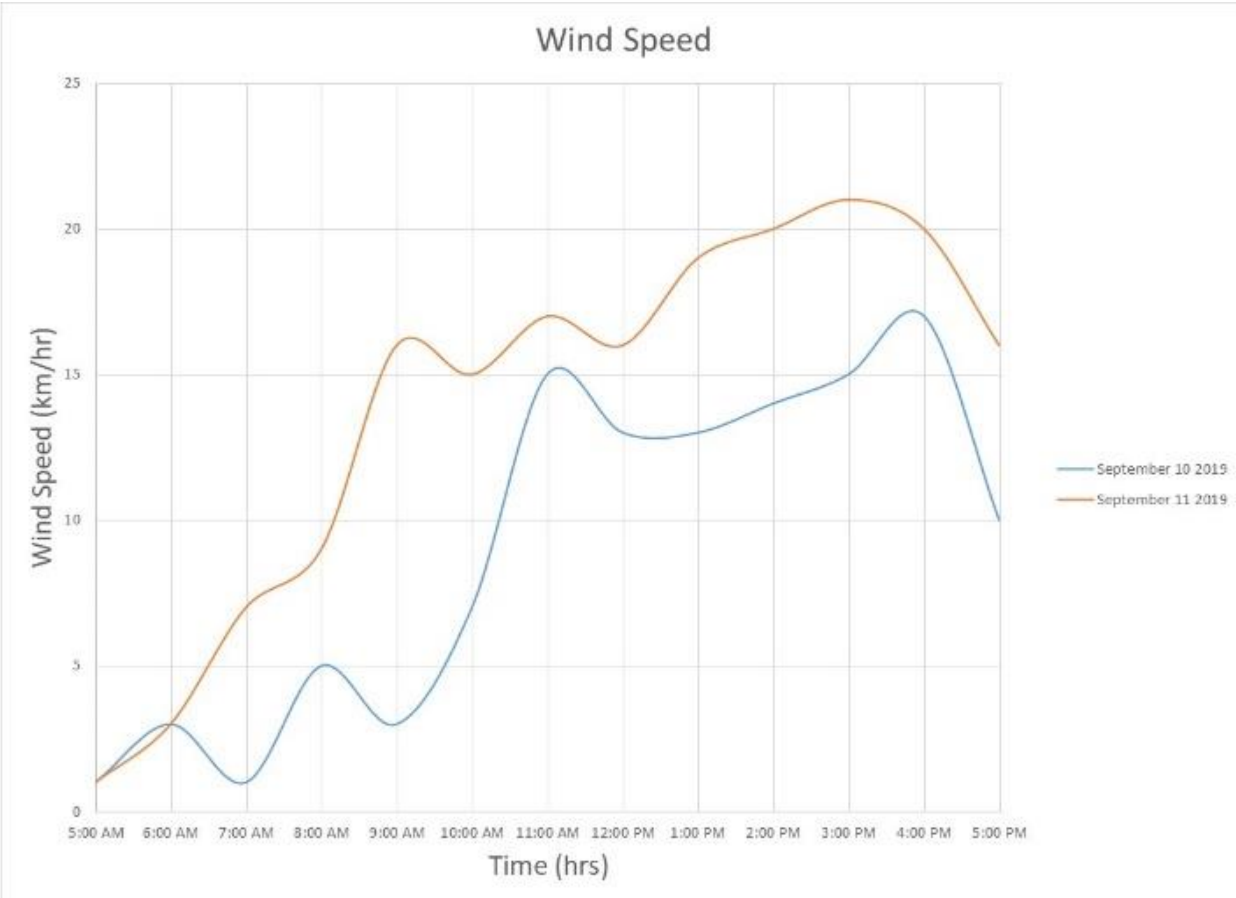


Figure 15. Tofino Airport wind speed for September 10 and 11 2019 (GOC 2020)

(Figure 8). The salinity was measured at 31 PSU (Figure 9) with the density between 22.75 kg/m^3 and 23.25 kg/m^3 (Figure 10). The dissolved oxygen was around 9 ml/L (Figure 11) and the fluorescence reached 5 mg/m^3 at a depth of 10 meters (Figure 12). The transmissivity showed 50% of the light being able to pass through at this station (Figure 13).

The temperature at station 32 was 14°C with a trend of being warmer at the surface and cooler at the bottom (Figure 8). The salinity was measured at 31 PSU (Figure 9) with a density that ranged from 22.75 - 23.25 kg/m^3 (Figure 10) and the dissolved oxygen was at 8 ml/L (Figure 11). The fluorescence at this station ranged from 2.50 - 5.00 mg/m^3 (Figure 12) and the

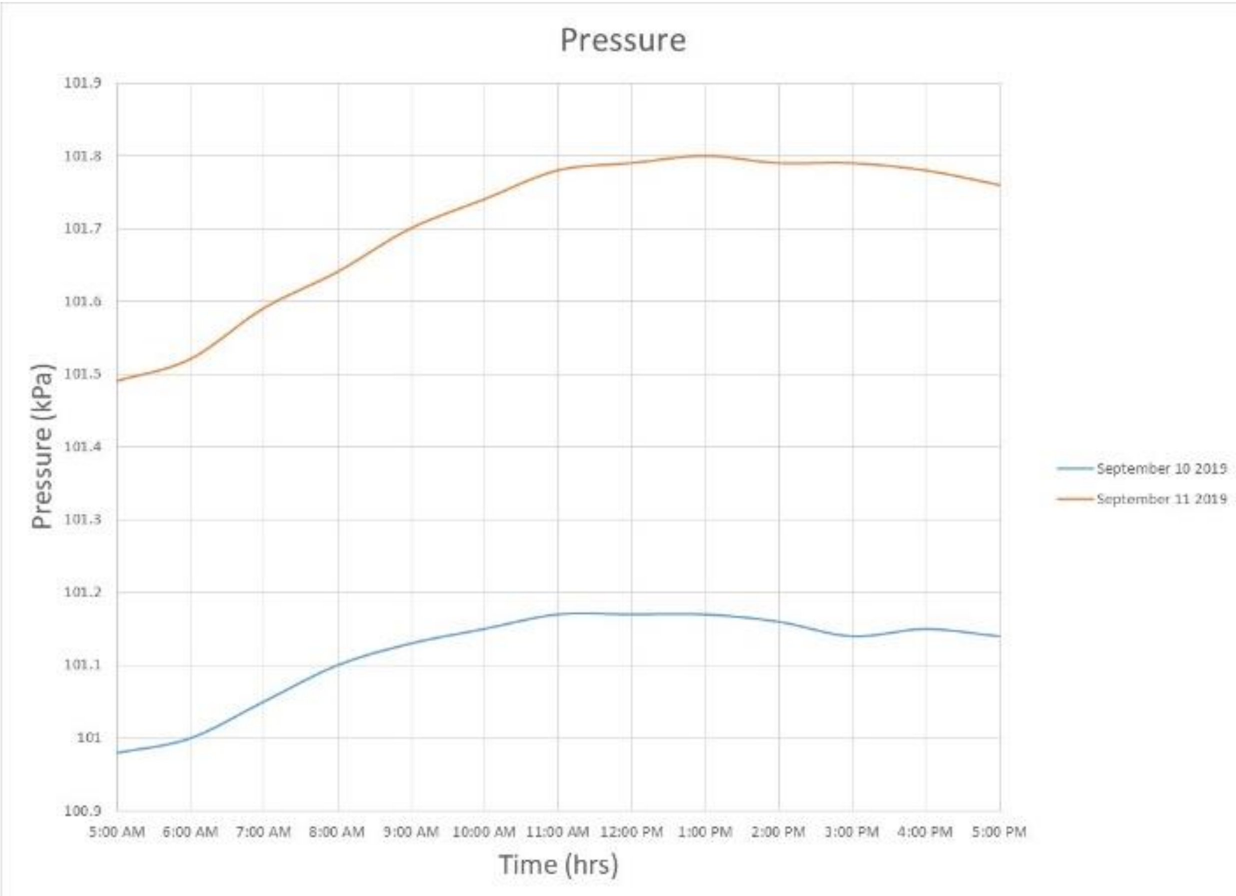


Figure 16. Tofino Airport air pressure on September 10 and 11 2019 (GOC 2020)

transmissivity measured at 50% with a rapid change at the surface where it changed to 90% before 10 meters (Figure 13).

Station 33 surface nitrate levels were measured at 0.01 - 2.50 µM and the bottom nitrate levels ranged from 10.01 - 20.00 µM (Figure 5). Surface phosphate levels were 0.03 - 0.75 µM and bottom levels were 1.51 - 2.50 µM (Figure 6). Surface silicate levels ranged between 20.01 - 30.00 µM and bottom silicate levels were between 30.01 - 50.00 µM (Figure 7). The temperature was 20°C at the surface and decreased as depth increased (Figure 8). The salinity at this station was measured at 31 PSU (Figure 9) with a density that ranged from 21.75 - 22.75 kg/m³ (Figure

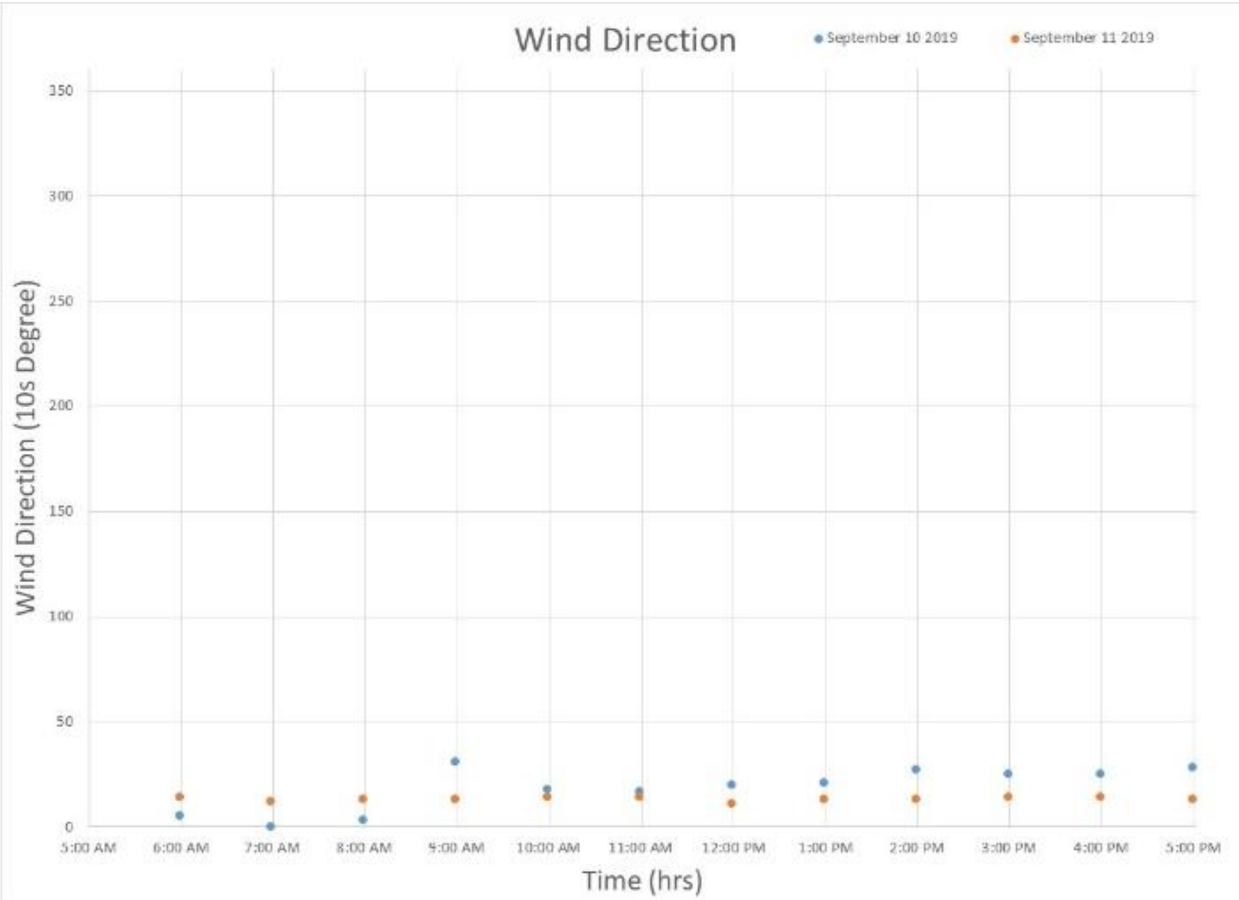


Figure 17. Tofino Airport wind direction on September 10 and 11 2019 (GOC 2020)

10), the dissolved oxygen was 8 ml/L (Figure 11) and the fluorescence at station 33 was 2.5 mg/m³ (Figure 12). The transmissivity showed 40% of light passing through at the surface then another rapid change to 90% before 10 meters (Figure 13). Between stations 33 and 34, transmissivity showed an accumulation of organic material in the deeper waters between 80 and 100 meters.

The temperature at station 34 was 20°C at the surface until 5 meters, where it decreased as the depth increased (Figure 8). The salinity at the surface showed a rapid change and increased to 31 PSU at 5 meters (Figure 9) and the density was measured at 15 kg/m³ at the

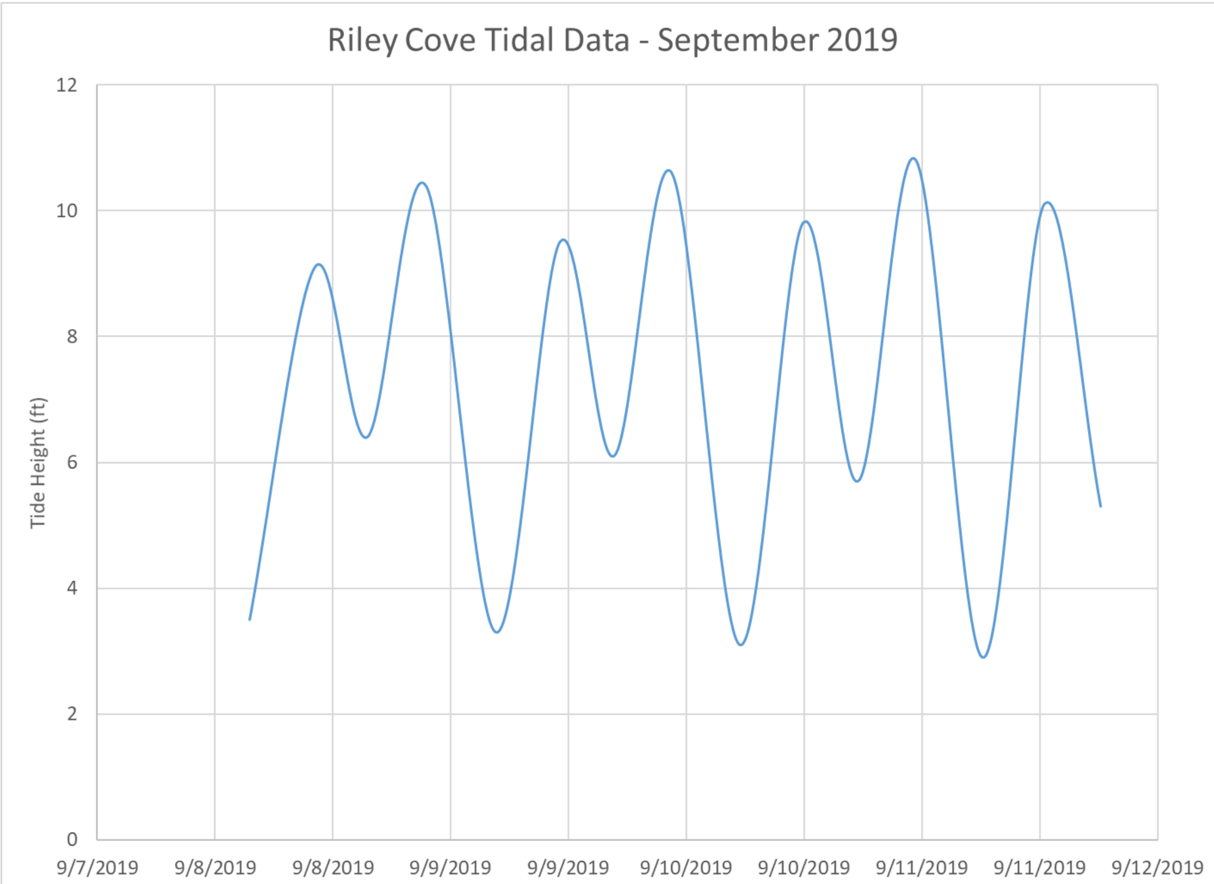


Figure 18. Riley Cove tidal information from September 7th - September 12, 2019 (SAILWX 2020)

surface and increased to 23.75 kg/m³ at 45 meters (Figure 10). The dissolved oxygen was 0 ml/L at the surface (Figure 11), and the fluorescence was at 0 mg/m³ at the surface, and 5 meters down there was an increase to 2.5 mg/m³ through to 15 meters (Figure 12). The transmissivity showed a 60% visibility with a rapid change to 90% (Figure 13).

Station 35 surface nitrate levels ranged between 0.01 - 2.50 µM and the bottom nitrate levels ranged between 20.01 - 30.00 µM (Figure 5). The surface phosphate levels ranged from 0.03 - 0.75 µM and the bottom levels ranged from 1.51 - 2.50 µM (Figure 6). Surface silicate levels ranged from 20.01 - 30.00 µM and the bottom silicate levels ranged from 30.01 - 50.00 µM (Figure 7). The temperature at station 35 was 20°C, then decreased to 14°C at 10 meters

(Figure 8). The salinity was measured at 30 PSU at the surface and reached 31 PSU at 10 meters (Figure 9) and the density was 15 kg/m³ at the surface and increased with depth (Figure 10). The dissolved oxygen at 5 meters, had a measurement of 9 ml/L, and the minimum amount was 3 ml/L (Figure 11). The fluorescence measured 0 mg/m³ at the surface until 5 meters down where it decreased to 2.5 mg/m³ then increased to 5 mg/m³ for a meter or two then back to 2.5 mg/m³ before decreasing to 0 mg/m³ at 15 meters (Figure 12). Transmissivity at this station showed 100% visibility at the surface, then changed to 90% visibility until 10 meters (Figure 13).

Station 36 surface nitrate levels ranged between 0.01 - 2.50 µM and the bottom nitrate levels ranged from 10.01 - 20.00 µM (Figure 5). The surface phosphate levels ranged from 0.03 - 0.75 µM and the bottom levels ranged between 1.51 - 2.50 µM (Figure 6). Surface silicate levels were 20.01 - 30.00 µM and the bottom silicate levels ranged from 50.01 - 80.00 µM (Figure 7). The temperature at station 36 was 20°C at the surface and decreased to 11°C near 40 meters (Figure 8). The salinity at the surface showed a 27 PSU and then reached 31 PSU at 10 meters (Figure 9) and the density at the surface was 15 kg/m³ and the maximum density reaching 23.75 kg/m³ at 45 meters (Figure 10). The dissolved oxygen at the surface reached 10 ml/L at 5 meters, and it decreased to 3 ml/L as the depth increased (Figure 11). Fluorescence measured 0 mg/m³ at the surface and at 5 meters it increased 2.5 mg/m³ then 5 mg/m³ for 2 meters, then back to 2.5 mg/m³, then it reached 0 mg/m³ by 15 meters (Figure 12). Transmissivity showed a rapid change from 60% to 90% at the surface then reached 100% visibility at 10 meters (Figure 13).

The temperature at station 37 was 20°C at the surface and quickly decreased to 13°C at 10 m deep and at 30 meters down it reached 11°C (Figure 8). The salinity was measured at 27 PSU at the surface and reached 31 PSU at 40 meters (Figure 9). The density at the surface was at 15 kg/m³, and increased to 22.75 kg/m³ at 5 meters, then at 10 meters it increased again to 23.25

kg/m³, before it reached it maximum of 23.75 kg/m³ at 40 meters (Figure 10). The dissolved oxygen at 5 meters was measured at 9 ml/L, and at 30 meters down it decreased to 3 ml/L (Figure 11). Fluorescence was 0 mg/m³ at the surface until 5 meters where it increased to 2.5 mg/m³, then it increased to 5 mg/m³ for 2 meters then decreased to 2.5 mg/m³ again before it reached 0 mg/m³ (Figure 12). The transmissivity showed 60% visibility at the surface before a small section increased to 100%, then decreased to 90% visibility around 10 meters (Figure 13).

Station 38 surface nitrate levels ranged between 0.01 - 2.50 µM and the bottom nitrate levels ranged from 20.01 - 30.00 µM (Figure 5). The surface phosphate levels were 0.03 - 0.75 µM and the bottom levels were 2.51 - 3.50 µM (Figure 6). The surface silicate levels ranged from 20.01 - 30.00 µM and the bottom silicate levels ranged from 30.01 - 50.00 µM (Figure 7). The temperature at station 38 was 20°C and decreased to 13°C at 10 meters and reached 11°C at 30 meters (Figure 8). The salinity was measured at 27 PSU at the surface and it reached 31 PSU at 40 meters (Figure 9) and the density reached 23.25 kg/m³ by 10 meters and at 40 meters it reached its maximum 23.75 kg/m³ (Figure 10). The dissolved oxygen reached 9 ml/L and by 30 meters it reached it minimum of 3 ml/L (Figure 11). The fluorescence measured 0 mg/m³ at the surface and at 5 meters the measurement read as 2.5 mg/m³ then decreased to 0 mg/m³ (Figure 12). The transmissivity showed a 70% visibility at the surface then switched to 100% visibility until 100 meters where there was another accumulation of organic material sitting near the bottom of the station (Figure 13).

Discussion

The data collected in 2014 was compared to the data collected in 2019 and multiple similarities and differences were found throughout the Inlet. The surface and bottom nitrates in

2014 were higher than the levels in 2019. Stations 31 and 33 were the most noticeable differences in nitrate levels for this Inlet (Figure 5). The surface phosphates in 2014 had a minimum of 0.06 µM and in 2019 the minimum was 0.03 µM, this difference indicated a decrease in phosphates at the surface in 2019. The bottom phosphates in 2014 showed large amounts of phosphates, whereas the phosphates in 2019 decreased throughout the stations in Herbert Inlet (Figure 6). The silicates at the surface in 2014 exhibited high concentrations at stations 38, 33, and 31. In 2019, the surface silicates displayed smaller amounts of silicates at stations 38, 33, and 31. The 2014 bottom silicates exhibited larger quantities then the silicates at the bottom in 2019 (Figure 7). The temperature of Herbert Inlet in 2014 was lower than it was in 2019, and the warmer waters stayed at the surface. In 2019, the minimum temperature in the Inlet had increased by 2°C and the warmer surface waters started to progress down the water column (Figure 8). There was a rapid change in temperature at the surface between stations 34 – 38 in 2019, which could be due to the increase of rain that year (GOC 2020). The freshwater from the waterfall near station 38, and the intersecting channels around station 34, quickly mixed and there was a rapid change in temperature. This was not the case in 2014, when there was a warm spot of surface waters that expanded between stations 35 – 38. The overall trend in temperatures from 2014 to 2019 was that in 2019, the water temperatures were increasing, and warmer waters were moving lower into the water column (Figure 8).

The salinity of the Inlet in 2014 was lower in the surface waters near station 38 (Figure 9). As the freshwater moved in from the Moyeha River waterfall and mixed with the salt water, the salinity slowly increased the farther away from the freshwater input. In 2019, there was an increase in freshwater at the surface waters at stations 36-38, then there was a rapid change in salinity with in the first few meters of the surface. In 2019, station 38 had a decrease in salinity from 29 PSU to 21 PSU around 110 meters, which could indicate an increase in fresh water due to the increased amount of rainfall around the Moyeha River (GOC 2020).

The density of Herbert Inlet in 2014 showed a less dense surface water at station 38 and 37 (Figure 10). As the stations move away from the freshwater input, the density began to increase, heading out to the ocean. As the depth increased, the density increased in both years 2014 and 2019. The density in 2019 showed an increase in density from station 38 through station 34. Like salinity, there was an accumulation of dense material in the deep waters near station 38 in 2019.

The dissolved oxygen of this Inlet in 2014 showed higher values throughout the surface waters and hypoxic conditions towards the bottom (Figure 11). Hypoxic waters occur when the water is deprived of oxygen and it is a serious threat for marine life. At 50 meters, the oxygen was nearly depleted at 1 ml/L in 2014, whereas in 2019, at 50 meters, the oxygen was 4 ml/L. The dissolved oxygen that was measured in 2019 showed rapid changes in oxygen levels from station 32 – 37, with station 34—where Millar Channel converges with Herbert Inlet—having hypoxic conditions before a rapid change in oxygen levels. The dissolved oxygen levels in 2019 were considerably higher than those in 2014 and as the depth increased, the oxygen slowly decreased but did not fully deplete like it did in 2014.

The fluorescence measured in the Inlet in 2014 showed a low amount of fluorescence at the surface between stations 31 – 37 around 5 – 10 meters deep (Figure 12). At 50 meters there was a change to 0 mg/m^3. In 2019, there was a higher abundance of fluorescence in the surface waters at all the stations. Station 31 had a higher concentration at the mouth of the Inlet, then it decreased at station 32 and stayed the same through to station 34. At station 34 the concentration increased to 5 mg/m^3 at 10 meters until station 37, where it decreased before reaching station 38, this is known as the chlorophyll max. The chlorophyll max was located near the thermocline—where the warmer surface waters meet the cold deeper waters—and the concentration of phytoplankton was the highest in this area. In 2019, there was a higher concentration of fluorescence found in surface waters. Around 30 meters there was an abundance of fluorescence that was found near station 33.

The transmissivity of this Inlet in 2014 was a 90% at the surface meaning that there was very little to no solid material at the surface waters (Figure 13). In 2019, the transmissivity fluctuated throughout the Inlet. There was a rapid change at the surface waters, then it cleared up as the depth increased. There were a couple of interesting spots in 2019 where the instrument picked up 90% visibility around 80 meters between stations 33 and 34, and 110 meters around stations 37 and 38. The depths of station 38 had higher concentrations of nutrients, salinity, and density. This accumulation was solid material that had sunk down into the dense waters where it became neutrally buoyant at these depths in 2019.

The increased temperatures that were measured in 2019 support the hypothesis because it was believed that the second incoming wave of “The BLOB” would push the warm waters deeper and farther into the Inlet. This created higher concentrations of nutrients, increased salinity, and fluorescence, and eventually produced an increased potential for harmful algal blooms to develop in 2019. While comparing the changes between 2014 and 2019, certain patterns through the water column were recognized. The strong stratification that developed supports the idea that conditions were favorable to support continued HABs. These differences can then be used to inform researchers on ways to monitor the spread and possibly predict the development of harmful algal blooms. Knowing what the favorable conditions are and how they develop is an important step in understanding how to predict the likelihood of the harmful algal blooms.

Variations that did not fit the patterns during this project were the minimum temperature of Herbert Inlet was raised by 2°C from 2014 to 2019. The deep waters at station 38 had values of salinity, density, and transmissivity that differed from 2014. The nitrate levels at the bottom of station 38 were also the highest recorded in 2019. Station 34, where Millar channel meets up, the dissolved oxygen in 2019 showed hypoxic conditions at the surface but a quick change at 5 meters and there was an abundance of dissolved oxygen just under the surface. The increase in fluorescence in 2019 suggested a higher concentration of chlorophyll-a, which indicated the potential presence of *Alexandrium*, a known toxic alga. This can be confirmed with the phytoplankton samples that have been collected but are awaiting examination.

Conclusion

This project involved gathering and organizing data sets from Herbert Inlet that had been collected in previous years from students and faculty at the UWT. Data from 2019 was compared to 2014 to determine the differences in nutrient levels, oceanic conditions, and water properties, and how these differences influenced the development of the HABs in Clayoquot Sound of British Columbia, Canada. Microsoft Excel, ArcGIS, and Surfer programs were used to conduct statistical analyses, create choropleth maps, and plot water properties of Herbert Inlet. The results of this project showed that the nutrient levels from 2019 are not as elevated as the levels found in 2014, but the temperature of Herbert Inlet had increased its minimum value by 2°C since 2014. The “BLOB” event that occurred in 2014 had a massive impact on the Clayoquot Sound, and in 2019 another event occurred, which moved the warm waters further and deeper into the inlets. Future work to expand on these findings could include finding other areas that have been impacted by the “The BLOB” and compare the results to find new ways of predicting patterns and monitoring environments. This project created a better understanding and analysis of the continuing problem that Herbert Inlet is facing.

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Appendix

Data files are located here:
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