Clayoquot Sound Harmful Algal Blooms Investigation of Warn Bay to Tranquil Inlet – 2019

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Abstract:	A large and successful shellfish and fish industry resides in the northeastern Pacific, so when a heat anomaly now known as the "Blob" was discovered in the area there was concern about its impacts. Since many harmful algal blooms (HABs) thrive in higher temperatures, it was important to determine if the "Blob" caused more favorable environmental conditions to support increased amounts of algae in the water. Measurements were taken in 2019 for essential nutrients such as nitrates, phosphates, and silicates, as well as water properties including temperature, salinity, density, dissolved oxygen, transmissivity, and fluorescence. These were then compared to data from 2014 to verify if there was a difference between two years that the "Blob" was confirmed to have appeared. This analysis focused on a transect from Warn Bay to Tranquil Inlet in Clayoquot Sound, British Columbia, Canada. In 2019, the comparison showed a decrease in nutrients at the water's surface despite consistent values at the sea floor, as well as an increase in temperature that correlated with a decrease in transmissivity and an increase in fluorescence near the surface. This evidence supported the possibility of increased favorable conditions for HABs with the "Blob" since 2014. If persistent, future years would have to face increased risk of these HABs contaminating seafood supplies.
Key Words:	HABs, harmful algal blooms, Clayoquot Sound, shellfish, seafood, the "Blob"
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Date Submitted:	12 June 2021

Recommended Citation: Whelan K. 2021. Clayoquot Sound Harmful Algal Blooms Investigation of Warn Bay to Tranquil Inlet - 2019. Environmental Science Undergraduate Thesis. https://digitalcommons.tacoma.uw.edu/es_theses/whelan_2021

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 to study this area to include undergraduates, graduates, middle & high school students, and research scientists. This work began as a 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

Towards the end of 2013, an area of water now known as the "Blob" was discovered in the northeastern Pacific Ocean with temperatures approximately 3°C higher than usual, thought to be caused by pressure and wind anomalies (OWSC 2014). There was concern for how this would affect weather in the area, but many also feared that these temperatures would impact local ecosystems. Under normal circumstances, harmful algal blooms (HABs) do not pose a substantial risk, but when given favorable conditions they could spread rapidly and contaminate food sources (NOAA 2016). In the northeastern Pacific there are plenty of resources that could be affected, including fisheries, shellfish farms, and sometimes the water itself. This ongoing study was the first to be based specifically in Clayoquot Sound on Vancouver Island in British Columbia, Canada, an area with high tourism and many seafood-based companies. For this study, 2019 data included a transect not analyzed in past years, with nine stations where samples were taken, stretching between major inlets from Warn Bay to Tranquil Inlet (figure 1). Despite this addition, the 2019 collections were linked to 2014 since both years were known to have the "Blob" develop in the northeastern Pacific, making a comparison of great interest and environmental importance. To determine if there was a correlation between the "Blob's" higher temperatures and the growth of algal blooms, measurements of water conditions and nutrients were taken and compared for potential signs of increased activity. The conditions measured were temperature and salinity, both of which contribute to the fitness of algae, as well as dissolved oxygen, transmissivity, and fluorescence, all three of which can be used to determine the relative presence of algae. The nutrients were collected to determine if there were additional causes for these algal blooms, rather than simply being related to temperature. This data was then also compared to past data from 2014 to determine if similar conditions occurred in response to the presence of the "Blob."

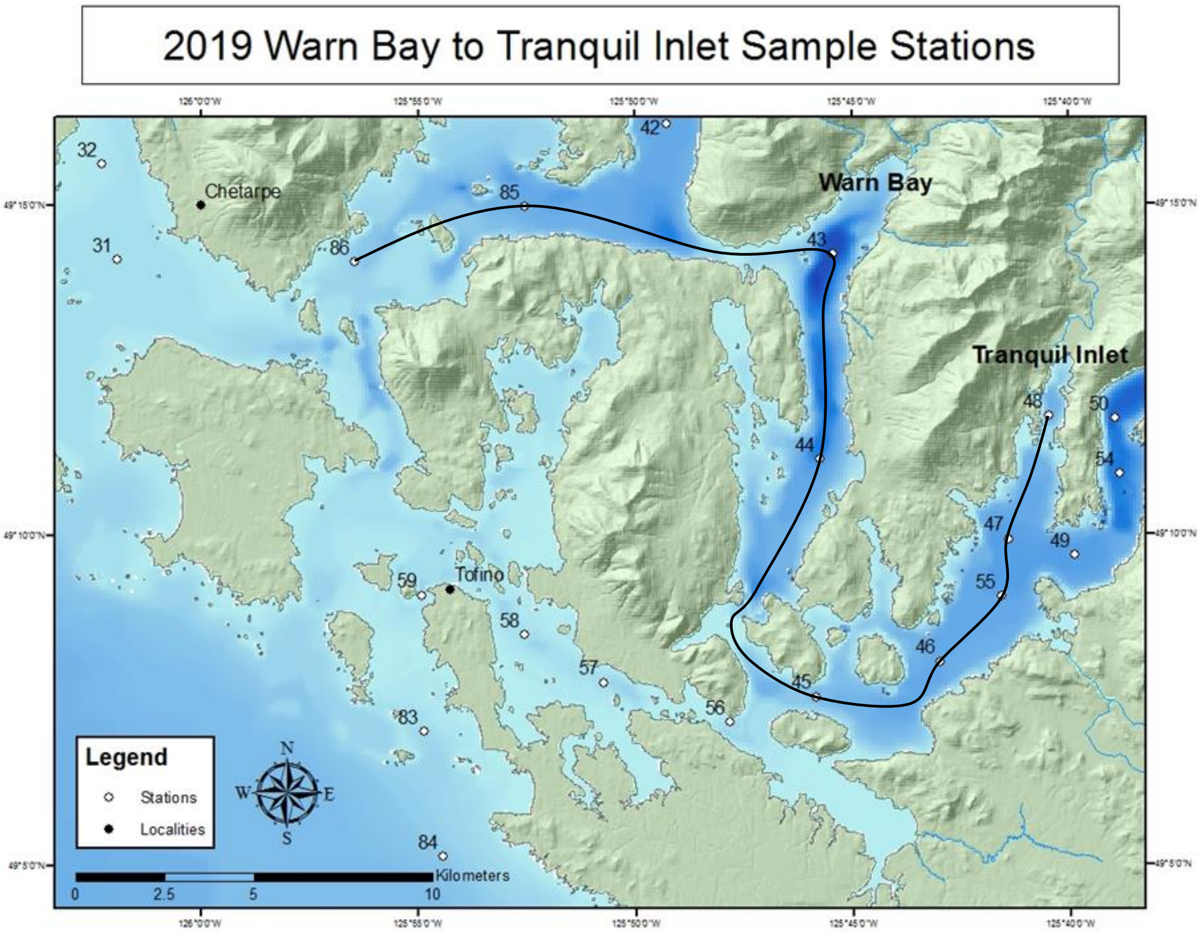

Figure 1. Map of sample stations where data was taken; the Warn Bay to Tranquil Inlet transect included stations 86, 85, 43, 44, 45, 46, 55, 47, and 48.

REVIEW OF LITERATURE

Clayoquot Sound has been a source of seafood ever since the First Nation Peoples inhabited the area. The Nuučaanuułatḥ (Nuu-chah-nulth), a group of multiple First Nation Peoples, had claim over the entire western coast of Vancouver Island. In Clayoquot Sound there were three specific First Nation Peoples territories; the Hesquiaht Territory at the north edge of Clayoquot Sound with Hesquiat Harbour, the Ahousaht Territory from Sydney Inlet to Warn

Bay, and the Tla-o-qui-aht Territory at the south from Meares Island to Kennedy Lake (FOCS c2014). Fisheries and shellfish farms could be found in this area, some of which were owned by First Nation Peoples, such as Tla-o-qui-aht First Nation Seafood LLP. As such, it was important to monitor the water and be aware of any contaminants that would be detrimental to consumer health. In February of 2014, Nicholas Bond and his associates discovered a heat anomaly in the northeastern Pacific, nicknamed the “Blob” (OWSC 2014). A portion of the water was up to 3°C warmer than the normal February temperature, and later that year reached record high summer temperatures (Bond et al. 2015). These findings brought concerns for the potential of rising algal growth, especially the formation of harmful algal blooms (HABs). One genus in particular, the dinoflagellate *Alexandrium*, grew optimally at 10°C to 24°C with the most rapid growth occurring at 17°C to 24°C (Bill et al. 2016). When the “Blob” first appeared, abnormal amounts of chlorophyll were not discovered, but as these heightened temperatures persisted algal blooms began to grow (McCabe et al. 2016). These blooms had the potential for widespread contamination of seafood such as fish and shellfish, and the consequences of ingesting such were found to include anything from mild abdominal pain to seizures to death. Fisheries and shellfish farms were required to close in response to these dangers, but a more permanent solution needed to be found, as well as consistent monitoring of oceanic conditions in the event that the “Blob” returns.

HABs were previously known to exist in Clayoquot Sound, but it was not yet completely understood what could lead to increased productivity. Oceanic conditions were measured and a number of samples were taken in order to analyze data on which HABs were present and what conditions were advantageous. Temperature was a major indicator of conditions to promote the possibility of algal blooms and was a necessary measurement to study the effects of the "Blob". A decreased amount of salinity would also suggest a favorable environment for HABs, since these organisms prefer the layers of density found in areas with both freshwater and saltwater (NOS 2020). These two conditions along with density gave researchers an idea of how the water came into Clayoquot Sound from the ocean, and how the rivers fed into the various inlets. Dissolved oxygen, transmissivity, and fluorescence together showed the areas the algae were most likely to be. Dissolved oxygen showed if there was an overwhelming amount of algae in the water, which would consume oxygen while decomposing and often cause hypoxic events, leaving little to no oxygen available for other organisms (National Geographic 2011). Transmissivity showed how much debris was in the water, and fluorescence showed how much of that debris contained chlorophyll-a, a molecule found in photosynthesizing organisms. Nitrates, phosphates, and silicates served a similar function, since it would indicate these nutrients were being used by phytoplankton if there were low concentrations at certain depths (EarthLabs 2020). With these variables in mind, plenty of data was recorded and analyzed for the 2019 "Blob" appearance and its effects on HAB growth in Clayoquot Sound.

METHODS

Sampling

Samples were collected in Clayoquot Sound spanning from Warn Bay to Tranquil Inlet at stations 86, 85, 43, 44, 45, 46, 55, 47, and 48 (figure 1). This transect was a new area for analysis, as it was not a major inlet but rather a stretch between Bedwell and Tofino Inlets. Temperature, salinity, density, dissolved oxygen, transmissivity, and fluorescence data were taken continuously by a CTD (conductivity, temperature, depth) instrument lowered through the water column. Temperature data was important to this study in that some harmful algal blooms grow better in warmer water. Salinity was calculated from conductivity, and density was calculated from temperature, salinity, and pressure. These qualities were used to understand where the water came in from the ocean, or where water was fed by freshwater rivers. Transmissivity was used to determine how much debris was in the water, in conjunction with fluorescence to determine how much of that debris contained a molecule associated with phytoplankton, chlorophyll-a. Nutrient samples were retrieved from the surface and bottom of the water column in closing bottles. They were frozen and stored until they could be analyzed at the University of Washington Seattle. These included nitrates and phosphates, both of which are essential for photosynthesis to occur, and silicates, essential for the material make-up of a common type of phytoplankton called diatoms. Samples of plankton were collected to determine what species were present, but will not be discussed in this paper.

Instrumentation

The CTD had sensors for conductivity, temperature, and pressure on the bottom, as well as an oxygen sensor, transmissometer, and fluorometer attached to the sides. Measurements were taken continuously by these sensors as the CTD traveled down the water column and were later downloaded as a computer file. The salinity of the water was calculated from conductivity, as the ions in water were what conducted electricity. The density was calculated from salinity, pressure, and temperature. The oxygen sensor had to be flushed for three minutes just under the surface of the water to purge any lingering air before taking further measurements. The transmissometer directed light from one end and recorded the amount of light received at the other end to determine how much debris was in the water. The fluorometer measured the presence of chlorophyll-a.

Data Analysis

Table 1. Five-number summaries involving all data collected for surface and bottom nutrients from Warn Bay to Tranquil Inlet.

		PO4	SiOH4	NO3	NO2	NH4
Surface	Q0 (Minimum)	0.03	2.02	0.01	0	0
	Q1 (25th percentile)	0.33	9.44	0.03	0.02	0
	Q2 (median)	0.53	13.94	0.05	0.02	0.09
	Q3 (75th percentile)	0.59	18.28	0.7	0.1	0.63
	Q4 (Maximum)	1.26	23.35	4.72	0.37	3.07
	Mode	0.58	13.63	0.03	0.02	0
Bottom	Q0 (Minimum)	0.61	5.14	0	0.01	0
	Q1 (25th percentile)	1.535	25.37	5.39	0.095	0
	Q2 (median)	2.23	42.57	18.58	0.16	0.75
	Q3 (75th percentile)	2.49	51.485	23.46	0.38	3.055
	Q4 (Maximum)	7.07	84.62	27.16	0.56	46.6
	Mode	#N/A	#N/A	#N/A	0.15	0

Table 2. Five-number summaries involving all data collected by CTD from Warn Bay to Tranquil Inlet.

	Pressure	Temperature	Fluorescence	Transmissivity	Oxygen	Salinity	Density	Depth
	db	°C	mg/m^3	%	ml/l	PSU	kg/m^3	m
Q0 (Minimum)	1	13.0203	-0.4411	14.7358	-0.8993	20.6358	13.7838	0.992
Q1 (25th percentile)	16	14.8353	0.990025	89.831075	4.162575	29.404425	21.695425	15.865
Q2 (median)	32	15.471	1.82995	92.0676	4.8884	29.6511	21.8468	31.729
Q3 (75th percentile)	51	15.58975	2.545725	95.7476	5.036325	29.859075	21.919775	50.566
Q4 (Maximum)	132	20.2307	10.9278	98.7744	7.9673	31.7449	23.6155	130.851
Mode	2	15.523	1.095	97.4338	4.993	29.8747	21.5963	3.966

The nutrient samples were kept frozen until the University of Washington Seattle could analyze them in the marine chemistry lab (UWO 2020). In the case of the CTD, the data was transferred directly from the instrument to an Excel comma-separated values file (.csv). The raw data was used to calculate five-number summaries for nutrients and water conditions separately (tables 1 and 2). These served as reference points for how measurements spanned when building choropleth maps and contour plots. ArcGIS was used to build choropleth maps of the transect, comparing the nutrient content near the surface to the bottom (figures 7-9). By determining if there was a large difference in concentrations between surface and bottom nutrients, this helped to show if nutrients were being consumed by phytoplankton near the surface. The CTD data was also applied to profile plots in Excel to get an idea of the general trends of the water's conditions (figures 10, 12, 14, 16, 18, 20). Surfer was used to create maps that showcased contoured cross-sections of each measurement at several different depths, giving the ability to visualize the water's conditions along the entire transect (figures 11, 13, 15, 17, 19, 21).

RESULTS

Weather and tidal conditions were retrieved from government data near Tofino, B.C., for 09 September 2019 and 10 September 2019. The semidiurnal tides for the week started on Sunday the 8th and ended on Saturday, the 14th (figure 2). The temperature ranged from lows of about 14°C and generally peaked at 17°C to 20°C in the early to mid-afternoon (figure 3). Atmospheric pressure was lower in the morning and peaked at midday for both the 9th and the 10th, with the second day consistently 0.25kPa to 0.35kPa higher (figure 4). The wind speed increased throughout both days, though the 9th peaked at 3km/h higher than the 10th in the mid-afternoon (figure 5). Before 9:00 am the wind for the 9th came from the north, and then settled into a consistent pattern from the south and west (figure 6). The

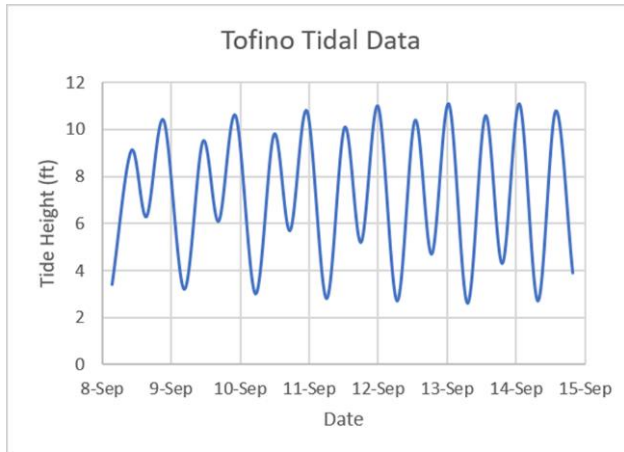

Figure 2. Tidal information for the week of the study; tidal heights were similar on 2020 Sep 09 and 2020 Sep 10 (Data Source: Mobile Geographics 2019).

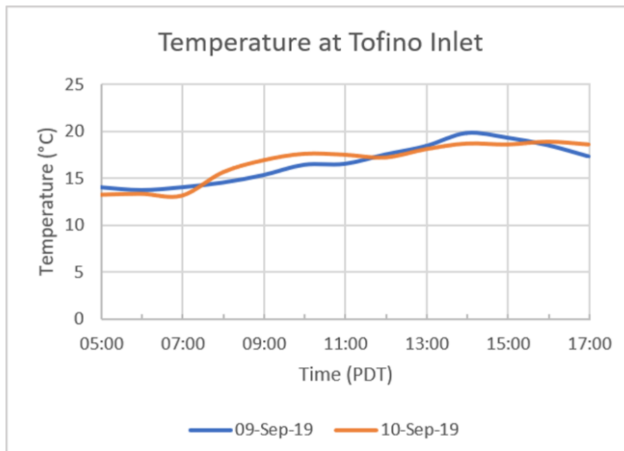

Figure 3. Temperature data for the two days of sampling; temperature slowly increased from a morning low to a mid-afternoon high (Data Source: Government of Canada 2019).

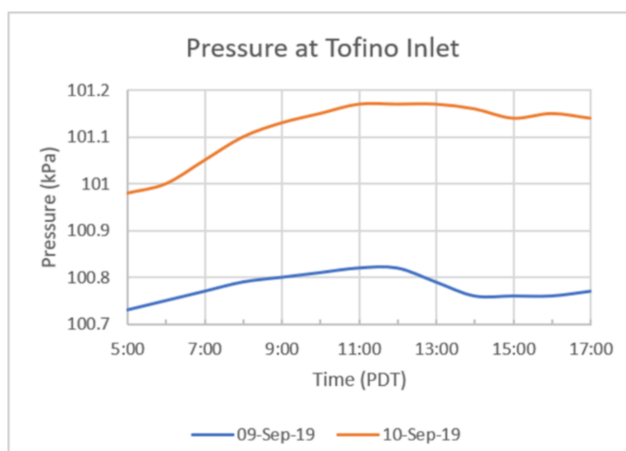

Figure 4. Pressure data for the two days of sampling; 10 Sep 2019 had about 0.3kPa higher pressure than 09 Sep 2019, but both increased from a morning low to a midday high (Data Source: Government of Canada 2019).

wind on the 10th, on the other hand, started the day coming from a northeast direction, jumped to the northwest at 9:00am, and then also continued the day from the south and west.

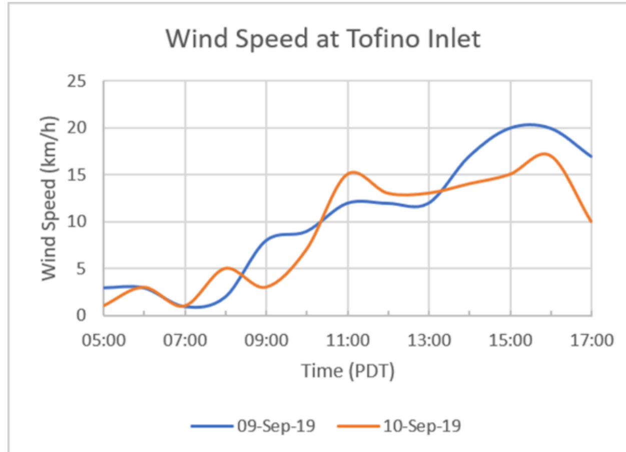

Figure 5. Wind speed data for the two days of sampling; wind speeds sporadically increased from a morning low to a late-afternoon high (Data Source: Government of Canada 2019).

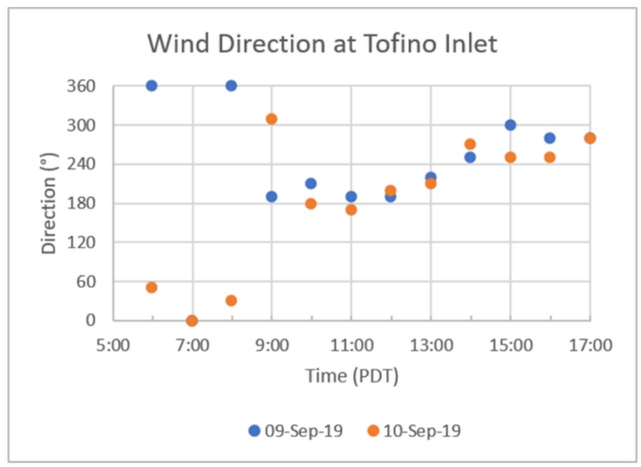

Figure 6. Wind direction data for the two days of sampling; winds started the morning coming from a northerly direction, switched at 09:00am to coming from a southwesterly direction and then gradually moved up the compass until they were coming from a westerly direction (Data Source: Government of Canada 2019).

For the Warn Bay to Tranquil Inlet transect, data was taken at stations 86, 85, 43, 44, 45, 46, 55, 47, and 48 over the course of two days (figure 1). Nutrients were measured in the lab for nitrates (NO_3), phosphates (PO_4), and silicates ($Si(OH)_4$), all of which had samples from both the surface and the bottom of the water column. Choropleth maps showed levels of concentration for comparison. The nitrates ranged between 0.01 µM and 4.72 µM near the surface and between 0.00 µM and 27.16 µM at the bottom (figure 7). The phosphates were all at the same relative level of 0.03 µM to 1.26 µM near the surface and ranged anywhere between 0.61 µM and 7.07 µM at the bottom (figure 8). The silicates were mostly within 2.02 µM to 23.35 µM near the surface, though station 43 was the only station measured above 20.00 µM. The bottom values for the silicates ranged between 5.14 µM and 84.62 µM (figure 9). For every nutrient, the concentration at the bottom was generally higher than at the water's surface. The largest differences in

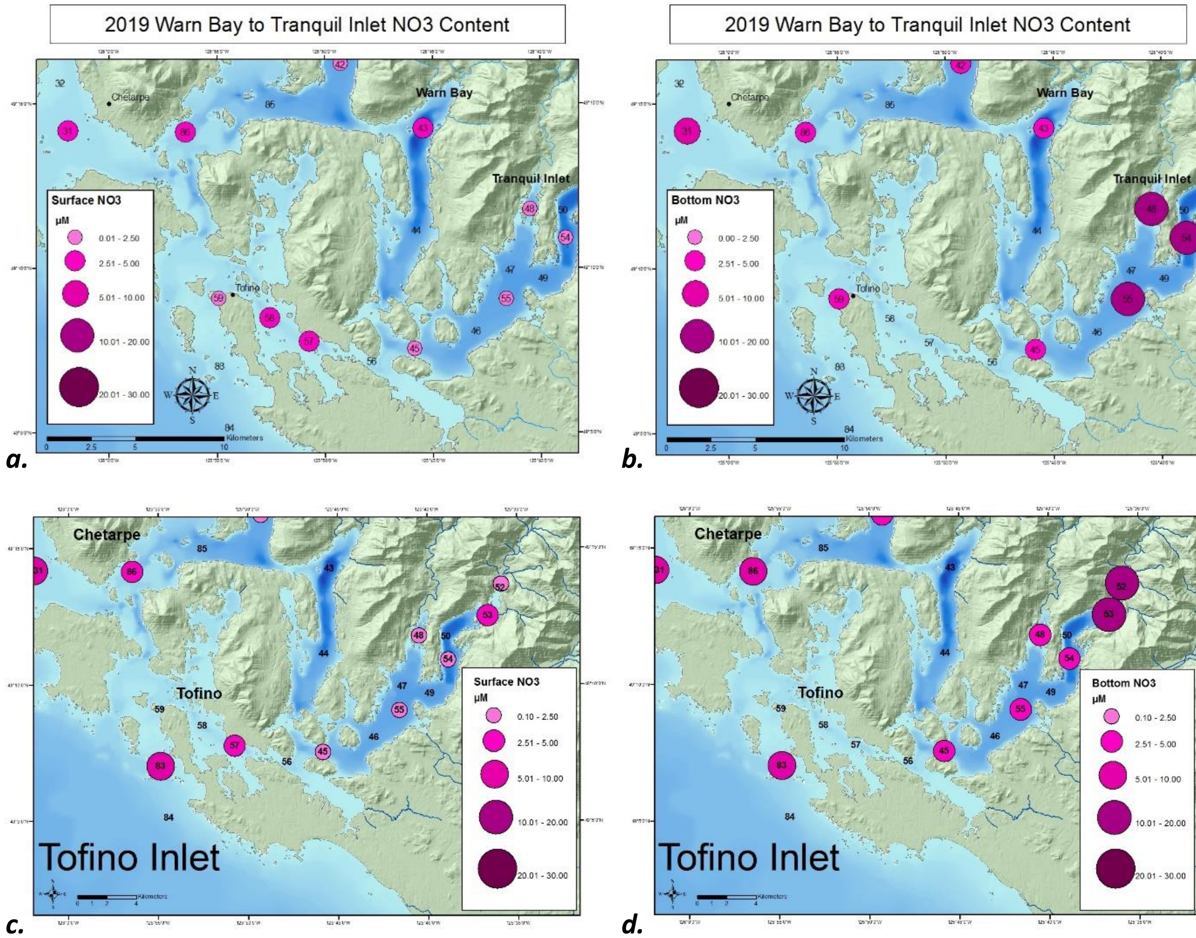

Figure 7a. Surface nitrates for Warn Bay to Tranquil Inlet in 2019 ranged between 0.01 µM and 4.72 µM. *7b.* Bottom nitrates for Warn Bay to Tranquil Inlet in 2019 ranged between 0.01 µM and 27.16 µM. *7c.* Surface nitrates for Tofino Inlet in 2014; since raw data was not readily available, the symbolized data on the choropleth maps was used instead; stations 45, 55, and 48 ranged between 0.01 µM and 2.50 µM, station 86 ranged between 2.51 µM and 5.00 µM (Baer 2020). *7d.* Bottom nitrates for Tofino Inlet in 2014; stations 45, 55, and 48 ranged between 2.51 µM and 5.00 µM, station 86 ranged between 5.01 µM and 10.00 µM (Baer 2020).

concentrations were consistently found at stations 55 and 48, directly in Tranquil Inlet and Tofino Inlet.

The water's conditions were measured continuously at every depth and included temperature, salinity, density, dissolved oxygen, transmissivity, and fluorescence. In most cases, temperature decreased as depth increased (figure 10). The stations more open to the rest of Clayoquot Sound were well-mixed, whereas stations within Tofino Inlet and Tranquil Inlet had many high stratification (figure 11a). Salinity typically increased with depth, with a

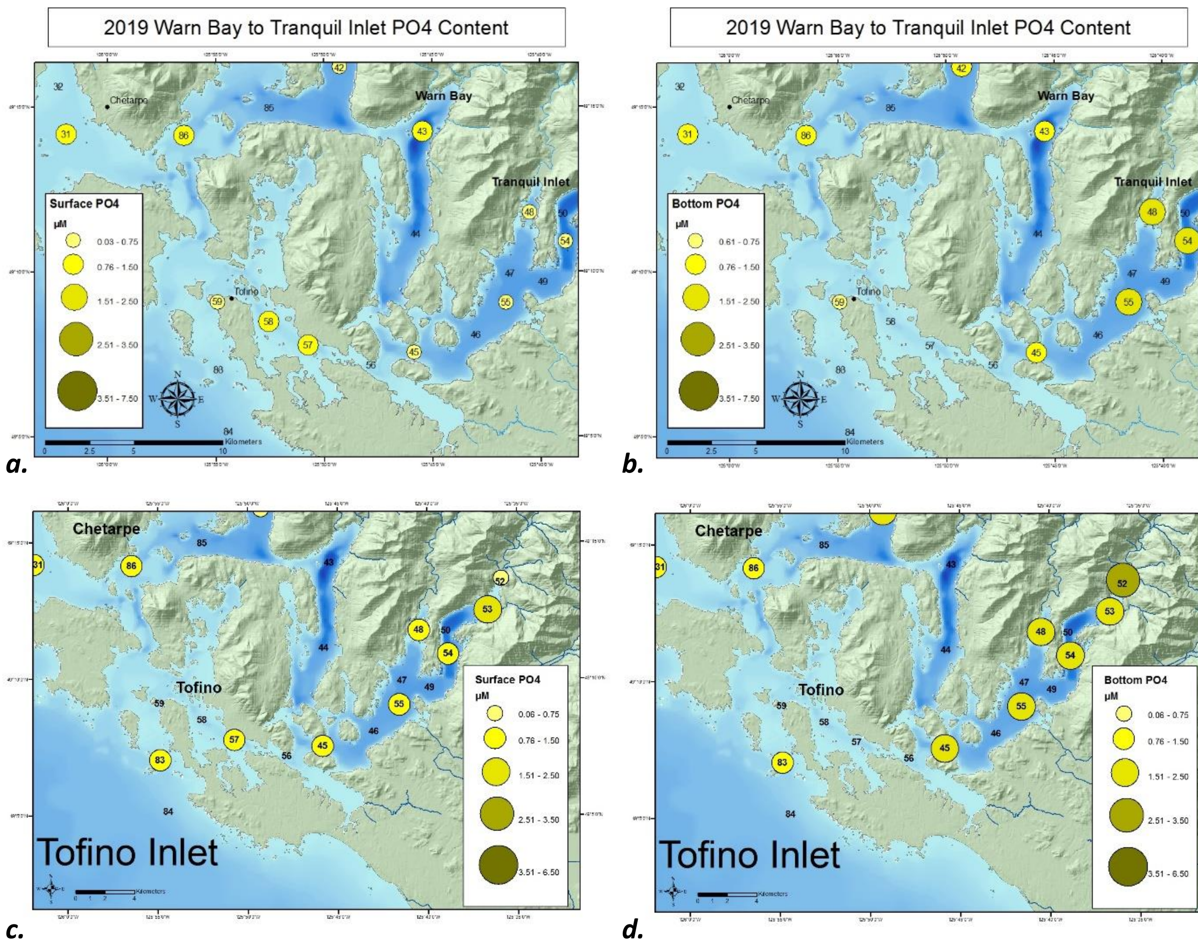

Figure 8a. Surface phosphates for Warn Bay to Tranquil Inlet in 2019 ranged between 0.03 µM and 1.26 µM. *8b.* Bottom phosphates for Warn Bay to Tranquil Inlet in 2019 ranged between 0.61 µM and 7.07 µM. *8c.* Surface phosphates for Tofino Inlet in 2014; since raw data was not readily available, the symbolized data on the choropleth maps was used instead; stations 86, 45, 55, and 48 ranged between 0.76 µM and 1.50 µM (Baer 2020). *8d.* Bottom phosphates for Tofino Inlet in 2014; station 86 ranged from 0.76 µM and 1.50 µM, stations 45, 55, and 48 ranged between 1.51 µM and 2.50 µM (Baer 2020).

few locations that suddenly decreased before continuing lower (figure 12). The salinity increased the closer a station was to the ocean (figure 13a). These patterns were strongly paralleled by density, which also increased as depth increased (figure 14). The contour plot shows that at nearly every station density increased with similar rates and depths (figure 15a). Only stations 86 and 85 diverged from the rest, with significantly higher density near the ocean. Dissolved oxygen decreased as depth increased, though as observed with temperature there were some stations that had a less rapid descent than others (figure 16). The stations closer to

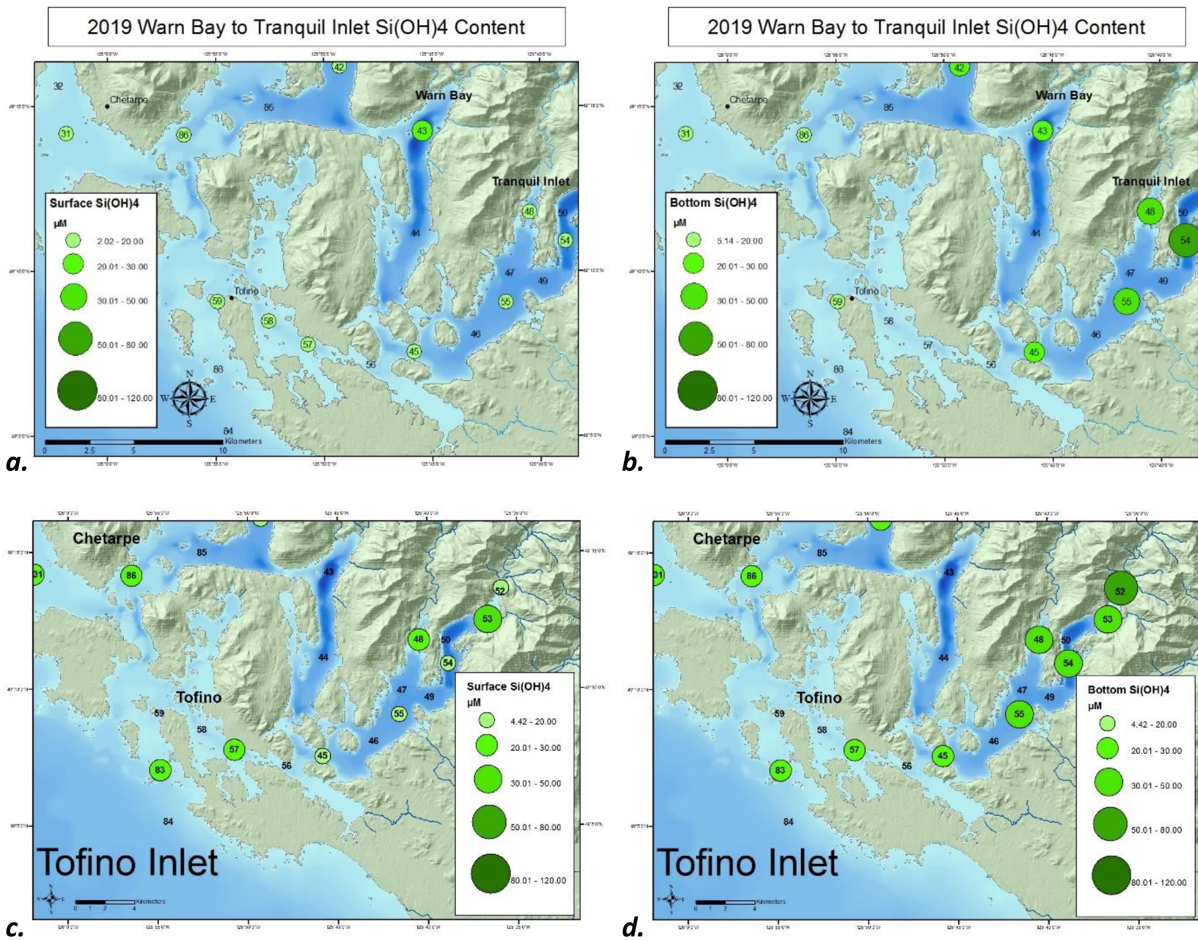

Figure 9a. Surface silicates for Warn Bay to Tranquil Inlet in 2019 ranged between 2.02 µM and 23.35 µM. *9b.* Bottom phosphates for Warn Bay to Tranquil Inlet in 2019 ranged between 5.14 µM and 84.62 µM. *9c.* Surface silicates for Tofino Inlet in 2014; since raw data was not readily available, the symbolized data on the choropleth maps was used instead; stations 45 and 55 ranged between 0.01 µM and 20.00 µM, stations 86 and 48 ranged between 20.01 µM and 30.00 µM (Baer 2020). *9d.* Bottom silicates for Tofino Inlet in 2014; stations 86 and 45 ranged between 20.01 µM and 30.00 µM, stations 55 and 48 ranged between 30.01 µM and 50.00 µM. (Baer 2020).

the ocean saw a higher concentration and less variation in dissolved oxygen than the stations at the head of the inlet (figure 17a). Transmissivity increased near the surface, but as the depth increased, the debris in the water decreased (figure 18). The sudden change near the surface contrasted with the data at lower depths, since once the CTD reached about 10 m below the surface the transmissivity levels plateaued and did not change noticeably again until 70 m to 100 m in depth (figure 19a). When comparing profile and contour plots, this observation was similar to fluorescence data, which increased rapidly at a shallow depth until 10m below the surface and then promptly decreased with further depth (figure 20). This shallow depth with the highest presence of chlorophyll-a was considered the chlorophyll maximum, where photosynthesizing organisms received plenty of sunlight. The stations farther out to sea also had higher fluorescence due to upwelling of nutrients from the ocean (figure 21a)

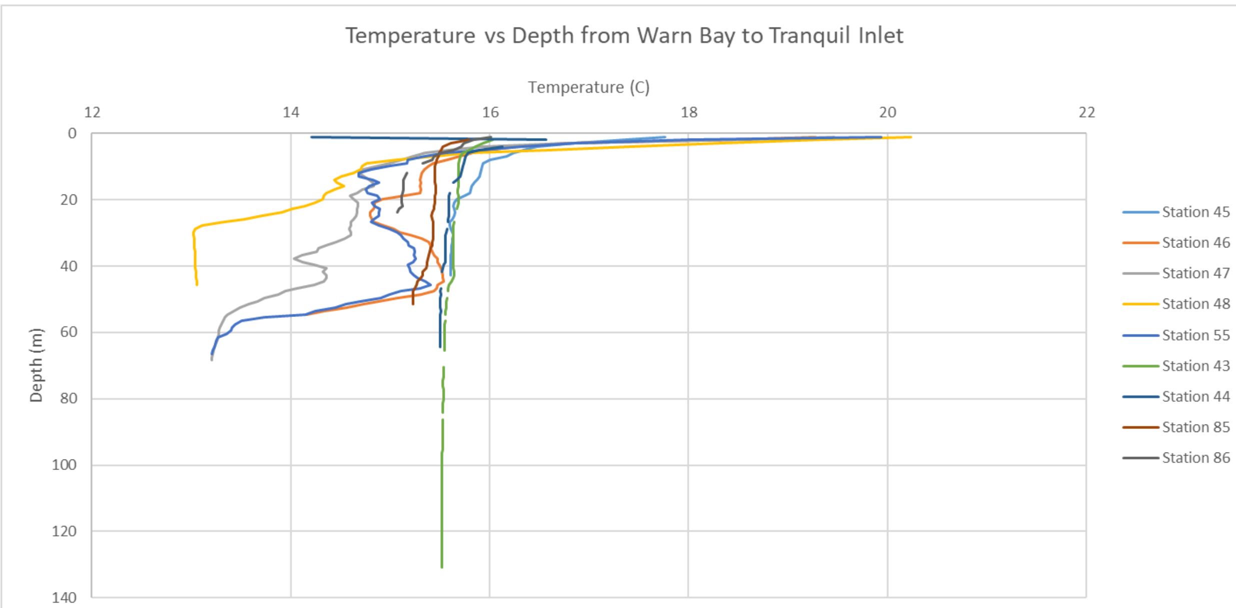

Figure 10. Profile plot for temperature from Warn Bay to Tranquil Inlet; temperature decreased as depth increased.

DISCUSSION

This study of Clayoquot Sound's harmful algal blooms (HABs) was a continuation of data collected in 2014, which was compared to this set in 2019 (Baer et al. 2020). However, during both 2014 and 2019 the "Blob" was known to be present, so this comparison does not include data for years with normal temperatures. The data from 2019 was overall similar to the data from 2014 when regarding the nutrients nitrate (NO_3), phosphate (PO_4), and silicate ($Si(OH)_4$). For comparisons with 2014 findings, the symbolized values on nutrients choropleth maps were used in place of raw measurements. There were four stations (86, 45, 55, and 48) within the Warn Bay to Tranquil Inlet transect that had samples taken from the surface and bottom of the

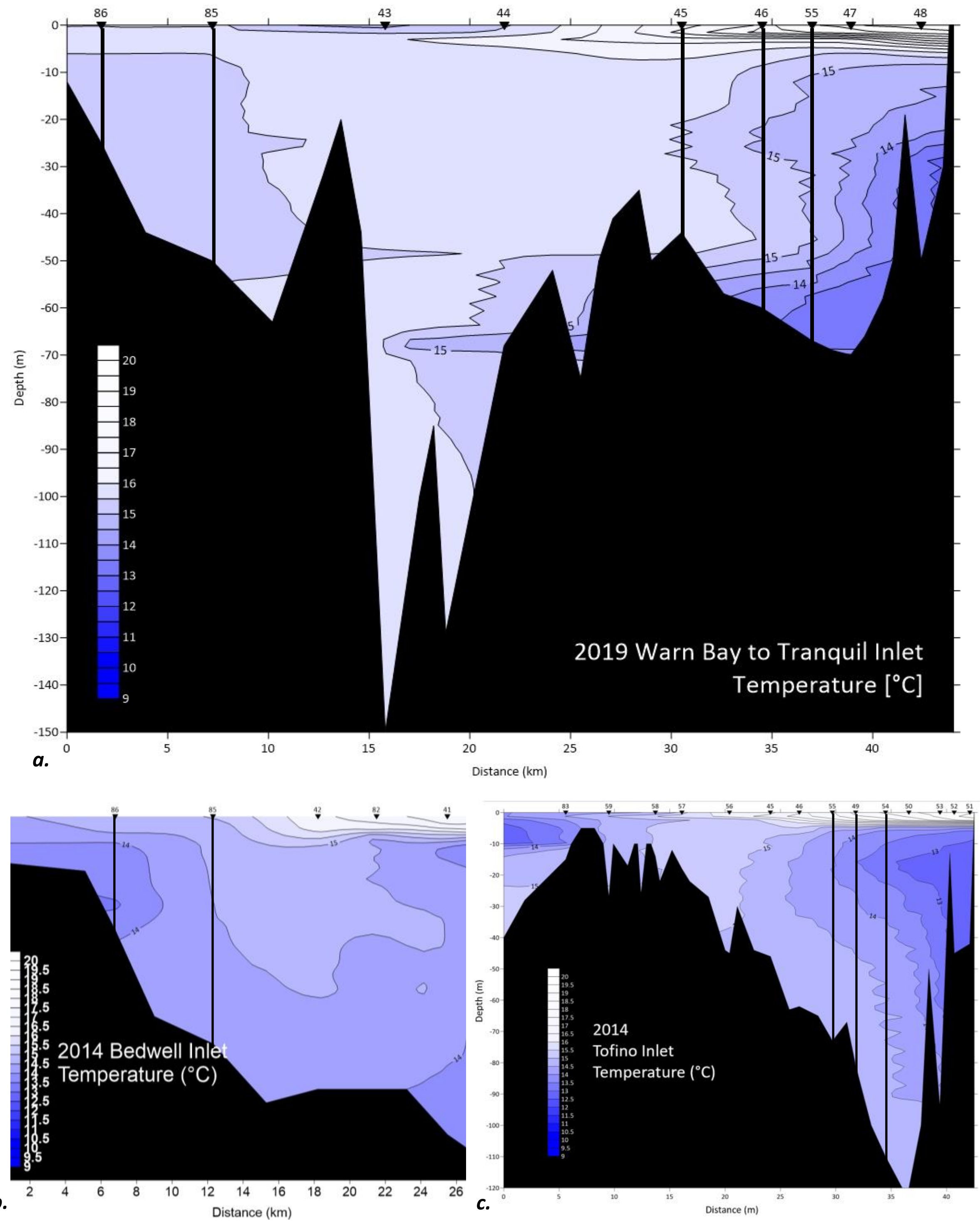

Figure 11a. Surfer plot for temperature from Warn Bay to Tranquil Inlet; the water coming in from the ocean was better mixed than that in Tranquil Inlet. *11b.* Surfer plot for temperature in Bedwell Inlet in 2014; there was a gradual increase in temperature as the water came further inland, with a large stretch halfway in with more consistent values (Roca 2020). *11c.* Surfer plot for temperature in Tofino Inlet in 2014; there was a very obvious columnar pattern in temperature (Baer 2020). Distance on the x-axis should be labelled as kilometers instead of meters.

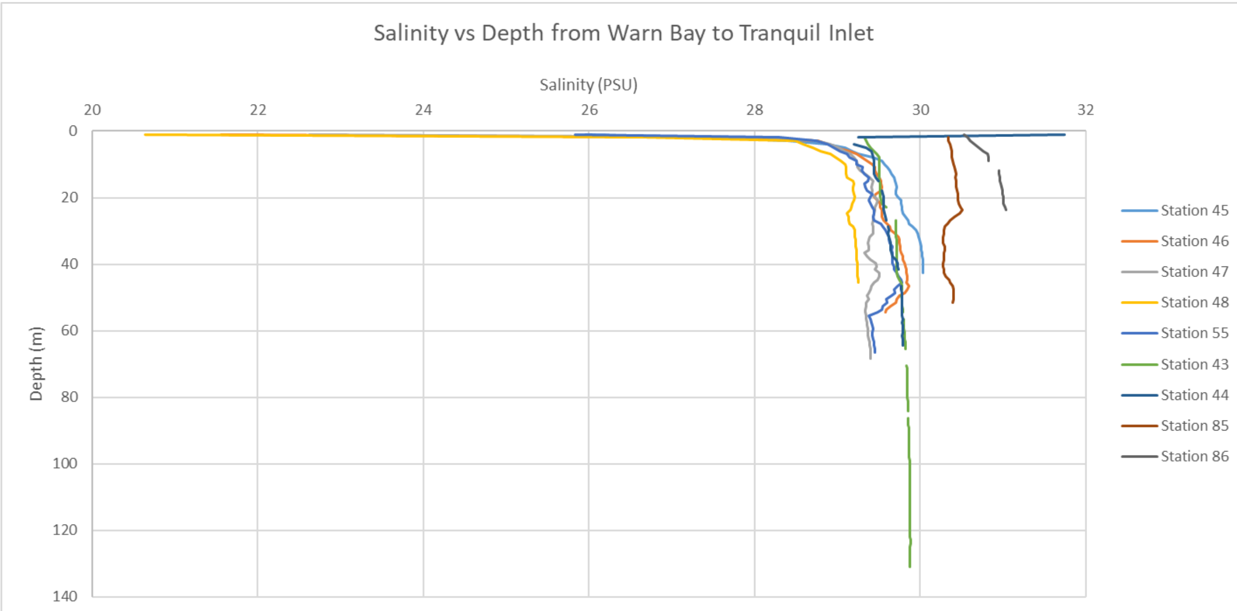

Figure 12. Profile plot for salinity from Warn Bay to Tranquil inlet; salinity increased as depth increased.

water column during both years. The same patterns emerged, with less nutrients near the surface and more at the bottom. The surface nitrates were the most similar set measured, with all four stations staying within the same range of symbolized values (figure 7). Stations 45, 55, and 48 were between 0.01 µM and 2.50 µM and station 86 was between 2.50 µM and 5.00 µM both years. In contrast, the bottom nitrates were the most consistently different to compare, with only station 45 staying in the same range of 2.51 µM – 5.00 µM for both years. Stations 55 and 48 in Tranquil Inlet saw an increase from the 2014 range of 2.51 µM – 5.00 µM to the 2019 range of 10.01 µM – 20.00 µM, but station 86 decreased from 5.01 µM – 10.00 µM in 2014 to 2.51 µM – 5.00 µM in 2019. The surface phosphates at stations 45, 55, and 48 decreased from the symbolized second-tier range of 0.76 µM – 1.50 µM in 2014 to the first-tier range of 0.01 µM – 0.75 µM in 2019 (figure 8). Only station 45 changed for the bottom phosphates, decreasing from 1.51 µM – 2.50 µM in 2014 to 0.76 µM – 1.50 µM in 2019. The surface silicates at stations 86 and 48 decreased from the second-tier range of 20.01 µM – 30.00 µM in 2014 to

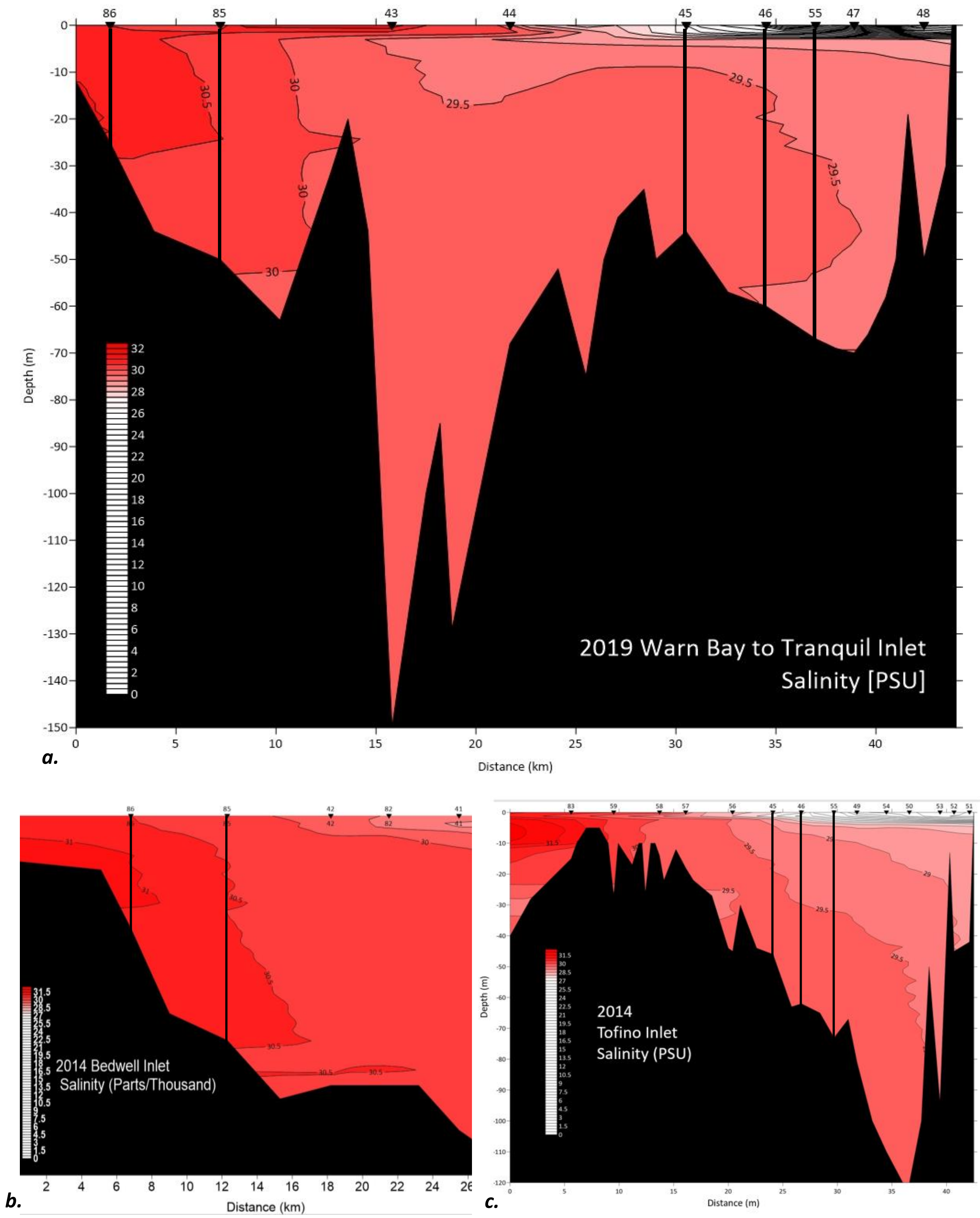

Figure 13a. Surfer plot for salinity from Warn Bay to Tranquil Inlet; salinity consistently decreased the farther it was from the ocean. *13b.* Surfer plot for salinity in Bedwell Inlet in 2014; very consistent salinity measurements with a slow decrease towards inland (Roca 2020). *13c.* Surfer plot for salinity in Tofino Inlet in 2014; salinity decreased rapidly at the mouth of the inlet and more gradually further inland (Baer 2020). Distance on the x-axis should be labelled as kilometers instead of meters.

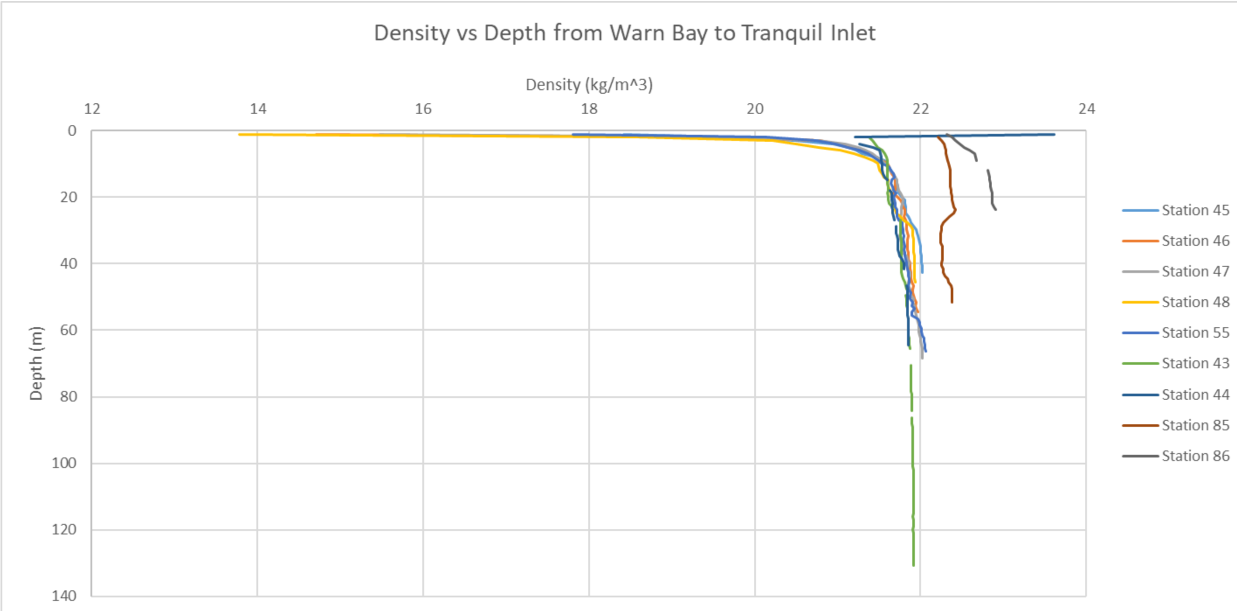

Figure 14. Profile plot for density from Warn Bay to Tranquil Inlet; density increased as depth increased.

the first-tier range of 0.01 µM – 20.00 µM in 2019 (figure 9). The only station to see change for the bottom silicates was a decrease at station 86, decreasing from 20.01 µM – 30.00 µM in 2014 to 0.01 µM – 20.00 µM in 2019. Overall, most surface samples decreased in concentration in 2019 when compared to 2014, but most bottom nutrients remained within the same range, with scattered exceptions. This hinted at the possibility of there brain more phytoplankton near the surface to consume such nutrients, but alone was not enough evidence for such.

To get a well-rounded idea for how the "Blob" affected oceanic conditions, temperature, salinity, density, dissolved oxygen, transmissivity, and fluorescence were measured by a CTD in both 2014 and 2019. Since the Warn Bay to Tranquil Inlet transect was not specifically studied in 2014, comparisons were gleaned from two separate inlets. Bedwell Inlet shared stations 86 and 85 with this area, and Tofino Inlet shared stations 45, 46, and 55. The water's temperature was overall higher in 2019, with stations 86 and 85 showing an increase from 13.5°C – 14.5°C in 2014 to largely being 15°C – 15.5°C (figure 11). Stations 45, 46,

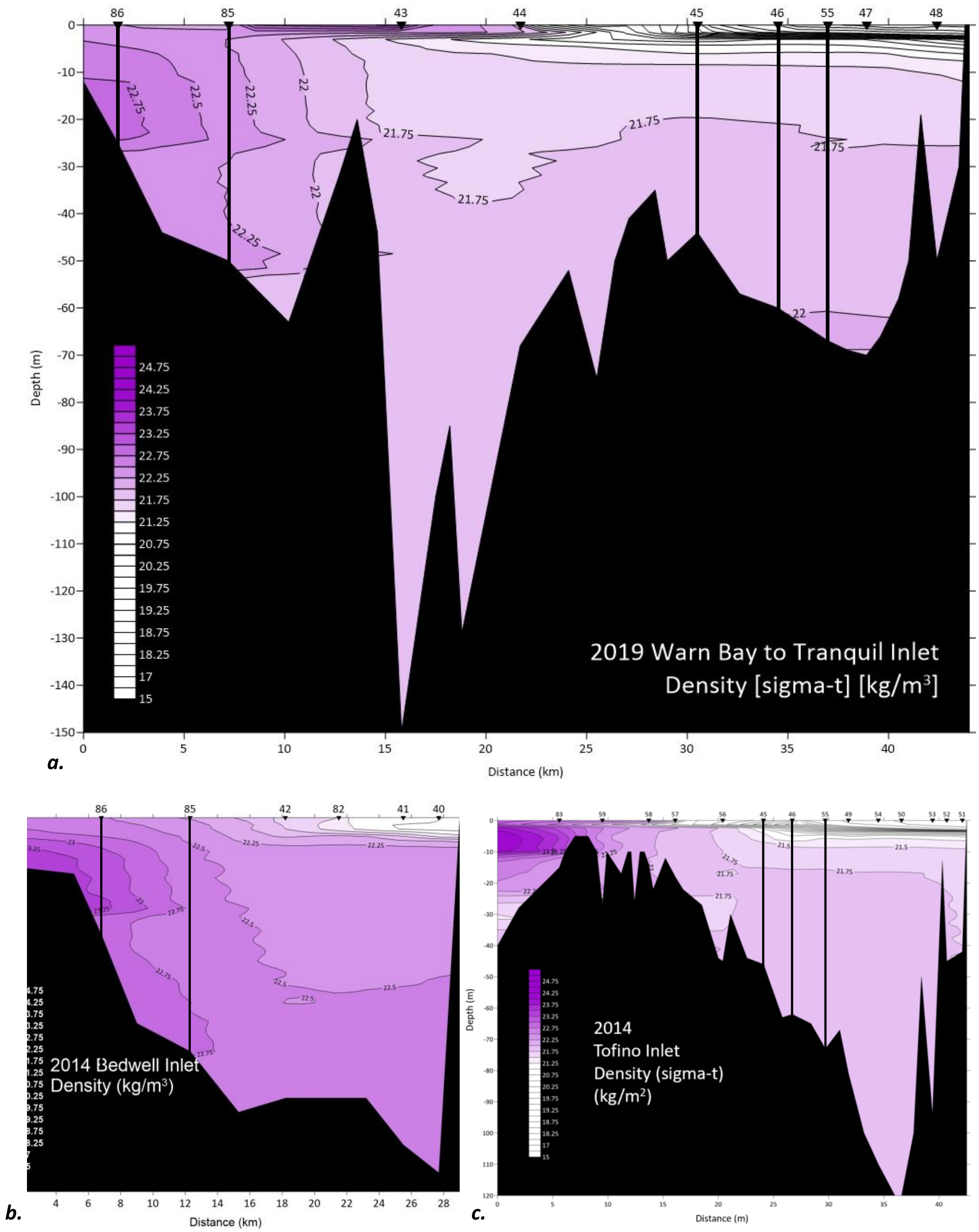

Figure 15a. Surfer plot for density from Warn Bay to Tranquil Inlet; density consistently decreased the farther it was from the ocean. *15b.* Surfer plot for density in Bedwell Inlet in 2014; there was a gradual increase in density as the water came further inland, with a large stretch further inland of more consistent values (Roca 2020). *15c.* Surfer plot for density in Tofino Inlet in 2014; density decreased rapidly at the mouth of the inlet and more gradually further inland (Baer 2020). Distance on the x-axis should be labelled as kilometers instead of meters.

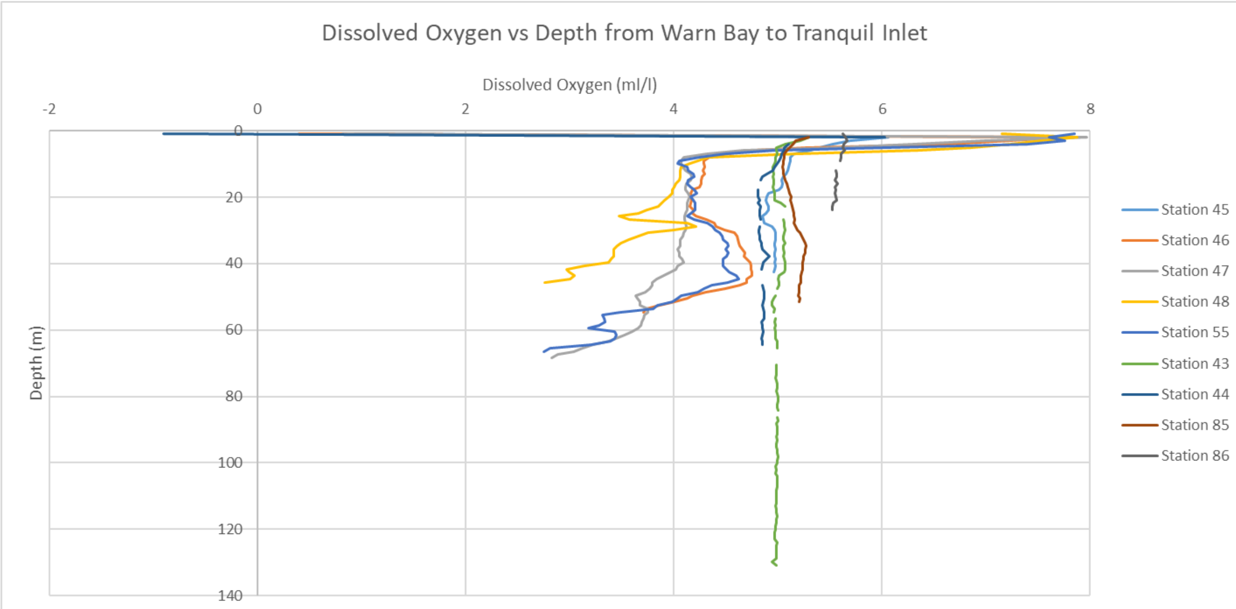

Figure 16. Profile plot for dissolved oxygen content from Warn Bay to Tranquil Inlet; oxygen increased near the surface at some stations and then decreased as depth increased.

and 55 also changed from 14°C – 15°C in 2014, but had temperatures ranging between 13°C and 16°C. Most of the water at these three stations was above 14°C, with the cooler water at the sea floor. Salinity at stations 86 and 85 lessened marginally from 30.5 PSU – 31.5 PSU in 2014 to 30 PSU – 31 PSU in 2019, but the range of 29 PSU – 30 PSU at stations 45, 46, and 55 was maintained for both years with the region that was above 29.5 PSU expanded to a larger area (figure 13). Density at stations 86 and 85 decreased slightly from a range of generally 22.5 kg/m^3 – 23.25 kg/m^3 in 2014 to 22.5 kg/m^3 – 23 kg/m^3 in 2019, and stations 45, 46, and 55 remained 21.5 kg/m^3 – 22 kg/m^3 for both years, paralleling the analysis for salinity (figure 15). Dissolved oxygen was more consistent throughout the water in 2019 and showed the beginnings of vertical mixing when compared to 2014 (figure 17). Stations 86 and 85 were split down the middle and ranged 5 mL/L – 6 mL/L in 2014 and lowered to 5 mL/L – 5.5 mL/L in 2019, while stations 45, 46, and 55 were largely 3.5 mL/L – 5 mL/L in 2014 and in 2019. The data from 2014 had larger pockets with heightened oxygen near the surface than in 2019.

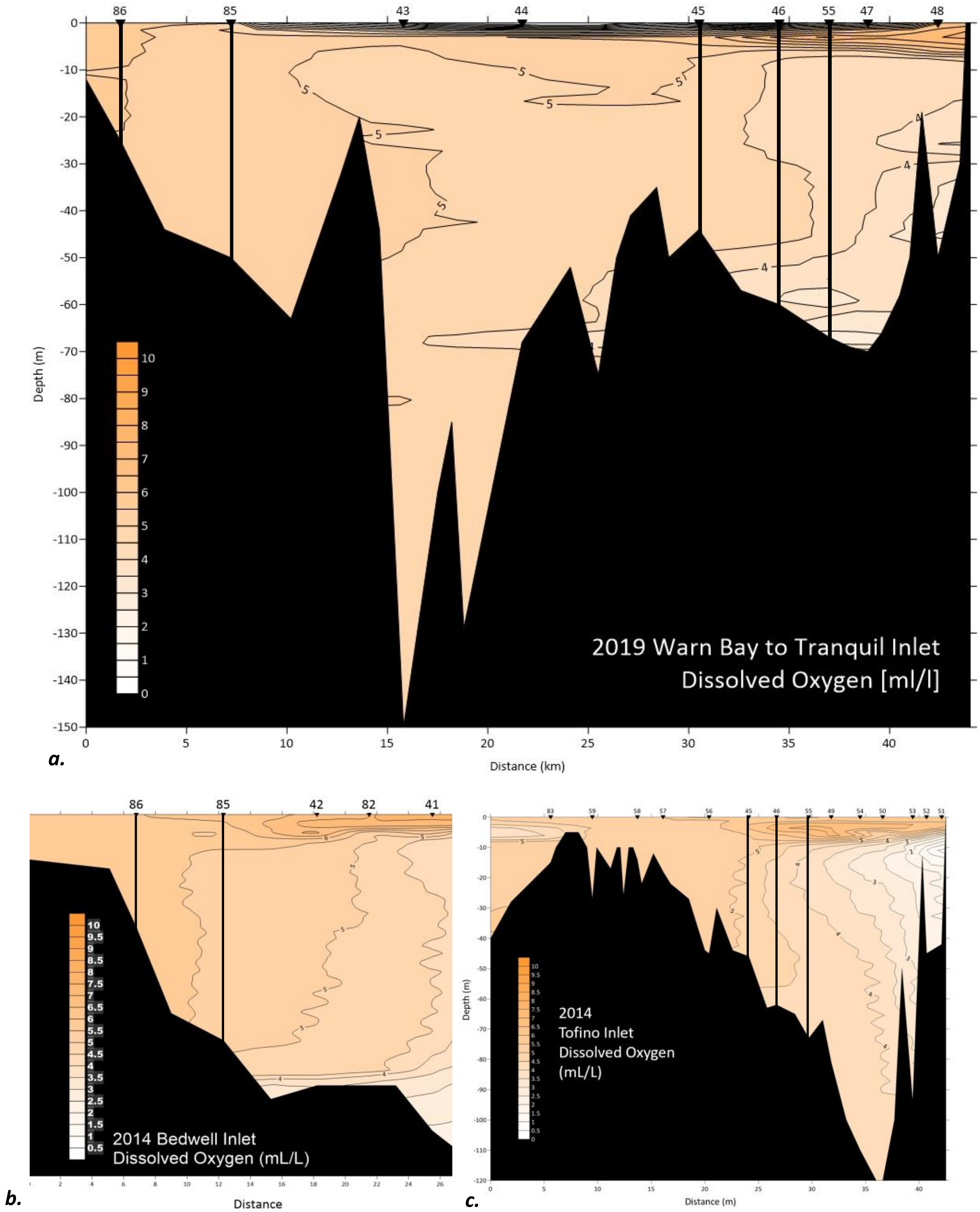

Figure 17a. Surfer plot for dissolved oxygen from Warn Bay to Tranquil Inlet; oxygen content decreased the farther it was from the ocean, there are also several layers of increasing oxygen seen at stations 45, 46, 55, 47, and 48. *17b.* Surfer plot for dissolved oxygen in Bedwell Inlet in 2014; there was a thick columnar pattern decreasing as the water goes further inland (Roca 2020). *17c.* Surfer plot for dissolved oxygen in Tofino Inlet in 2014; there was a consisttent oxygen content before an obvious columnar pattern further inland (Baer 2020). Distance on the x-axis should be labelled as kilometers instead of meters.

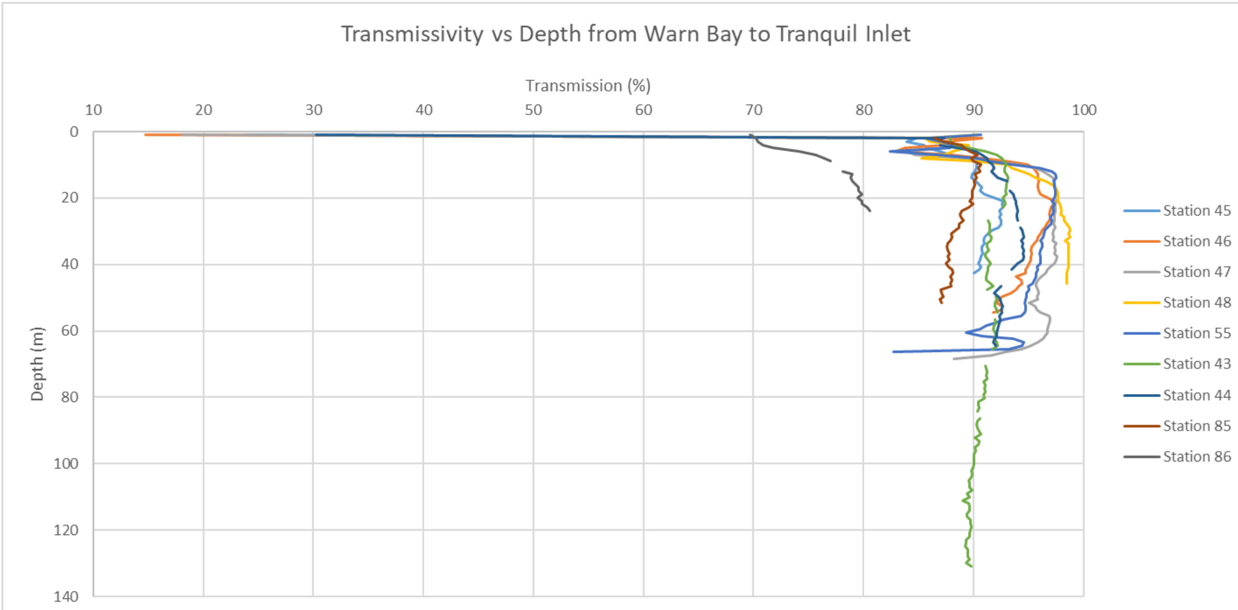

Figure 18. Profile plot for transmissivity from Warn Bay to Tranquil Inlet; transmissivity was very low near the surface, increased a bit before decreasing again just under the surface, quickly increased once more, and then decreased as depth increased.

Transmissivity at station 86 decreased from 70% – 80% in 2014 to 60% – 70%, though station 85 remained 70% –80% (figure 19). Station 45 increased transmissivity from 80% – 90% in 2014 to 90% – 100% throughout most of the water column, but stations 45, 46, and 55 all had increased debris near the surface. Fluorescence was the most different when comparing 2014 to 2019 (figure 21). Stations 86 and 85 increased from 0 mg/m^3 – 2.5 mg/m^3 in 2014 to largely ranging between 2.5 mg/m^3 – 5 mg/m^3 in 2019, whereas stations 45, 46, and 55 decreased from 2.5 mg/m^3 – 5 mg/m^3 in 2014 to 0 mg/m^3 – 2.5 mg/m^3 in 2019. There was more activity near the surface, and overall the contours match those of the transmissivity plots in 2019. The heightened temperature and slightly lowered salinity in 2019 appeared to have created an ideal environment for higher productivity. The oxygen seemed to have slightly increased. However, the area of fluorescence had greatly increased and, along with a matching transmissivity plot, showed evidence of more productivity in 2019. With these sets of data, it appeared that

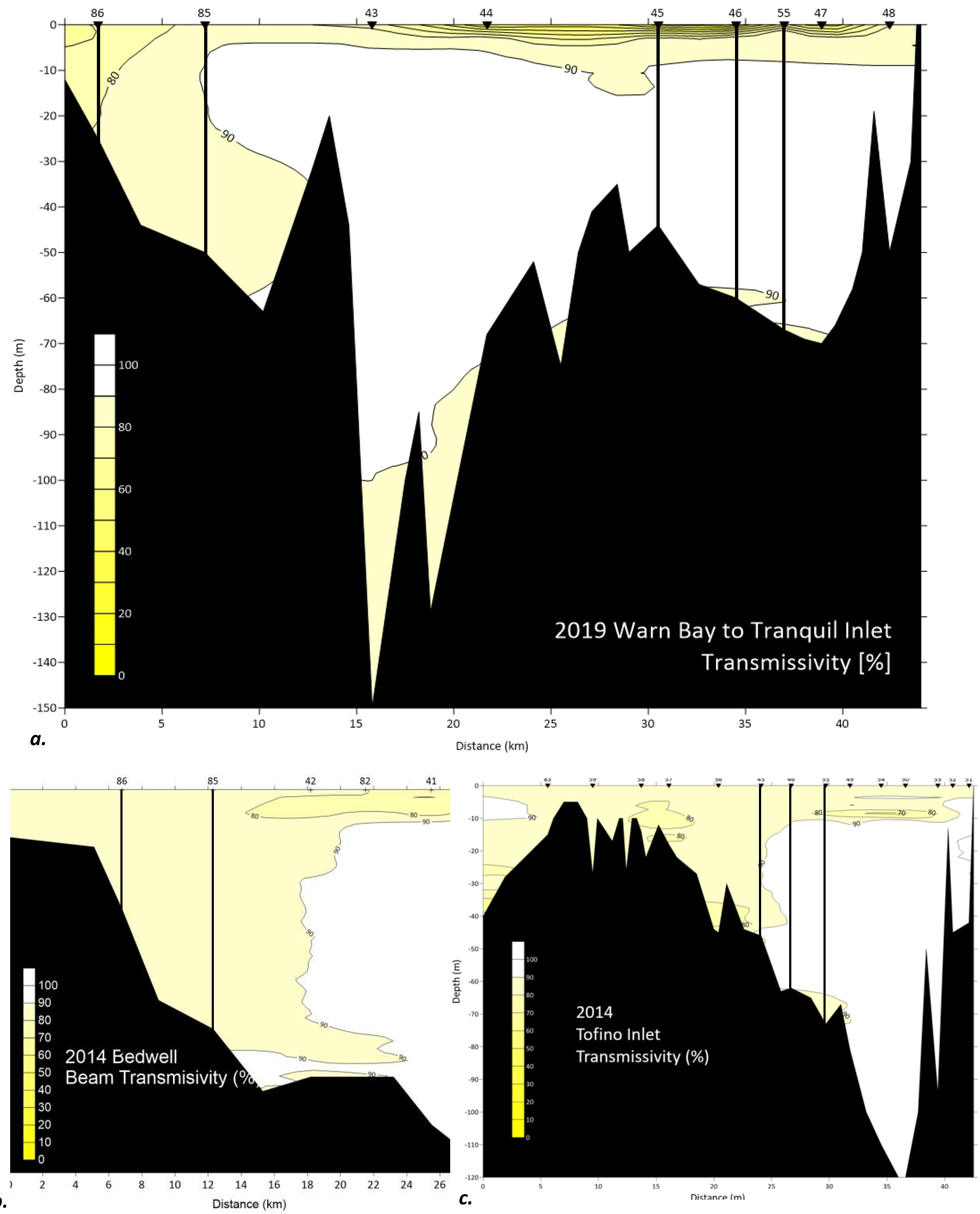

Figure 19a. Surfer plot for transmissivity from Warn Bay to Tranquil Inlet; most low transmissivity was concentrated very near the surface. *19b.* Surfer plot for transmissivity in Bedwell Inlet in 2014; transmissivity was largely one of two percentages throughout (Roca 2020). *19c.* Surfer plot for transmissivity in Tofino Inlet in 2014; transmissivity had inconsistent pockets of lower percentages in several areas (Baer 2020). Distance on the x-axis should be labelled as kilometers instead of meters.

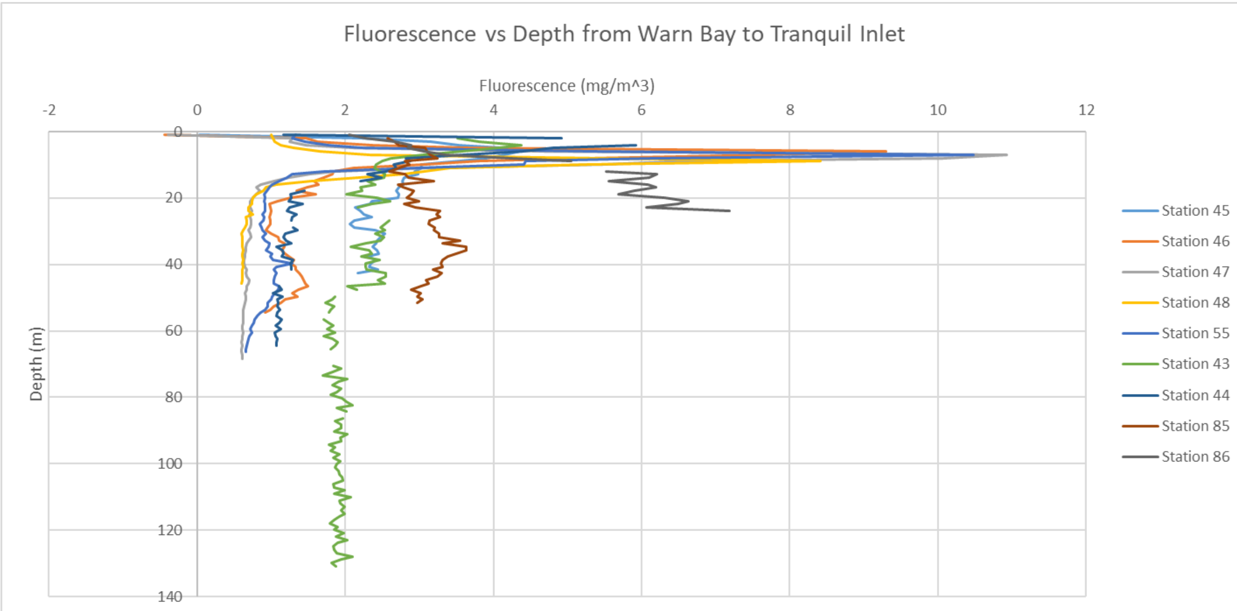

Figure 20. Profile plot for fluorescence from Warn Bay to Tranquil Inlet; fluorescence increased quickly near the surface and then decreased as depth increased.

productivity had overall increased in the Warn Bay to Tranquil Inlet transect in 2019 when compared to 2014 data. The nutrients had been comparatively depleted near the surface, which supported this observation, while the nutrients at the bottom maintained similar concentrations in both years. Fluorescence was greatly increased and matched transmissivity contours almost exactly, showcasing that much of the debris blocking light transmission contained chlorophyll-a. Though oxygen had risen in 2019, it did so minimally and seemed overall unaffected. This information along with the increase in temperature generally supports the hypothesis that increased temperature improves the biological fitness of algae. However, since the null hypothesis was not rejected, this study must be followed-up in future years to determine if the patterns analyzed will be consistent. Studies of the plankton must also be conducted to determine if phytoplankton was the cause of increased productivity.

These observations also supported previous studies' findings that algal blooms showed increased growth at higher temperatures. In the past, the "Blob" has maintained surface

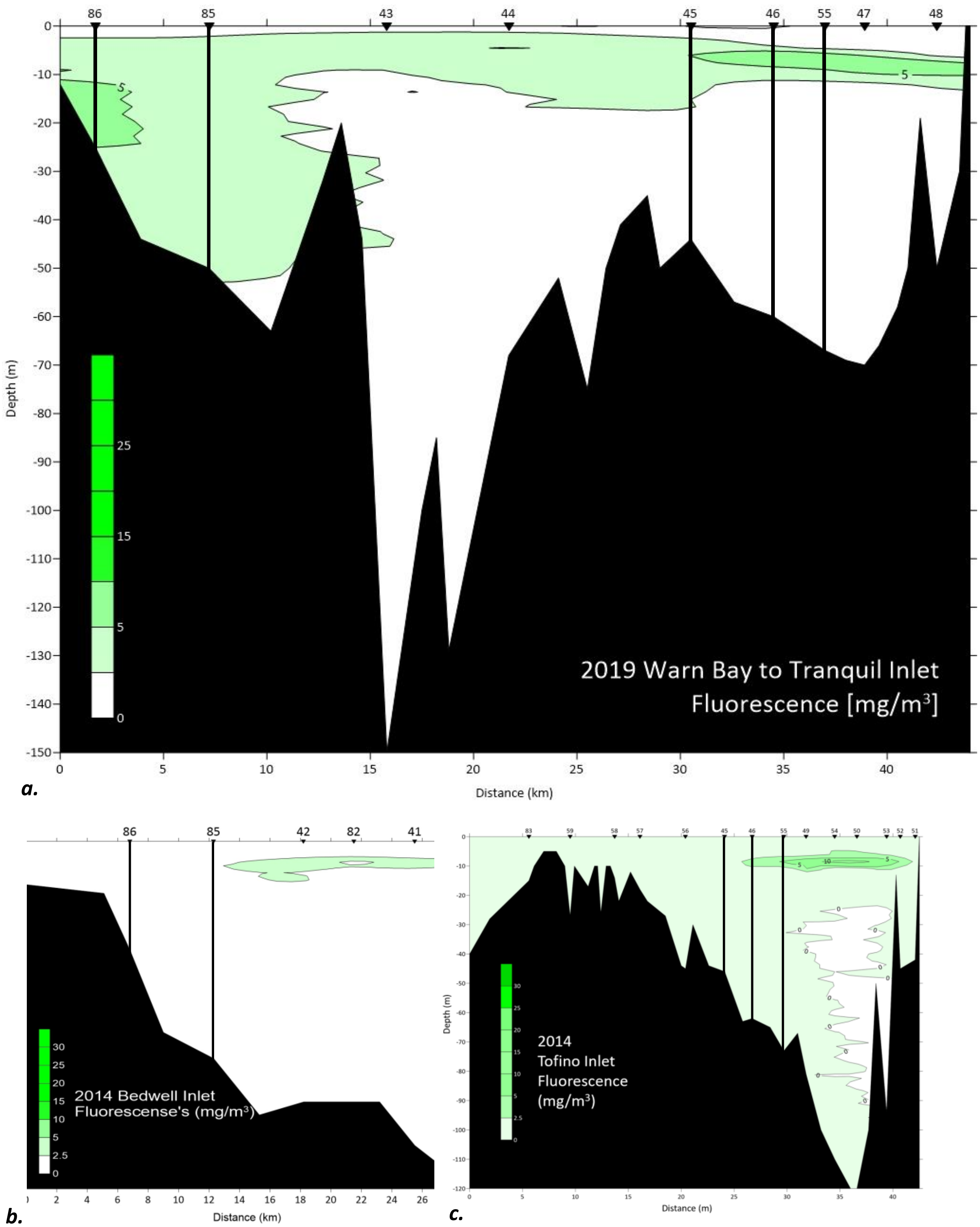

Figure 21a. Surfer plot for fluorescence from Warn Bay to Tranquil Inlet; most fluorescence was concentrated very near the surface. *21b.* Surfer plot for fluorescence in Bedwell Inlet in 2014; fluorescence was almost entirely the same range of values throughout the water, with the exception of a pocket of heightened activity near the surface (Roca 2020). *21c.* Surfer plot for fluorescence in Tofino Inlet in 2014; fluorescence was mostly similar throughout the water, with the exceptions of a pocket of heightened activity near the surface and a column of lessened activity beneath that (Baer 2020). Distance on the x-axis should be labelled as kilometers instead of meters.

temperatures of 14°C through October, a temperature normally seen in summer surface temperatures (Ross et al. 2019). *Alexandrium*, found in the northeastern Pacific, grew optimally at ideal temperatures of 10°C to 24°C with little effect from changes in salinity (Bill et al. 2016). This was also shown to be comparable to real-world data in 2015 when HABs grew into the largest outbreak in history, affecting wildlife and forcing seafood harvest closures throughout the west coast of North America (McCabe et al. 2016). The heightened temperatures from the 2019 study of Clayoquot Sound showed a favorable environment for HABs, and the clear increase in activity when compared to 2014 data was shown to have potential for another major outbreak. However, since the "Blob" was still a new occurrence, more data must be collected to ensure consistency throughout.

CONCLUSION

The purpose of this study was to determine if the "Blob" provided an environment for increased HAB productivity by comparing nutrient data and oceanic conditions from 2019 to 2014, two years the "Blob" was present. Nutrients were collected by direct samples from the surface and bottom of the water column and compared using choropleth maps. Water conditions were measured continuously through the water column by a CTD before being transferred to contour plots, to help find correlations. There was evidence of an increase in the amount of phytoplankton productivity when the water was warmer, with heightened fluorescence and lowered transmissivity near the surface. From 2014 to 2019 there also appeared to be consistently decreased nutrient levels near the surface when there was little difference in bottom nutrients. This study generally supported that temperature increases the productivity of algae, and by extension greater potential for harmful algal blooms (HABs) in

Clayoquot Sound, but was not found to be absolute. Furthermore, 2019 was the first year that the Warn Bay to Tranquil Inlet transect was analyzed, so future studies should explore past data to make direct comparisons. Overall, progress was made in determining the effects the “Blob” had on local HAB productivity, but must be supplemented by continued study in the future. Potential studies could include data collection if the “Blob” reappears, and comparisons to the years without this anomaly. It would also be useful to know if other areas in the northeastern Pacific have been affected in similar ways. In addition, the effects these blooms have on the nutrients available for other organisms native to the area could point to where the blooms do the most harm, or if they primarily affect the seafood industry and its ability to safely function.

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APPENDICES

Data files are located here:
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