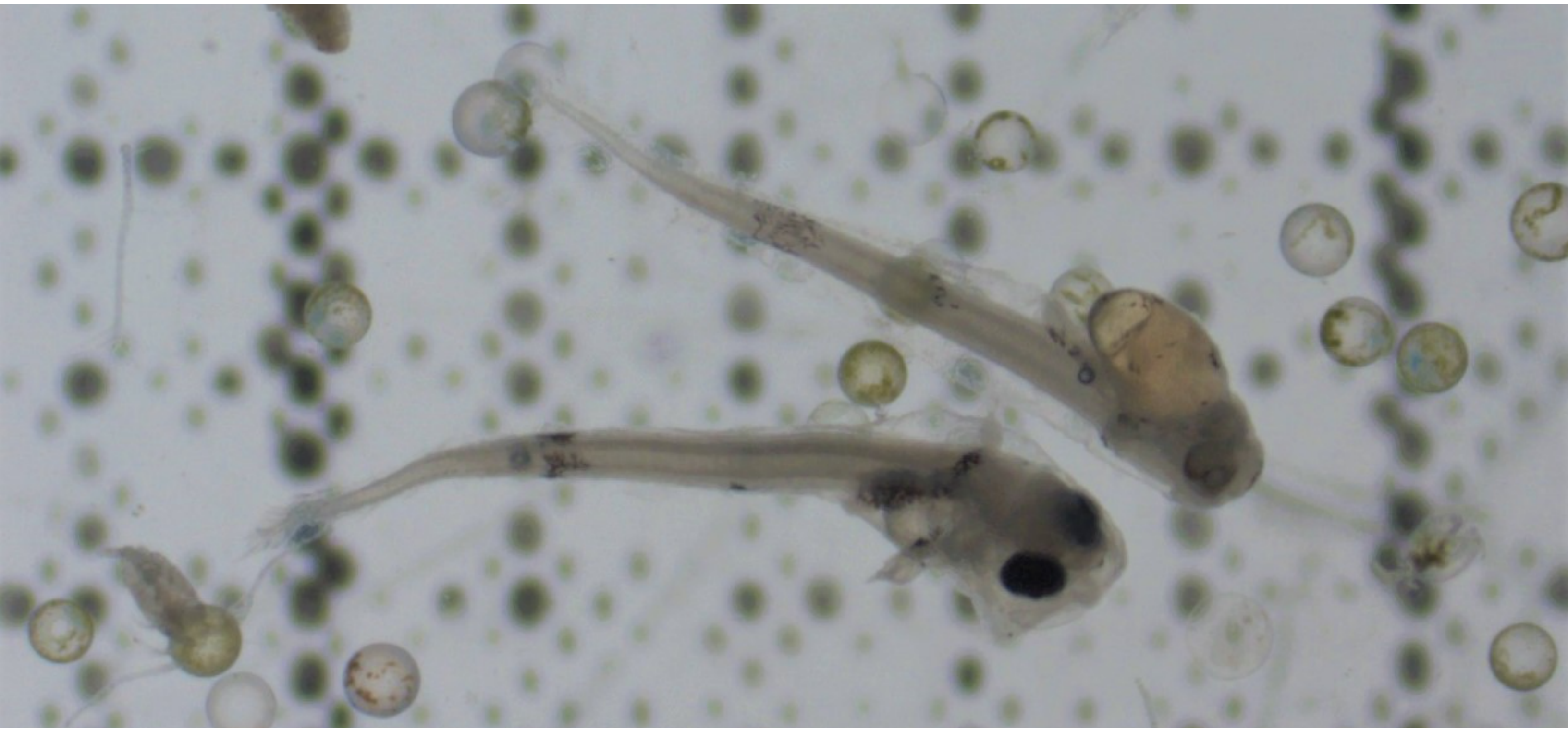
THE DISTRIBUTION AND BIOMASS OF PLANKTON IN ÁTL'KA7TSEM/HOWE SOUND IN 2021

December 2022

Átl'ka7tsem/Howe Sound Marine Stewardship Initiative



Two larval Pacific Hake (*Merluccius productus*). Photo by Kelly Young

Prepared by:

Átl'ka7tsem/Howe Sound Marine Stewardship Initiative
Bridget John, BSc, MSc Candidate, Plankton Team Lead
BridgetMaryJohn@gmail.com
www.howesoundguide.ca

Edited by:

Fiona L. Beaty, BASc, PhD Candidate
Fiona.L.Beaty@gmail.com

Courtney Smaha, MSc Candidate
MarineStewardshipInitiative@gmail.com

The Átl’k̲a7tsem/Howe Sound Marine Stewardship Initiative (MSI), on MakeWay’s shared platform, is an initiative whose mission is to foster ocean stewardship in Átl’□a7tsem/Howe Sound and support regional planning by mobilizing tools, sharing knowledge, and building community. The Marine Stewardship Initiative has helped to fill the data gap on plankton in Átl’k̲a7tsem, as was indicated in the Átl’□a7tsem/Txwnéwu7ts/Howe Sound 2017 and 2020 Ocean Watch report, to update the baseline data building off a study on plankton abundance and distribution in completed in Átl’k̲a7tsem in the early 1970s. For more information on the MSI or this report, go to: www.howesoundguide.ca or contact us at marinestewardshipinitiative@gmail.com or bridgetmaryjohn@gmail.com.

Photo by Bridget John

Table of Contents

1.0 Abstract

Plankton forms the base of the food web in Átl’ḵa7tsem/Howe Sound, British Columbia, and is an excellent indicator of ecosystem health. Átl’ḵa7tsem (pronounced “At-KATsum”) is one of three Squamish Nation place names for Howe Sound and means paddling out of the Sound towards the Salish Sea. The main objectives of this project are to research: 1) the seasonal distribution of phytoplankton, 2) the seasonal distribution of zooplankton, and 3) factors influencing phytoplankton production. Small changes in the distribution and abundance of phytoplankton and zooplankton can have cascading effects on the biodiversity, ecosystem services, climate, and food web in the ocean, so regular monitoring is needed. Over the past fifty years, Átl’ḵa7tsem/Howe Sound has experienced extensive changes in its biological, chemical, and physical oceanographic systems. In particular, the past 15 years have seen a reduction and remediation of industrial impacts, likely contributing to an increased abundance of cetaceans, pinnipeds, and forage fish in Átl’ḵa7tsem/Howe Sound. With Átl’ḵa7tsem’s new designation of UNESCO Biosphere Region, rapid growth in the area, and climate change, it is becoming increasingly important to continue this monitoring plankton as it impacts fisheries health and marine wildlife populations. As part of the Marine Stewardship Initiatives’ five-year strategic plan, this plankton research will happen every three years if funding permits to continue to fill this data gap in Átl’ḵa7tsem.

2.0 Introduction

2.1 Importance of Plankton

Plankton (Figure 1) plays a critical ecological role by forming the base of marine food webs. Since phytoplankton regulate our atmosphere by sequestering approximately 25% of the world's carbon dioxide (NOAA, 2019), changes in the distribution and abundance of these organisms can have significant impacts on the Earth's climate and biogeochemical systems. Subsequently, plankton produces about 50% of the oxygen life on Earth needs to survive (IMO, 2019). Phytoplankton play critical roles in biological carbon fixation and nutrient cycling for key elements, including nitrogen, iron, and silica. Given these processes, studying phytoplankton ecology can improve our understanding of how regional nutrient cycles and carbon sequestration are related to global climate change. Zooplankton is extremely important in marine food webs as they link the lower trophic levels (e.g., phytoplankton) to secondary and tertiary consumers (e.g., invertebrates and fish) (Johnson *et al.*, 2011). Accordingly, changes in zooplankton assemblages can potentially create cascading effects on the marine food web.

Figure 1. Plankton collected just south of Bowen Island. Photo: Bridget John.

2.2 About Átl'ka7tsem/Howe Sound

This study was completed in Átl'ka7tsem/Howe Sound, an inlet of the Salish Sea (referred to hereafter as Átl'ka7tsem). The water in Átl'ka7tsem flows into the Strait of Georgia, across the Canada-US border into Puget Sound, and through the Juan de Fuca Strait, entering into the greater Pacific Ocean. Átl'ka7tsem is strongly affected by the rivers and streams flowing into and around it, including but not restricted to the Fraser River and the glacially fed Squamish River. Átl'ka7tsem has been inhabited by the Squamish Nation for over 8600 years (Squamish Nation, 2022) and is approximately 60 km from the bustling city of Vancouver. The uniquely wild Átl'ka7tsem area provides many cultural, ecological, economic, and social values to myriads of rights holders and stakeholders living and visiting the region.

2.3 Past Biological Oceanographic Research in Átl’ka7tsem

Plankton creates more than half of the air we breathe and are critical for maintaining a flourishing and sustainable ecosystem. In the *Átl’⍰a7tsem/Txwnéwu7ts/Howe Sound 2017 Ocean Watch report* (Miller et al., 2017), the Ocean Wise Research Institute stated that plankton has limited data in the Átl’ka7tsem/Howe Sound noting the last extensive plankton study was completed in 1972. In *Phytoplankton Production and Distribution in Howe Sound, British Columbia: A Coastal Marine Embayment-Fjord Under Stress* (Stockner et al., 1972), phytoplankton production rate, biomass, and distribution were measured over two years in Átl’ka7tsem at ten sampling sites (Figure 2). This report focused on man-induced and natural factors that affect light attenuation in Átl’ka7tsem’s surface layer. Their study also identified the dominant species of phytoplankton during spring blooms and changes in the timing of the spring blooms. The Ocean Watch report (Miller et al., 2017) states that a satellite sensor, no longer in operation, called MERIS, was used for Átl’ka7tsem to sense changes in water colour showing phytoplankton blooms.

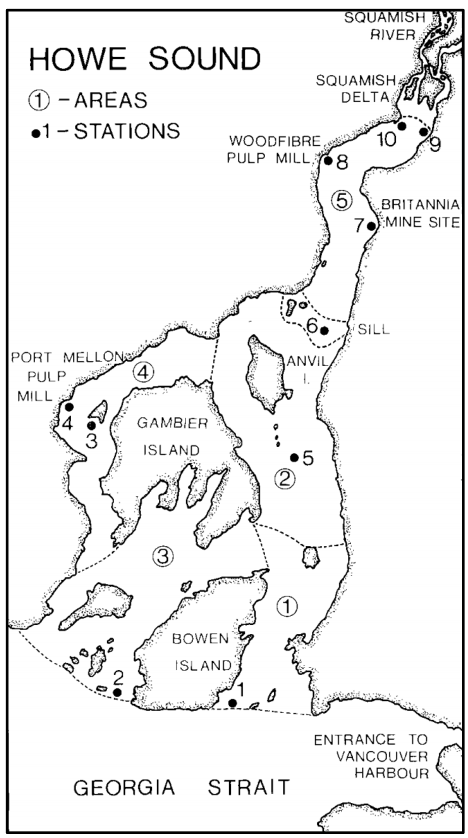


Figure 2. Map of Átl’ka7tsem/Howe Sound, situated northwest of Vancouver, British Columbia. The (●) refers to the ten station locations and (◯) the five zones where oceanographic sampling was done by Stockner et al. (1972).

2.4 Changes in Átl'ka7tsem Since the 1970s

Over the past century, there has been a boom in industrial development, pollution, and anthropogenic stressors in Átl'ka7tsem. Átl'ka7tsem has supported two pulp mills, foreshore log booms, gravel washing operations, the Britannia copper mine (Figure 3), and the Squamish Terminals. Even though the Britannia copper mine was held to the environmental regulations of its time, it was the greatest point source of metal pollution in Canada until 2005 (McCandless, 2016). In the 1970s and 80s, the Britannia mine allowed copper and other metal mine tailings to be discharged into Átl'ka7tsem. Gravel washing discharge and log-boom storage reduced light penetration in Átl'ka7tsem, harming the habitat quality for phytoplankton and other estuarine plants. Since the 1970s, however, industrial activities in Átl'ka7tsem have subsided, and remediation efforts have been implemented to address water and habitat quality. As of September 2021, Átl'ka7tsem has been designated as Canada's 19th United Nations Education, Scientific, and Cultural Organization (UNESCO) Biosphere Region, led by the Átl'ka7tsem/Howe Sound Biosphere Region. This designation further encourages people to live and work in harmony with nature.

Figure 3. Britannia copper mine - a source of copper ore for almost 70 years. Photo: Bridget John.

2.5 Why is Plankton a Good Biological Indicator?

Over the past few decades, the recovery of whales, dolphins, herring, and larger organisms in the Sound indicates that plankton may also be recovering. However, this has yet to be confirmed by empirical studies. Tracking biological indicators is an essential step toward determining the health of aquatic environments (Cantin, 2011). Understanding marine ecosystem health, in turn, provides a foundation to assess cumulative anthropogenic impacts and develop mitigation techniques. Regular monitoring is required to see the changes in productivity and abundance of phytoplankton and zooplankton, which can then be used to assess environmental conditions that have bottom-up influences on the watershed of Átl'ka7tsem.

3.0 Materials and Methods

In January 2020, a pilot study was performed to evaluate the feasibility, time, and cost and improve research methods and procedures before the full-scale sampling protocol. With the global pandemic of COVID-19, the year-long study was postponed from 2020 to 2021, when all the necessary safety protocols could be taken. The full-scale project ran from January 2021 to September 2021 in Átl'ka7tsem, giving the Átl'ka7tsem/Howe Sound Marine Stewardship Initiative almost a year to collect oceanographic data in the Sound, in partnership with the Pacific Salmon Foundation, Ocean Networks Canada, and the Plankton Ecology group at IOS, Fisheries and Oceans Canada.

Annual growth activity of phytoplankton and zooplankton in pelagic systems can be identified by studying the spring and fall blooms (Smayda, 1997). As spring begins, the increased temperature, solar radiation, and thermal stratification drive blooms in phytoplankton abundance and biomass (Cushing, 1959). After a lag, there is typically a zooplankton bloom as they graze on the phytoplankton. These biomass peaks usually remain for a few weeks to months until nutrient limitation collapses the blooms (Sommer *et al.* 1986). In late summer or fall, a fall bloom of phytoplankton and zooplankton can occur due to excess nutrients in the water (Sommer *et al.* 1986). However, annual phytoplankton and zooplankton patterns can significantly differ depending on the ecosystem and the year (Cloern & Jassby, 2008).

Using wavelet analysis to extract periodic components from phytoplankton time series (Winder & Cloern, 2010) from Stockner *et al.* (1972) and the 2020 data from the Pacific Salmon Foundation's Gibson's citizen science crew (Ocean Networks Canada, 2020), sampling periods were determined to get a better understanding of the changes in plankton biomass throughout the year. Samples were taken on January 25th, March 24th, April 19th, August 9th, and September 27th of 2021 to get an accurate representation of the spring and fall blooms of phytoplankton and zooplankton. January and August were able to act as a baseline compared to the spring and fall months. This baseline plankton study uses the sampling sites based on

Stockner et al. 1972 stations (Fisheries and Oceans Canada (DFO)) that were completed over fifty years ago. For this study, the MSI plankton team re-sampled at Stockner et al. (1972) sites 1, 4, 5, 6, 7, 8, 10, and 11, and sites 2, 3, and 9 were dropped from the 1972 study as they were redundant. MSI plankton stations included the Squamish Estuary (1-RZ), Woodfibre (2-F), Britannia Beach (3-R), Porteau Cove (4-BZ), Port Mellon (5-RZ), Pam Rocks (6-RZ), South Gambier (7-F) and Strait of Georgia/South Bowen (8-BZ). Station 7-F has been added to act as a control. Figure 4 shows the eight plankton sampling locations in Átl’ḵa7tsem along with the depth zones, the Átl’ḵa7tsem/Howe Sound Biosphere Region boundary, and the waterways that flow into Átl’ḵa7tsem. The map also includes some of the Squamish Nation (S□wx□wú7mesh Úxwumixw) place names in the area from the Squamish Atlas (link)

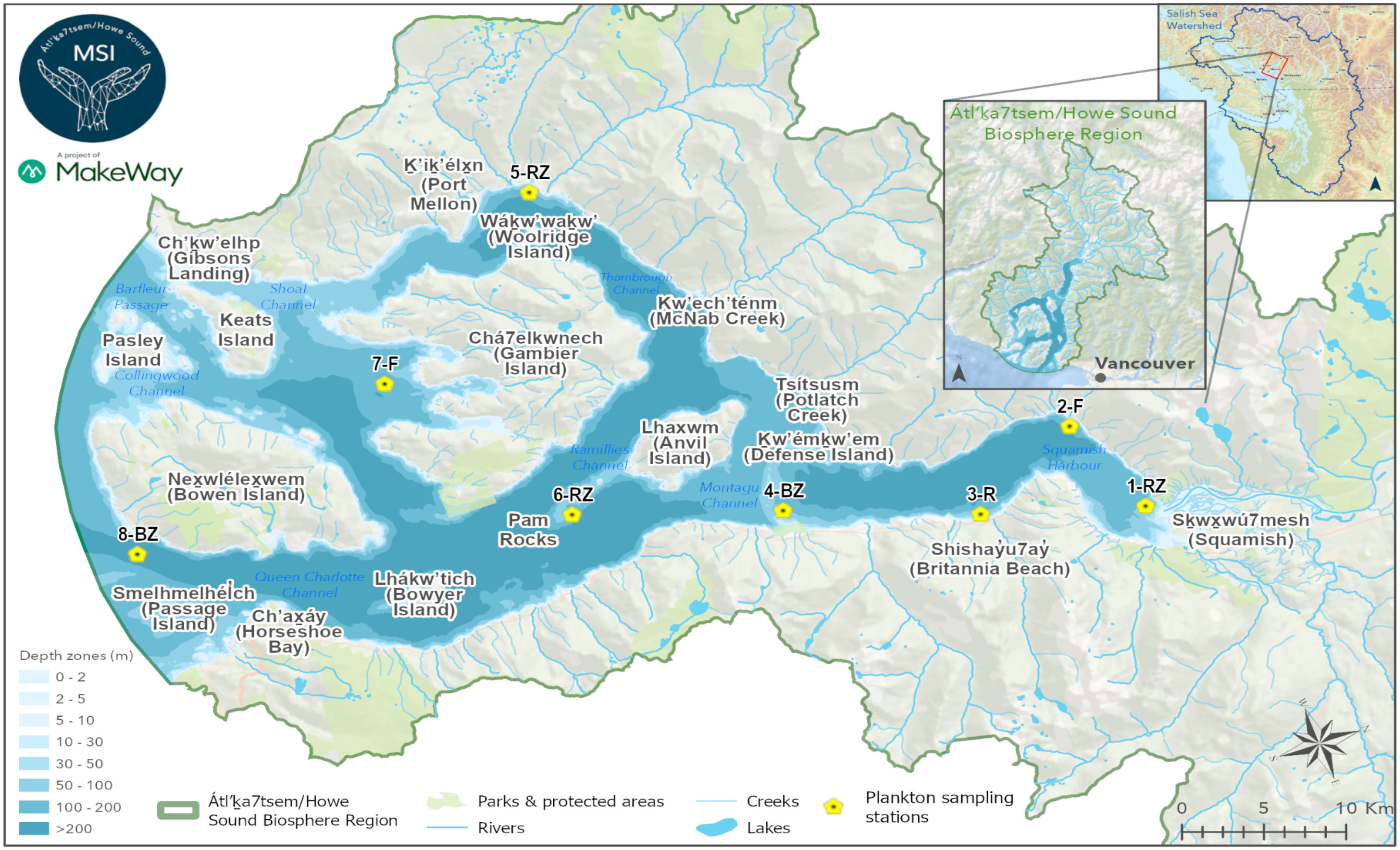


Figure 4. Map of the UNESCO Átl'k̲a7tsem/Howe Sound Biosphere (outlined in green) within the Salish Sea (inset map). The map shows the eight sampling locations used in 2021 by the Átl'k̲a7tsem/Howe Sound Marine Stewardship Initiative for oceanographic sampling. The map was created using ESRI ArcGIS Pro 2.9.0, and the coordinate system is WGS 1984 Web Mercator.

3.1 Sampling Methods

This survey includes standard physical, chemical; nutrients and oxygen, and biological; dominant species, phytoplankton, and zooplankton biomass, and primary productivity data as recommended by Bodtker et al. (2017). This study uses the methods from the Salish Sea Marine Survival Project, an international collaborative research project led by the Pacific Salmon Foundation and Long Live the Kings (Pacific Salmon Foundation, 2021) (Figure 5). The description of the methods partly reproduces the wording from the citizen science program (Pacific Salmon Foundation, 2021).

For this survey, there are four different types of stations in terms of tasks and samples needed - these include Regular and Zooplankton (RZ), Full (F), Regular (R), and Busy and Zooplankton (BZ). The sampling stations' latitude, longitude, and depths, as well as the samples and tasks required, can be seen in Table 1. The typical route taken while sampling went from South Gambier (7-F) to Port Mellon (5-RZ) to Pam Rocks (6-R) to Porteau Cove (4-BZ) to Britannia Beach (3-R) to Woodfibre (2-F) to Squamish (1-RZ) to Bowen Island (8-BZ). A GPS was used to determine the sampling coordinates of the sites, making sure each location was within 100 m from the station, and a depth sounder on board was used to determine sampling depths.

Figure 5. April 19th, 2021, at station 1-RZ. Left to right: Myia Antone, Kevin Swoboda, Fiona Beaty, and Bridget John.

Table 1. Átl'ka7tsem/Howe Sound Oceanographic Sampling Stations* and the samples and tasks required at eight of the sampling locations.

Stations	Stockner 1972 Stations	Latitude	Longitude	Depth (m)	Samples	Tasks
1-RZ	10	49.67844	-123.18560	87	Phyto 1 Zoop 1	• CTD cast • Phyto: surface • Secchi disk (x2) • Zooplankton tow
2-F	8	49.66422	-123.24671	124	Phyto 1 Nutr 2	• CTD cast • Phyto: surface • Secchi disk (x2) • Nutrients: surface (1), 20m (1)
3-R	7	49.62242	-123.21169	180	Phyto 1	• CTD cast • Phyto: surface • Secchi disk (x2)
4-BZ	6	49.55711	-123.25071	100	Phyto 4 Nutr 4 Zoop 1	• CTD cast • Phyto: surface, 5m, 10m, 20 • Secchi disk (x2) • Nutrients: surface (2), 20m (2) • Zooplankton tow
5-RZ	4	49.5163	-123.47744	142	Phyto 1 Zoop 1	• CTD cast • Phyto: surface • Secchi disk (x2) • Zooplankton tow
6-R	5	49.48612	-123.28782	161	Phyto 1	• CTD cast • Phyto: surface • Secchi disk (x2)
7-F	N/A	49.44153	-123.39966	146	Phyto 1 Nutr 2	• CTD cast • Phyto: surface • Secchi disk (x2) • Nutrients: surface (1), 20m (1)
8-BZ	1	49.33774	-123.35017	218	Phyto 4 Nutr 4 Zoop 1	• CTD cast • Phyto: surface, 5m, 10m, 20m • Secchi disk (x2) • Nutrients: surface (2), 20m (2) • Zooplankton tow

**Z= zooplankton station, F= full station, B= busy station, R= regular station. At the last full/busy station of the day, a Niskin bottle was used to collect chlorophyll samples at 5m.*

3.2 Biological Oceanographic Sampling

A simple ring zooplankton net (250 μm mesh size, 50 cm diameter) was used to complete a vertical net haul (VNH) at stations 1-RZ, 4-BZ, 5-RZ, and 8-BZ. After attaching an RBR solo and 5kg bottom weight, the net was lowered at 0.5 m/s until the weight hit bottom or 150 m was reached, then it was raised manually at an average of 0.4 m/s until just below the surface. The net sample was processed in a jar with ½ to ¾ zooplankton. Each zooplankton sample was preserved with 5% formalin in seawater (buffered with 30 g/L of Borax), using 25 mL for each of the 300 mL samples (Figure 6). The metadata that was collected for each zooplankton sample included date, station, time, net event #, CTD #, latitude, longitude, wire out, wire angle, bottom depth, net type, and tow type. Time and location represent when the net is at the bottom, the wire out is the depth (m) of the tow for the sample, and the bottom depth (m) is the station depth (m). Flow start and flow end were not recorded as a flowmeter was not a piece of equipment the plankton team had, and therefore the volume of water filtered was calculated from the depth of the tow.

Figure 6. March zooplankton samples at stations 5-RZ, 4-BZ, 1-RZ, and 8-BZ (left to right). Photo: Bridget John.

To align these collaborative sampling efforts with the rest of the Pacific Salmon Foundation's citizen science programs, Kelly Young, Moira Galbraith, and Akash Sastriwere at the Plankton Ecology group at the Institute of Oceans Sciences (IOS) in Sidney, BC, completed the zooplankton analysis. After each sampling period, the raw data sheets, RBR file, CTD data, nutrient, phytoplankton, and zooplankton spreadsheets were sent to IOS by email. The zooplankton samples were sent by mail to IOS after one or two sampling dates. In the laboratory, zooplankton samples were observed and counted under a microscope. The zooplankton samples were split within their size classes to determine the species present within the populations and the total number of organisms observed (Perry, 2020). A calibrated Folsom splitter was used for all sub-sampling for the ≥5mm portion if there was a large number in each size class to approximately 100 individuals. The <5mm portion of the sample, with all the large taxon removed, was split and enumerated to approximately 400 organisms and then sorted in a 1mm gridded Bogorov tray. The other <5mm portion that wasn't enumerated is split with a Folsom splitter and scanned for rare species. Abundance (#/m^3) was then calculated from the total number in the sample divided by the volume filtered. Lastly, this zooplankton data is archived in the IOS Zooplankton Database, which has data from the marine realm of the Northeast Pacific Ocean spanning from 1980 to 2021 (Fisheries and Oceans Canada, 2021)

A Niskin bottle was used to collect phytoplankton. Phytoplankton surface samples were taken at every station. At the "BUSY" station, three additional samples were taken at 5 m, 10 m, and 20 m. Samples 5 m and deeper were collected with the Niskin bottle by sending a weighted messenger down the cable to trigger a trip mechanism. Samples were preserved using a few drops of Lugol's iodine solution until the water turned a dark tea colour. All plankton samples were stored at room temperature in a dark, cool area. Phytoplankton samples were analyzed by the Pacific Salmon Foundation.

3.3 Chemical Oceanographic Sampling

Nutrient samples were only taken at "FULL" and "BUSY" stations. One sample was taken at the surface, and one was taken at 20 m. For the "BUSY" station, duplicate nutrient samples were taken at the surface and 20 m (total of four samples). The Niskin bottle was hung on the cable, allowing for equilibration at 20 m for approximately 30 seconds before it was closed remotely using a messenger. A 60 ml syringe was rinsed three times with the collected water before a filter holder was attached to the syringe. Next, the water was forced through the filter and filled to the line. This was repeated for surface samples. These samples were placed in a cooler and then frozen in a standard freezer as soon as possible after disembarking the boat to prevent bacterial damage. For the last "FULL" or "BUSY" station of the day, duplicate chlorophyll samples were taken at 5m and collected using the Niskin bottle. These GF/F filter samples were placed in a vial and ziplocked in a small black bag to avoid pigment degradation. These water samples were used for oxygen, chlorophyll a, and nitrate concentrations analysis. The nutrient and chlorophyll samples were sent to the Pacific Salmon Foundation, which completed the analysis.

3.4 Physical Oceanographic Sampling

At each station, four devices were used, including an electronic AML-6 LGR A60008 CTD probe, Alec Electronics Rinko-III 178, Turner Cyclops-7F Fluorometer, and an Android GPS Nexus 7 Tablet to measure conductivity, temperature, depth, pressure, practical salinity, chlorophyll, and oxygen saturation. The "Community Fishers" app on a tablet was synchronized with the CTD before lowering. At each location, the CTD (Figure 7) was clipped to a downrigger, turned on, lowered into the surface water, and held there for 30 seconds to allow the instrument to equilibrate to seawater. After the CTD was lowered to the ocean floor at 0.5 m/s until the line went slack or until the 150 m maximum safe depth was reached for the Scotty downrigger. The depth was recorded, and after 30 seconds, the CTD was hauled out of the water. With a wifi link, the CTD data is transferred to an Android GPS Nexus 7 Tablet (SN DBOKBC175709) to determine whether the cast was accurate. This CTD data was then sent to and processed by Ocean Networks Canada, where they identified and corrected potential problems with the data (including casts without positions, profiles that appear incorrect, and extra profiles that are generated).

Figure 7. This CTD instrument is used to measure physical oceanographic parameters. Photo: Bridget John.

An additional sensor (a Turner Cyclops-7F Fluorometer) was equipped onto the CTD that transmits an excitation beam of blue light and then detects a red fluorescent light emitted by the chlorophyll in the water column. As part of the sampling procedure, the Átl'ka7tsem/Howe Sound team additionally obtained chlorophyll from a duplicate water sample at 5m depth at the last busy/full station of the survey. 120mm of water was pushed through a 1.2 μm glass-fiber filter, so all phytoplankton containing chlorophyll are kept. In the laboratory, this sample was analyzed to determine the actual amount of chlorophyll at 5m depth. The SOG Atlas has found that CTD fluorometer chlorophyll concentrations are accurate by a factor of 0.6 when compared to laboratory analysis of water samples in the Strait of Georgia (Strait of Georgia Data Centre, 2022), and so the scaling factor was applied to the CTD fluorometer chlorophyll concentrations.

The CTD profile was also equipped with another sensor (Alec Electronics Rinko-III 178) to measure dissolved oxygen. The sensor uses a "fluorescence quenching" technique that uses a standard equation that outputs the actual dissolved oxygen equilibrated with the atmosphere. These measurements were then cross-compared with calibrated oxygen concentrations from surveys in the Strait of Georgia.

The Secchi depth was estimated using a Secchi disk to determine the extinction of surface light with depth (*k*) as a light meter to receive a more accurate measurement was not available. Light attenuation coefficient, *k*, can be calculated using the following equation: $k = 1.7/Secchi\ depth\ (m)$.

For a more detailed sampling procedure see '*A Manual for Oceanographic Data Collection for the Salish Sea Project 2021'* written by the Pacific Salmon Foundation.

4.0 Results and Discussion

This plankton study aimed to help better understand species abundance and diversity trends in Átl'ka7tsem and changes in plankton and ecosystem productivity. This research may further our understanding of how climate change and other anthropogenic drivers impact phytoplankton and zooplankton abundance and productivity, with potential cascading impacts on Átl'ka7tsem's marine food web. This baseline inventory and regular monitoring of plankton will inform future development and monitoring studies in Átl'ka7tsem.

4.1 Biological Parameters

In analyzing the average number of phytoplankton individuals counted during April, August, and September of 2021 in the region at each station, it was found that station 1-RZ in August showed the greatest count (200), 8-BZ in April the second greatest (72), and 4-BZ in April the third greatest (47) (Figure 8). The phytoplankton individual count is found highest at the Squamish River (station 1-RZ). This pattern is opposite to the 1972 study showing that in the summer, the murky freshwater from the Squamish River forces phytoplankton away and towards the Strait of Georgia (Stockner et al., 1972). Station 8-BZ in April shows the second-highest phytoplankton count, which is similar to what was seen before, where the highest populations were found around Bowen Island and near the Strait of Georgia.

Additionally, all ten phytoplankton samples from the January 25th, 2021 sampling date had preservation issues potentially due to a combination of factors such as a heat wave, storage out of a fridge, no readdition of preservative, and analysis that happened after six months of the sampling date. Additionally, four samples from March 21st, 2021, at 4-BZ (3) and 6-R (1), had preservation issues potentially due to the same factors as listed above. Due to this, no phytoplankton were identified for the months of January and March. Additionally, the phytoplankton samples at the 1-RZ and 2-F sampling stations from September 27th, 2021, could not be sampled as there was too much debris of millions of inorganic particles in 1 ml.

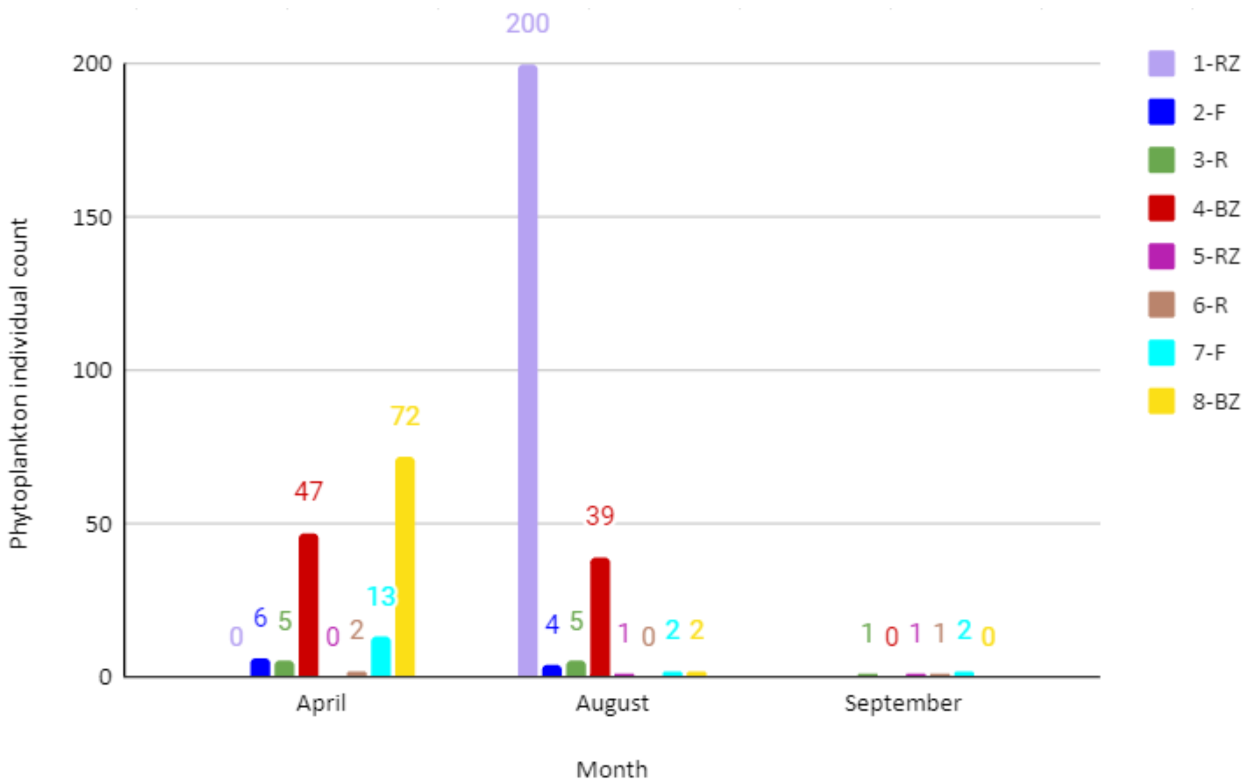


Figure 8. Average phytoplankton individuals counted in April, August, and September of 2021 in Átl'ka7tsem at all eight stations.

In analyzing the phytoplankton biodiversity in the region throughout 2021, the dominant phytoplankton individuals, regardless of month or location, ordered from most to least, are *Pseudo spp.*, *Dictyocha spp.*, *Alexandrium spp.*, *Chaetocerus spp.*, and *Dinophysis spp.* Throughout the sampling months, it was found that *Pseudo* (98.2%) represents the dominant samples in April, *Pseudo* (55.5%) and *Dicto* (41.9%) in August, and *Dino* (60%), *Dicto* (20%), and *Alexa* (20%) in September (Figure 9). April 2021 showed the highest count of phytoplankton individuals at 501, and August the second highest count at 375. While September has extremely low phytoplankton counts at 5. As mentioned above, phytoplankton data from January and March were not included due to preservation issues.

A study conducted in Alaska conducted from 1972 to 2019 shows from 1998 to 2019 shows that phytoplankton spring blooms are becoming less prominent over time (Gulf Watch Alaska, 2019). Another study, conducted in Prince William Sound in the Gulf of Alaska, shows that certain phytoplankton and seasonal timing and abundance changes created more phytoplankton when it was warmer, leading to better herring growth (Batten et al., 2016). Therefore, it is important to continue monitoring plankton populations with climate change and a warming ocean.

Figure 10 shows stations 1-RZ, 2-F, 3-R, 7-F, and 8-BZ to be dominated by *Pseudo*, whereas station 4-BZ and 6-R is predominantly *Dicto*, and 5-RZ is equally dominated by *Dino* and *Alexa*. Overall, the phytoplankton individuals counted irrelevant of the group were greatest to lowest at the stations as follows: 1-RZ (200), 8-BZ (25), 7-F (18), 3-R (12), 2-F (10), 4-BZ (10), 6-R (3), and 5-RZ (2).

Comparing these results to the Stocker et al. (1972) study, it seems as if the dominant phytoplankton species are different from the 1970s to 2021. Two of the phytoplankton species that Stocker et al. (1972) found to be dominant were *Chaeto* and *Dino*; however, these were seen to be the least dominant in 2021, compared to the other three groups. The other species that Stocker et al. (1972) found to be dominant were not seen in the top five dominant groups from 2021. Further studies with more extensive sampling are recommended to see whether the dominant phytoplankton species have changed.

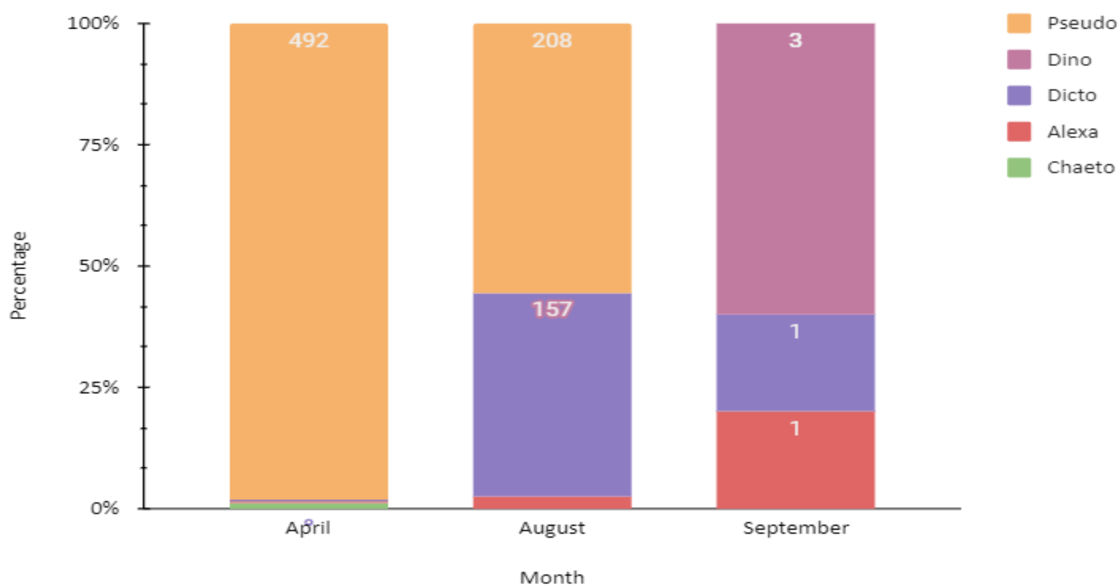


Figure 9. Percentages of five phytoplankton groups across March, April, August, and September in 2021 in Átl'�a7tsem.

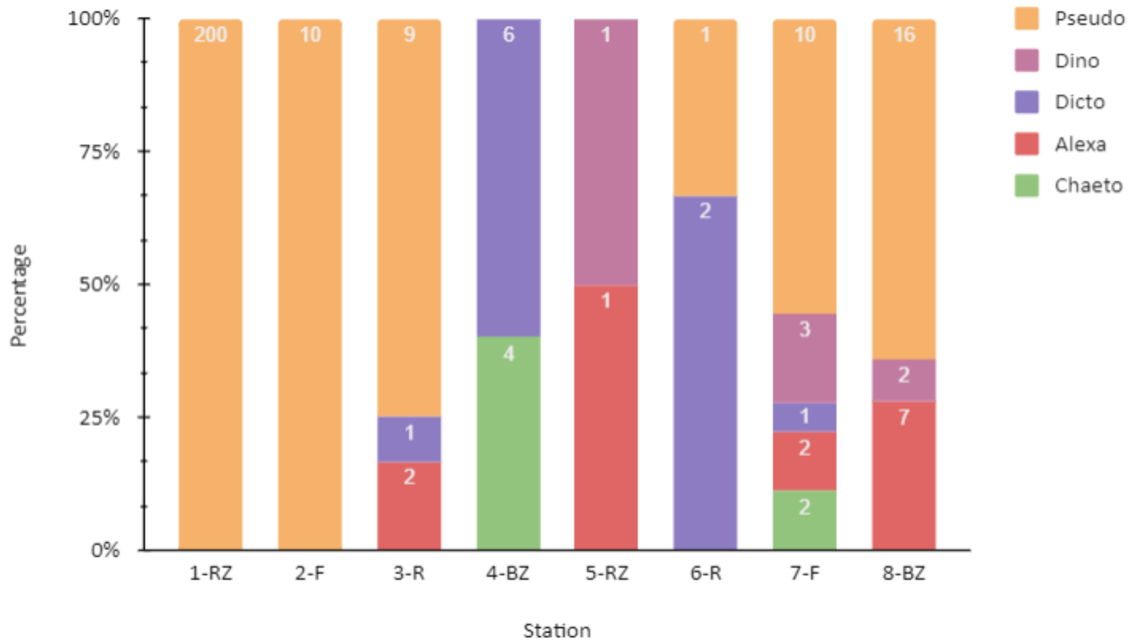


Figure 10. Percentages of five phytoplankton groups across the eight stamping stations in 2021 in Atl'ka7tsem.

In terms of zooplankton, the volumes sampled for the zooplankton net differed by station. The plankton team made every effort to sample a similar volume each month. The average monthly volumes per zooplankton station were found to be 12.95m^3 at 1-RZ, 15.77m^3 at 4-BZ, 22.16m^3 at 5-RZ, and 21.91m^3 at 8-BZ. However, in January 2021, the RBR was not available for use. It is worthwhile to note that the rate of ascent for a vertical zooplankton tow is supposed to be 1m/s. However, since the plankton team pulled up the net by hand, the rate of ascent averaged 0.4 m/s.

Overall, the highest number of zooplankton individuals was counted in April at station 5-RZ (142), whereas the lowest number of zooplankton individuals was counted in January at station 1-RZ (54) (Figure 11). The highest number of zooplankton individuals for stations 1-RZ and 5-RZ was counted in April (117 and 142). The highest number of zooplankton individuals for stations 4-BZ and 8-BZ was counted in March (119 and 117). Whereas the lowest number of zooplankton individuals for stations 1-RZ, 4-BZ, and 5-RZ was counted in January (54, 64, and 83). The lowest number of zooplankton individuals for station 8-BZ was counted in September (63); however, January was not sampled due to weather.

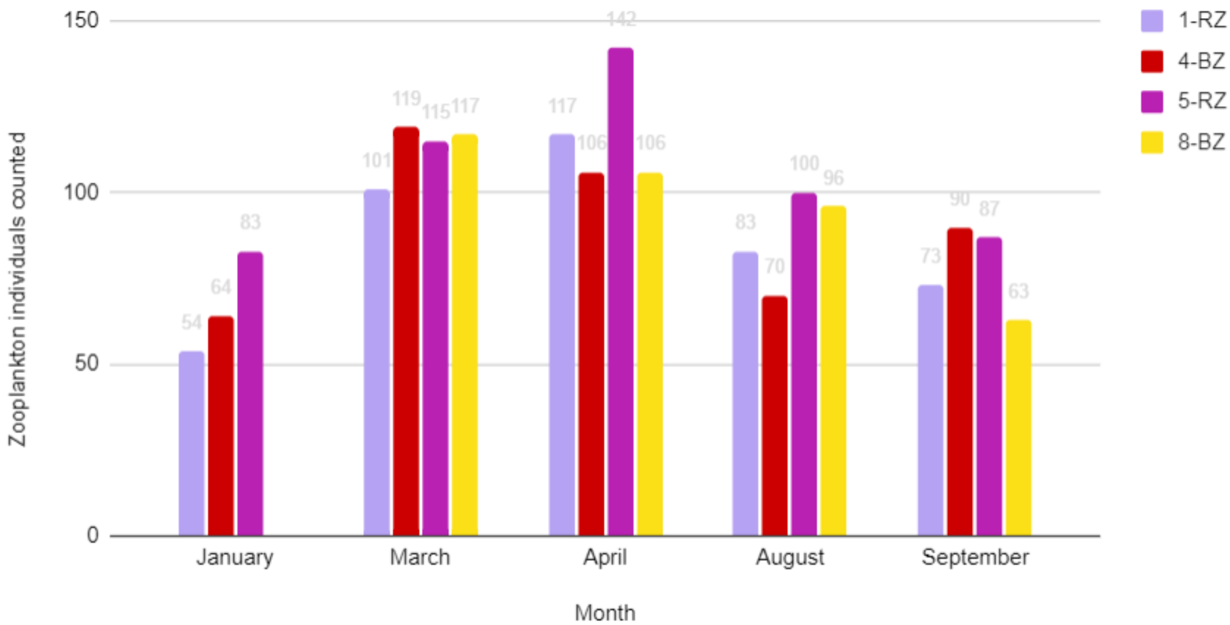


Figure 11. Zooplankton individuals counted during the five sampling months of 2021 in Átl’k̲a7tsem for the four zooplankton stations, including 1-RZ (Squamish Estuary), 4-BZ (Porteau Cove), 5-RZ, and 8-BZ (Bowen Island).

The highest number of zooplankton species counted during sub-sampling and averaged for all stations for each of the five sampling months was seen in March (67.5 species) (Figure 12). Looking at the four zooplankton sampling sites, station 5-RZ showed the highest number of zooplankton on average throughout the months (59 species), whereas station 1-RZ showed the lowest number (50). The highest number of zooplankton species at a singular station during a singular month were seen in March at 8-BZ (72 species) and April at 5-RZ (72 species). The lowest number of zooplankton species at a singular station during a singular month was seen in September at 8-BZ (32 species).

Working on the water throughout the year is inherently challenging, and so in January 2021, station 8-BZ was not visited or sampled due to the loss of daylight and weather.

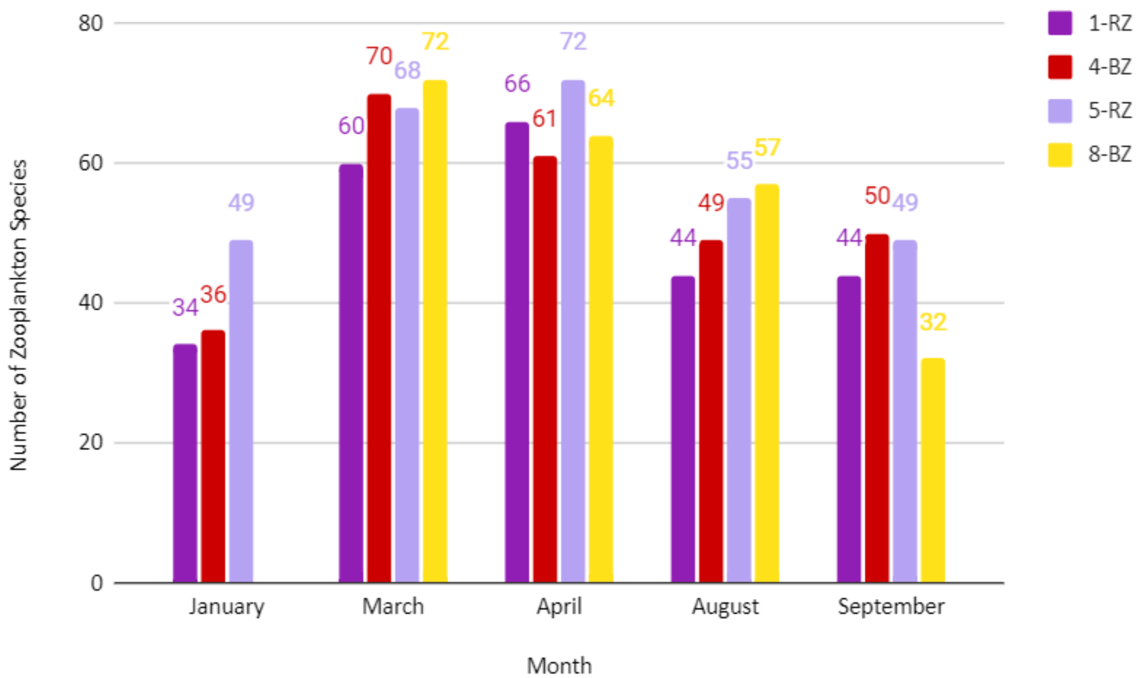


Figure 12. The number of zooplankton species counted during sub-sampling for each zooplankton sampling station by sampling month

The top five dominant zooplankton genera by abundance for all sampling dates are shown in Figure 13. January 2021 was predominantly dominated by *Oithona*, March by *Euclanus*, April by *Metridia*, and August and September by *Paracalanus*. Overall, March and April show the largest abundance of the dominant zooplankton genera compared to the other sampling months. *Metridia* is seen in all sampling months. *Oithona* is seen in four of the five months, including January, April, August, and September. *Paracalanus* is seen in three of the five months, including January, August, and September. *Pseudocalanus* is also seen in three of the five months, including March, April, and September.

The top five dominant zooplankton species by abundance for all sampling dates are shown in Figure 14. January was predominantly dominated by *Oithona atlantica*, March by *Eucalanus sp.*, April by *Metridia sp.*, and August and September by *Paracalanus indicus*. Overall, March shows the largest abundance of the dominant zooplankton species compared to the other sampling months. *Metridia sp.* and *Oithona atlantica* are seen in four of the five months, including January, March, April, and September. *Paracalanus indicus* is found in three of the five months, including January, August, and September.

Due to the manually hauling the zooplankton net slower than recommended speeds of the upcasts, larger zooplankton, such as mesozooplankton and macrozooplankton, may have extruded the zooplankton net, which may have caused lower zooplankton abundances and species diversity. Other zooplankton net sampling issues include extrusion, where individuals may be smaller than the mesh of 250 μm and therefore escape. Extrusion may have also happened due to water pressure when plankton larger than the mesh opening are pushed through. Plankton are in a highly dynamic ecosystem, so it is difficult to sample the same population. A fixed station still means that different plankton populations are present in each sampling period. Due to these issues, all plankton sampling, including this one, is accompanied by dominant processes that may affect plankton, including conductivity, density, temperature, practical salinity, oxygen saturation, and chlorophyll.

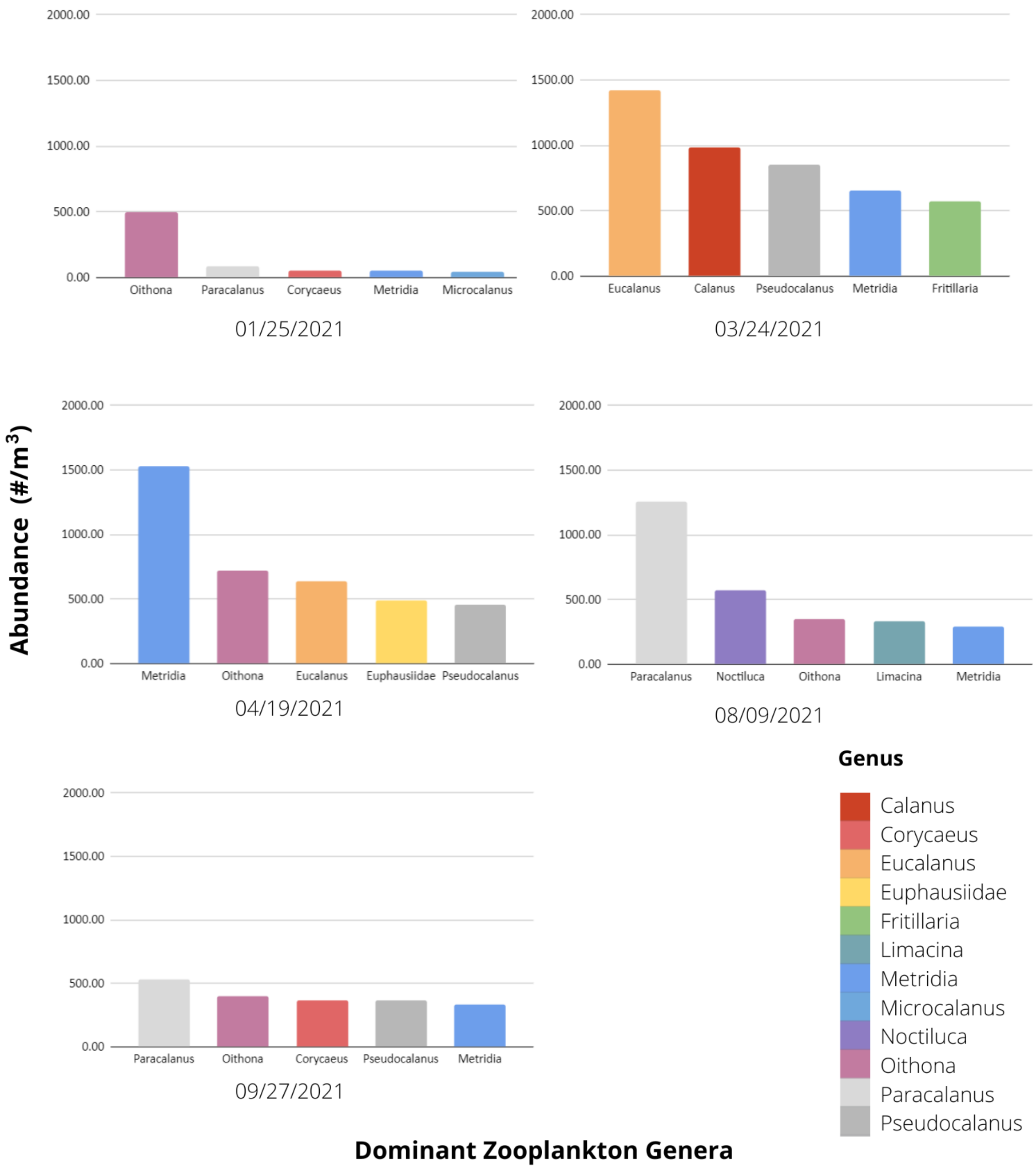


Figure 13. Top five dominant zooplankton genera by abundance for sampling dates in January, March, April, August, and September of 2021 in Átl'k̲a7tsem/Howe Sound at stations 1-RZ, 4-BZ, 5-RZ, and 8-BZ.

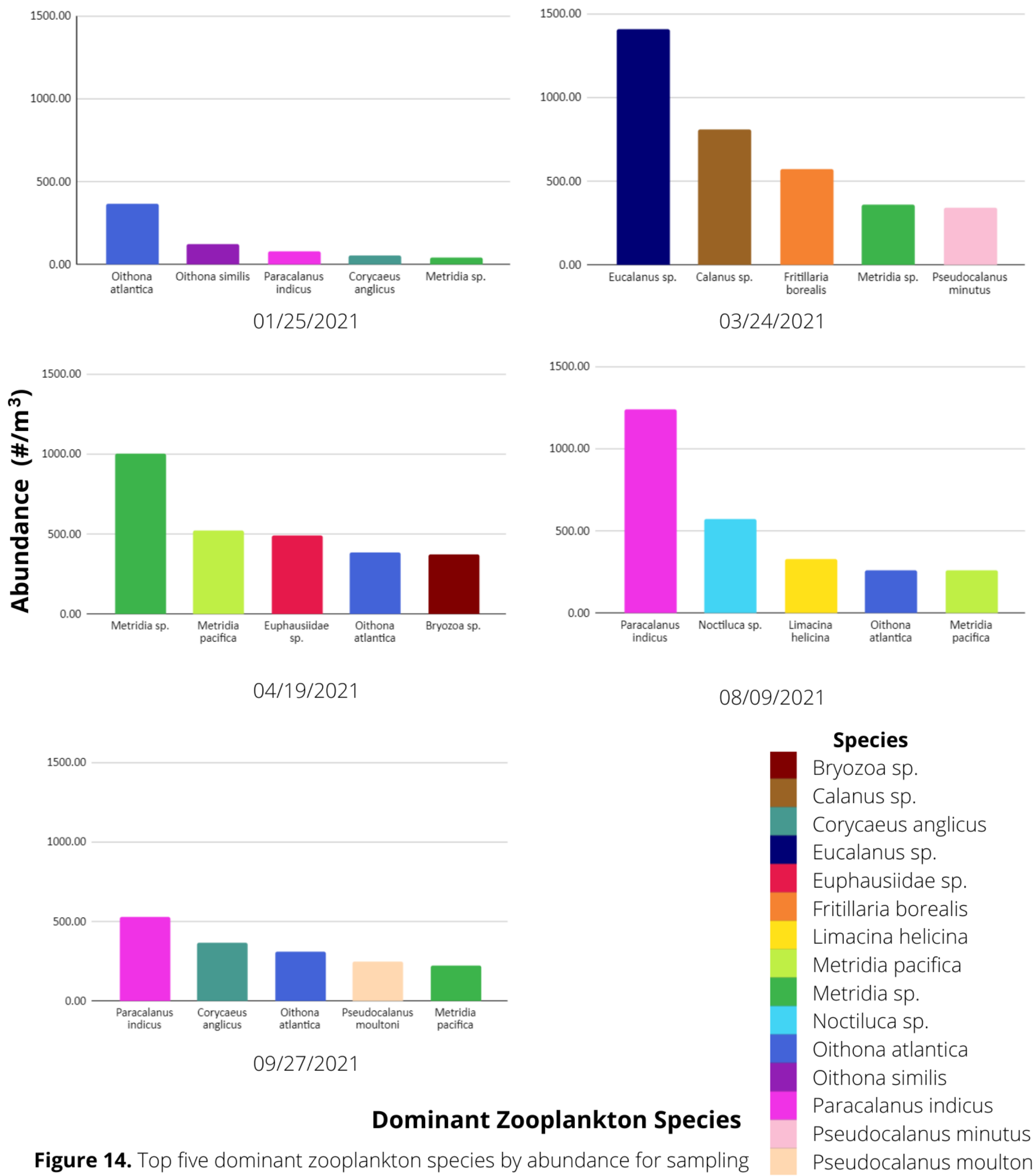


Figure 14. Top five dominant zooplankton species by abundance for sampling dates in January, March, April, August, and September of 2021 in Átl'ḵa7tsem/Howe Sound at stations 1-RZ, 4-BZ, 5-RZ, and 8-BZ.

4.2 Physicochemical Parameters

The average Secchi depth throughout the whole year and all the sampling sites was 4.36m. Figure 15 shows the light extinction coefficient (k-value) for the eight sampling sites over five months. Using the Secchi disk data, the k value was calculated for each sampling event. The average k-value for all sampling events was found to be 1.08. The k value was between 0.2 and 2.22 monthly, where January was 0.2, March was 0.41, April 0.63, and August 1.61, as determined by a Secchi disk. Therefore, from January to September, the light attenuation (*k*) increases. The k value was lowest to highest at 5-RZ (0.31), 7-F (0.34), 6-R (0.41), 8-BZ (0.47), 4-BZ (0.56), 3-R (1.14), 2-F (2.32), and 1-RZ (3.12). The highest light attenuation is seen at 1-RZ (Squamish) and the second highest at 2-F (Woodfibre). The lowest light attenuation is seen at 5-RZ (Port Mellon) and the second lowest at 7-F (Gambier).

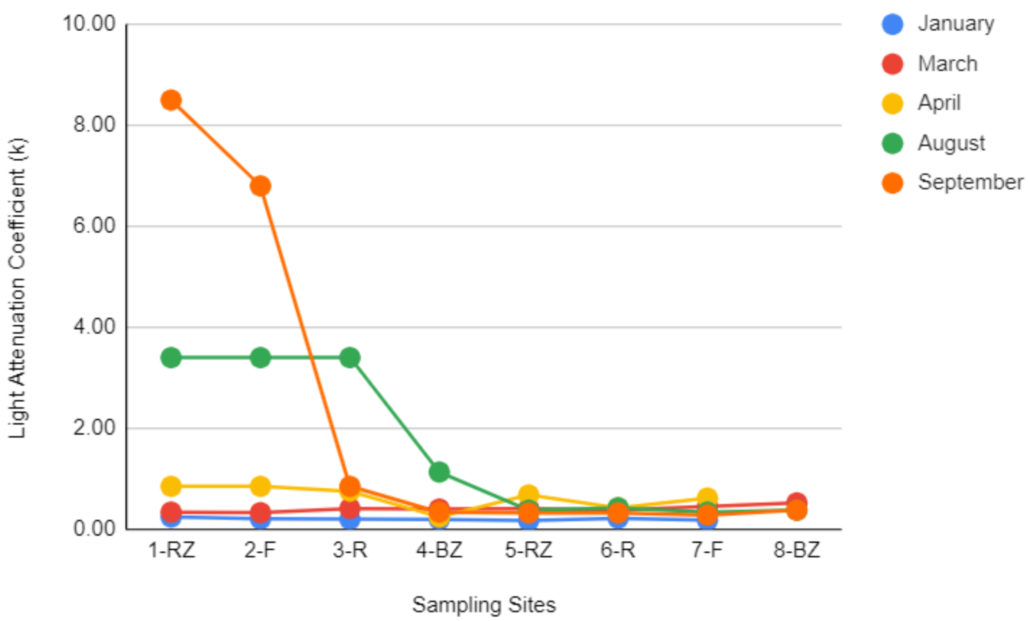


Figure 15. Light attenuation (*k*) for each of the eight sampling sites (1-RZ, 2-F, 3-R, 4-BZ, 5-RZ, 6-R, 7-F, and 8-BZ) in Átl'ka7tsem over January, March, April, August, and September 2021.

Ocean Data View 5.6.3 is the software (Reiner, 2018) that was used to create the section plots showing the changes in conductivity, density, temperature, practical salinity, oxygen saturation, and chlorophyll for the eight sampling stations (Figure 16 a-e).

Conductivity profiles were high at the surface and reached a maximum of around 20m for January, April, August, and September for all sampling sites. The conductivity profile for March resembled a slightly different shape, where conductivity quickly increased for all stations until 40m. At station 8-BZ in March, conductivity decreased between around 55-75m.

Density profiles increased with depth predominantly between surface and 20m for all stations throughout each of the five sampling months.

Temperature profiles at the eight sampling stations helped to identify different water masses. In January, water temperature for all stations increased from a minimum at the surface to a warm layer of about 20m and then increased again from 60 - 70m. The shape of the temperature profiles in January was consistent between the seven sampling sites. March showed a very scattered temperature profile. Similar to conductivity at station 8-BZ in March, the temperature for station 8-BZ decreased between around 55-75m. April, August, and September showed very similar temperature profiles where the surface layers' temperature decreased from about 5 - 20m. The temperature in August, from surface to 20m, was dramatically warmer than the other sampling months. The record heatwave of July 2021 killed off an estimated 1 billion marine animals along Canada's Pacific coast (The Guardian, 2021). This may have had a significant effect on the abundance, timing, and phytoplankton and zooplankton species composition, as well as other physicochemical parameters, due to heightened glacier melt and flooding, causing more silt and water flow.

The shape of the practical salinity profiles was consistent throughout all the months and for all the stations. Salinity increased from the surface to approximately 20 m and stayed consistent from 20m to the bottom. Station 1-RZ, at the Squamish River, had fresher surface water than the other stations.

Oxygen saturation profiles for January increased with depth. For March, April, August, and September, oxygen saturation was high at the surface and reached a maximum just below 5 m for most stations before it decreased. From this maximum, oxygen saturation decreased with depth.

The shape of the chlorophyll profiles were consistent throughout all the months and for all the stations. For each month, chlorophyll increased from the surface to a maximum of approximately 5 to 10m, and then decreased after about 20m. For January, station 1-RZ had the highest maximum chlorophyll amounts. For March and April, station 8-BZ had the highest maximum chlorophyll amounts. For August and September, station 5-RZ had the highest maximum chlorophyll amounts.

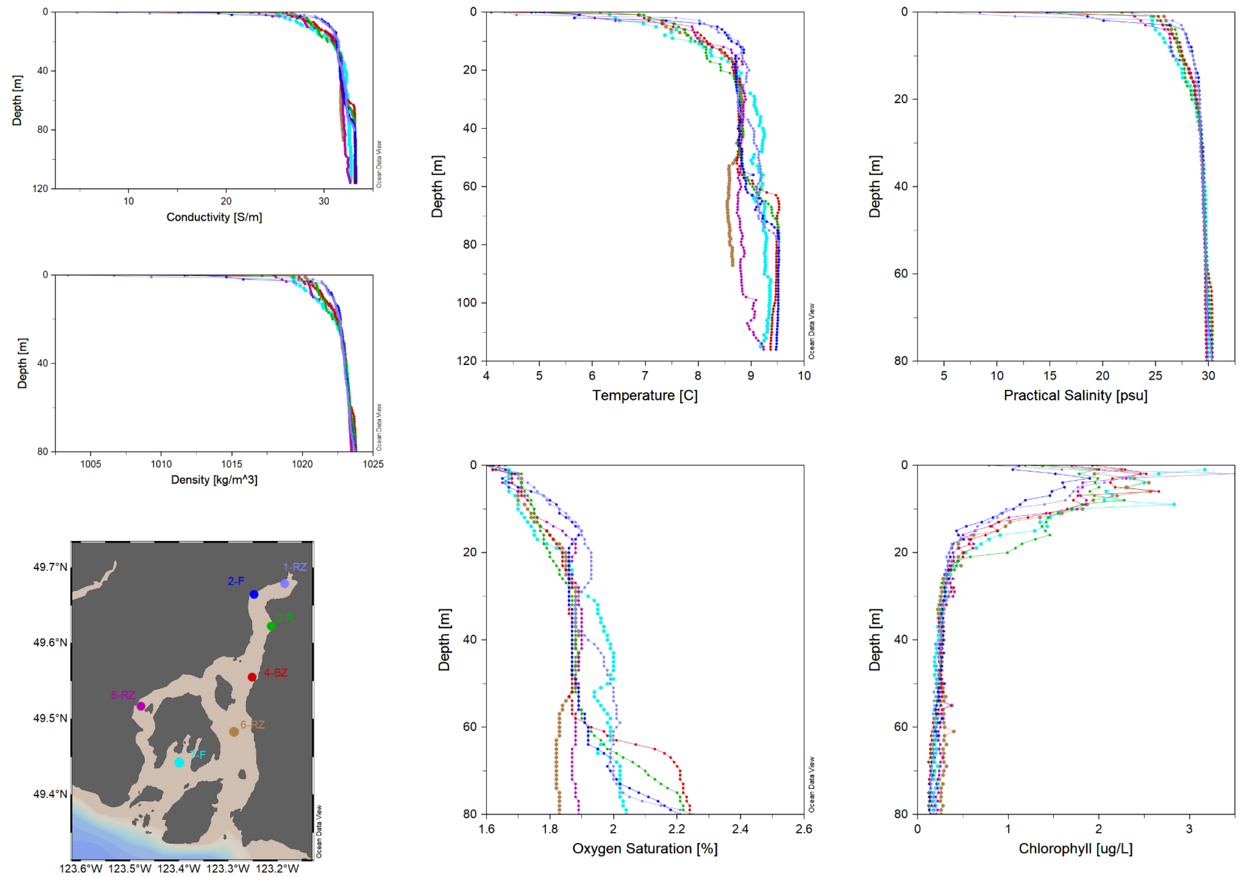


Figure 16a. January 25th, 2021, showing the changes in conductivity, density, temperature, practical salinity, oxygen saturation, and chlorophyll between eight stations (Squamish Estuary (1-RZ), Woodfibre (2-F), Britannia Beach (3-R), Porteau Cove (4-BZ), Port Mellon (5-RZ), Pam Rocks (6-RZ), South Gambier (7-F)). Created with Ocean Data View 5.63.

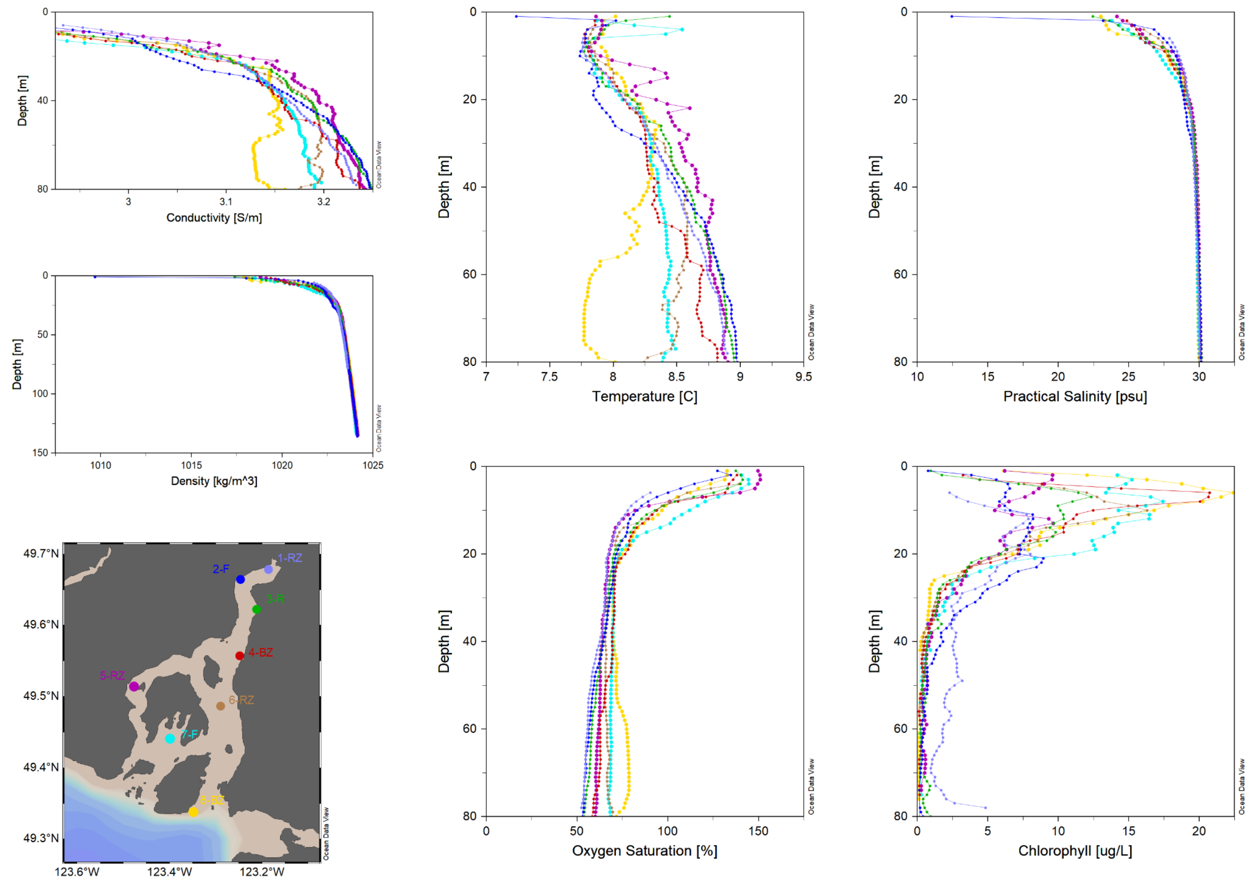


Figure 16b. March 21st, 2021, showing the changes in conductivity, density, temperature, practical salinity, oxygen saturation, and chlorophyll between the eight stations (Squamish Estuary (1-RZ), Woodfibre (2-F), Britannia Beach (3-R), Porteau Cove (4-BZ), Port Mellon (5-RZ), Pam Rocks (6-RZ), South Gambier (7-F) and Strait of Georgia/South Bowen (8-BZ)). Created with Ocean Data View 5.63.

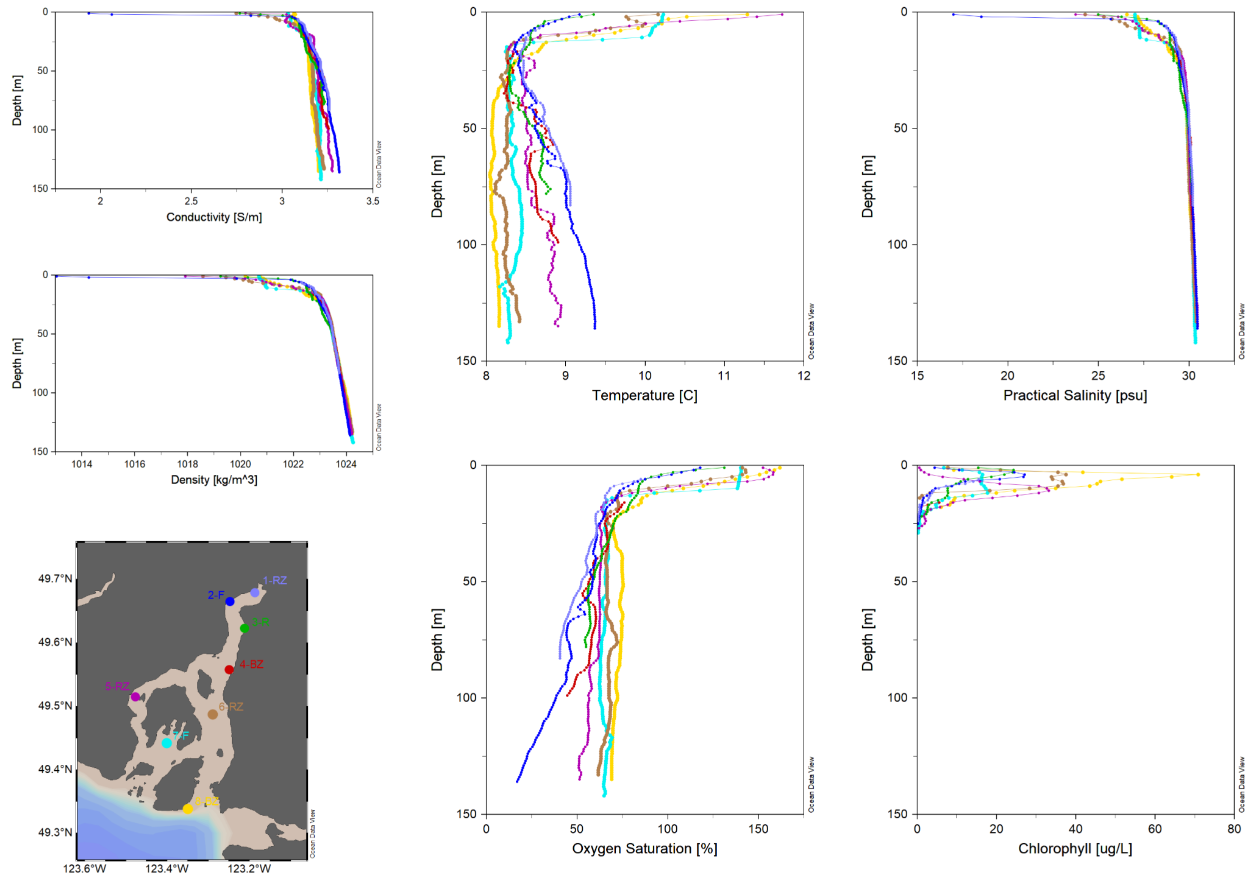


Figure 16c. April 19th, 2021, showing the changes in conductivity, density, temperature, practical salinity, oxygen saturation, and chlorophyll between the eight stations (Squamish Estuary (1-RZ), Woodfibre (2-F), Britannia Beach (3-R), Porteau Cove (4-BZ), Port Mellon (5-RZ), Pam Rocks (6-RZ), South Gambier (7-F) and Strait of Georgia/South Bowen (8-BZ)). Created with Ocean Data View 5.63.

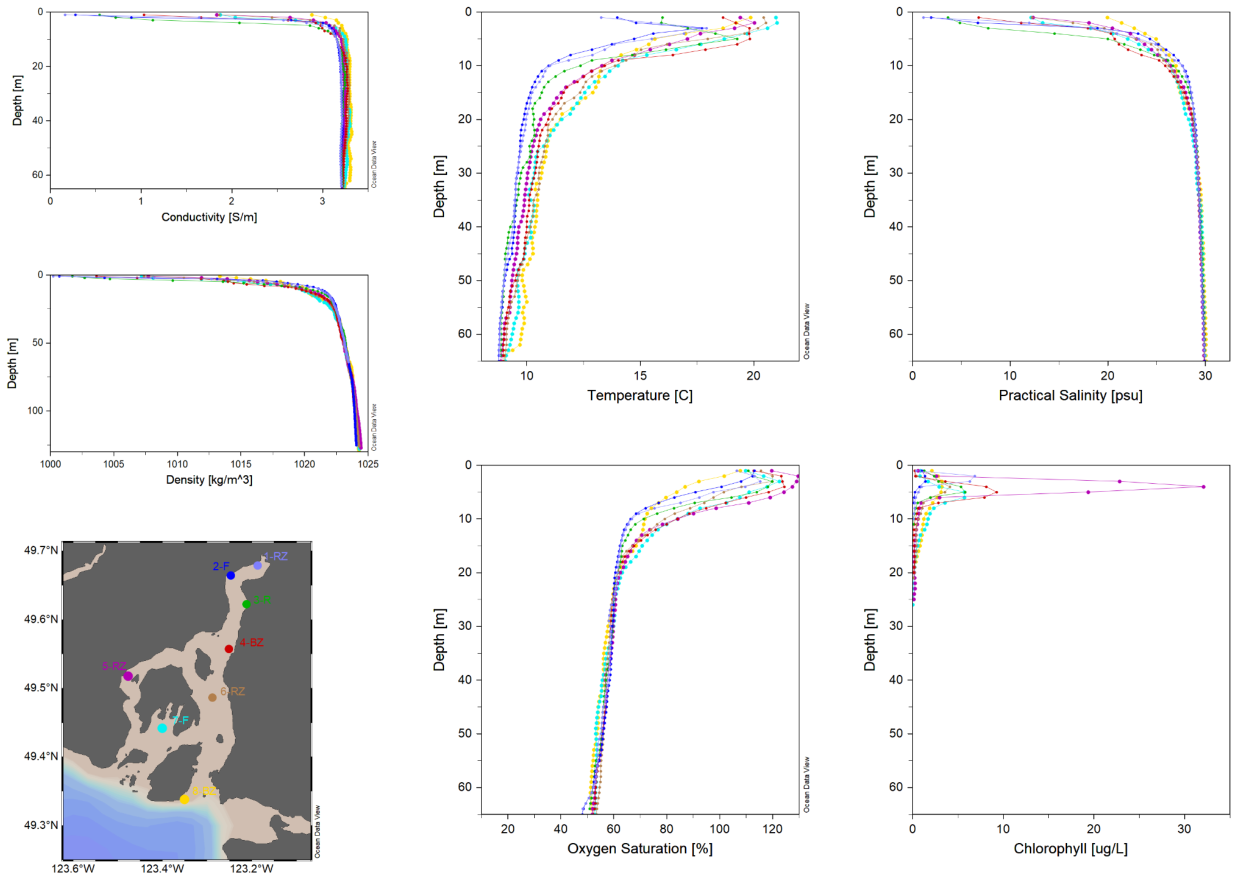


Figure 16d. August 9th, 2021, showing the changes in conductivity, density, temperature, practical salinity, oxygen saturation, and chlorophyll between the eight stations (Squamish Estuary (1-RZ), Woodfibre (2-F), Britannia Beach (3-R), Porteau Cove (4-BZ), Port Mellon (5-RZ), Pam Rocks (6-RZ), South Gambier (7-F) and Strait of Georgia/South Bowen (8-BZ)). Created with Ocean Data View 5.63.

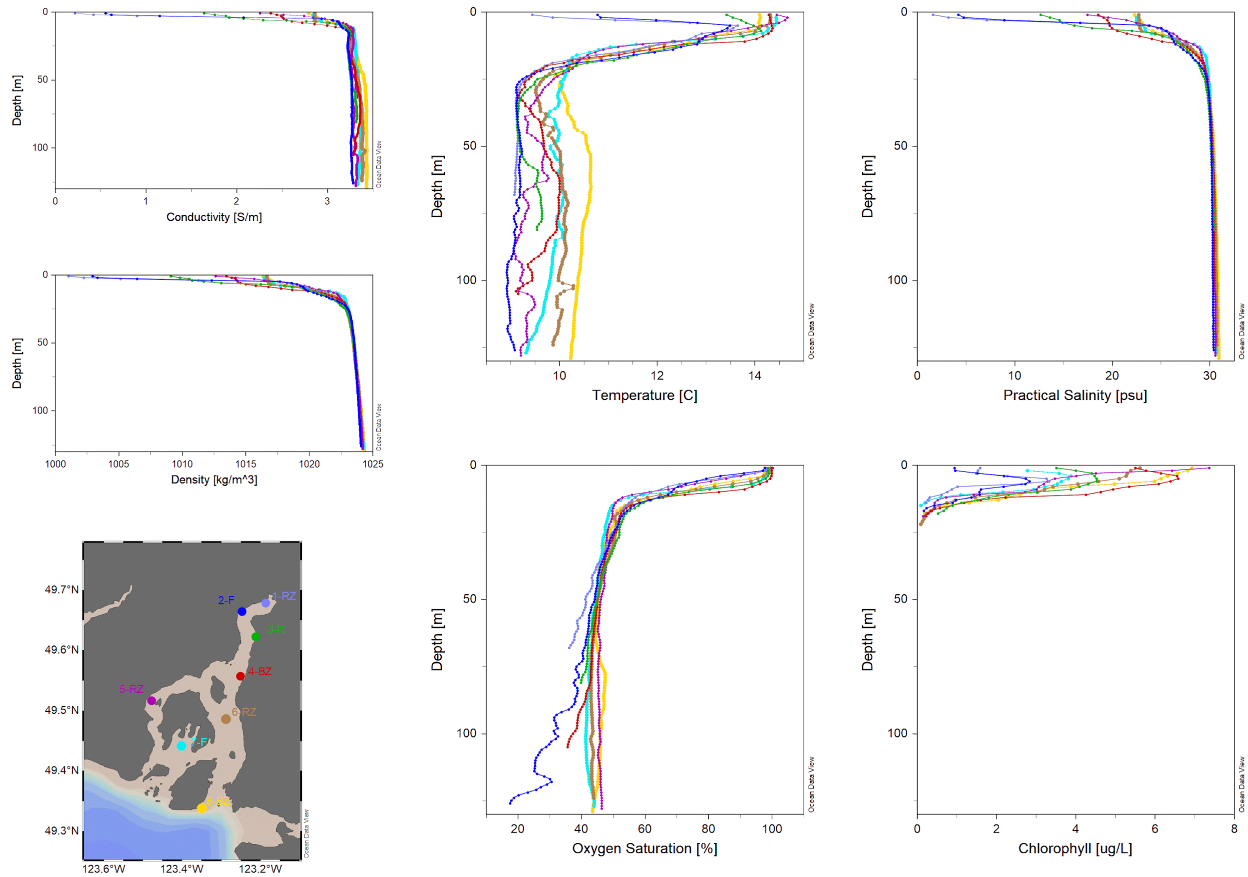


Figure 16e. September 27th, 2021, showing the changes in conductivity, density, temperature, practical salinity, oxygen saturation, and chlorophyll between the eight stations (Squamish Estuary (1-RZ), Woodfibre (2-F), Britannia Beach (3-R), Porteau Cove (4-BZ), Port Mellon (5-RZ), Pam Rocks (6-RZ), South Gambier (7-F) and Strait of Georgia/South Bowen (8-BZ)). Created with Ocean Data View 5.63.

5.0 Conclusion

Plankton plays a critical ecological role by forming the base of marine food webs, and so as was mentioned in the Ocean Watch Report (2020), long-term studies are needed in the future so that comparisons can be made over time. With Átl’ḵa7tsem’s new designation of UNESCO Biosphere Region, rapid growth in the area, and climate change, it is becoming increasingly important to continue this monitoring plankton as it provides an excellent indicator of marine health. Regular monitoring is required to see the changes in productivity and abundance of phytoplankton and zooplankton, which can then be used to assess environmental conditions that have bottom-up influences on the watershed of Átl’ḵa7tsem.

Small changes in the distribution and abundance of phytoplankton and zooplankton can have cascading effects on the biodiversity, ecosystem services, climate, and food web in the ocean. Ocean acidification will impact plankton, for example, many calcium carbonate-creating planktonic species may not have the necessary materials to build those structures (Bodtker, 2017). Warming temperatures will also impact the biodiversity, abundance, and distribution of plankton as warmer temperatures will favor a subset of plankton species. The spatial and temporal persistence of plankton communities is important as there are clear implications for the health of fisheries and marine wildlife populations (Hoover et al., 2021). As part of the Marine Stewardship Initiatives' five-year strategic plan, this plankton research will happen every three years if funding permits to continue to fill this data gap in Átl'ka7tsem.

6.0 Acknowledgements

The Marine Stewardship Initiative is grateful to be conducting this research within Átl'ka7tsem/Howe Sound, which is within the ancestral and unceded territory of the Skwxwú7mesh Úxwumixw (Squamish Nation) and borders the Tsleil-waututh, Sechelt and Musqueam Nations' territories. These Nations have been stewarding these waterways since time immemorial. Given the connection of this project with the Nation's principles, the Skwxwú7mesh Nation is engaged in the Marine Stewardship Initiative's leadership, steering, and management bodies.

The Marine Stewardship Initiative is grateful to Isobel Pearsall, Nicole Frederickson, Terry Curran, Svetlana Esenkulova, and other staff members at the Pacific Salmon Foundation who provided gear, guidance, methods and classification and processing of the phytoplankton. The Initiative also wants to thank Kelly Young, Moira Galbraith, Akash Sastri, and Ian Perry at the Plankton Ecology group at the Institute of Ocean Sciences, Fisheries and Oceans Canada, who provided the zooplankton taxonomy analysis, zooplankton gear, valuable suggestions, and resources. Our thanks also to Kevin Swoboda and Ben Zander of Freedom Diving Systems for boating the plankton team from site to site. Tanner Owca, Megan Kot, Ryan Flagg, and the data team at Ocean Networks Canada for the CTD use and processing of the data. The Initiative also wants to thank all the staff and volunteers who came out on the boat to help with sampling, including Bridget John, Fiona Beaty, Tanner Owca, Johnny Williams, Myia Antone, and Matthew Van Oostdam. This research could not have been accomplished without the support and funding of the National Geographic Grant.

7.0 References

Bodtker K., Day A. (2017). *Ocean Watch Howe Sound Edition 2017.* Ocean Wise Research Institute, Ocean Wise Conservation Association, Vancouver, B.C., Canada. 364 pp. Accessed from https://oceanwatch.ca/howesound/wp-content/uploads/sites/2/2017/02/OceanWatchHoweSoundReport.pdf.

Cantin, A., et al. (2011). *Effects of thermocline deepening on lake plankton communities. NRC Research Press*. doi:10.1139/F10-138.

Cloern, E., Jassby, D. (2008) *Complex seasonal patterns of primary producers at the land–sea interface*. Ecol. Lett. 11, 1294–1303. doi:10.1111/j.1461-0248.2008.01244.x.

Cushing, H. (1959). *The seasonal variation in oceanic production as a problem in population dynamics*. J. Cons. Cons. Perm. Int. Explor. Mer. 24, 455–464.

Fisheries and Oceans Canada. (2021). *Zooplankton Database.* Institute of Ocean Sciences. Accessed from https://open.canada.ca/data/en/dataset/9447ecf8-a7f7-4904-8ab0-3c597c534c4b.

Gulf Watch Alaska. (2019). Oceanographic Conditions in Prince William Sound. Accessed from https://gulfwatchalaska.org/monitoring/environmental-drivers/oceanographic-conditions-in-prince-william-sound/.

Hoover et al. (2021). Spatio-temporal persistence of zooplankton communities in the Gulf of Alaska. Accessed from https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0244960.

McCandless, R. (2016). *Ending pollution at the Britannia copper mine*. BC Studies. doi: https://doi.org/10.14288/bcs.v0i188.184906.

Miller A, Chapman J, Dearden A, Ross P (Editor). (2020). *Ocean Watch Átl⍰a7tsem/Txwnéwu7ts/Howe Sound Edition 2020*. Ocean Wise Research Institute, Ocean Wise Conservation Association, Vancouver, B.C., Canada. 388 pp. ISBN: 978-1-7772408-2-0 Accessed from: http://oceanwatch.ca.

Miller, A., John, B. (2020). *Plankton* in *OceanWatch Howe Sound Edition.* Ocean Wise Research Institute, Ocean Wise Conservation Association, Vancouver, B.C., Canada. Accessed from http://oceanwatch.ca/howesound/species-habitats/plankton/?doing_wp_cron=1555617803.5549728870391845703125.

NOAA. (2019). *Ocean-Atmosphere CO2 Exchange*. NOAA GFDL Earth System Model (ESM2M). Accessed from https://sos.noaa.gov/datasets/ocean-atmosphere-co2-exchange/.

Ocean Networks Canada. (2020). *Ocean Networks Canada Plotting Utility - Pacific - Salish Sea - Salish Sea Marine Survival Project - Gibsons - Patrol 11 - Fluorometer - Chlorophyll.* Accessed from https://data.oceannetworks.ca/PlottingUtility?TREETYPE=26&LOCATION=1866&DEVIC

ECATEGORY=17&SENSOR=14760&DATEFROM=01-Jan-2020%2000:00:00&DATETO=01-Jul-2020%2000:00:00.

Pacific Salmon Foundation. (2021). *A Manual for Oceanographic Data Collection for the Salish Sea Project 2021.*

Perry, I. (2020). *Zooplankton Taxonomic Analysis: Lab. IOS.* Sent by email.

Schlitzer, Reiner. (2018). *Ocean Data View*. Accessed from https://odv.awi.de.

Smayda, J. (1997). *What is a bloom? A commentary*. Limnol. Oceanogr. 42, 1132–1136.

Sommer, U., Gliwicz, M., Lampert, W., Duncan, A. (1986). *The PEG-model of seasonal succession of planktonic events in fresh waters*. Arch. Hydrobiol. 106, 433–471.

Stockner, J., Cliff, D., Buchanan, D. (1972). *Phytoplankton production and distribution in Howe Sound, British Columbia: A coastal marine embayment-fjord under stress*. J. Fish. Res. Board Can. 34: 907-917.

Strait of Georgia Data Centre. (2022). *Hydrography methods and evaluation of data quality.* Accessed from https://sogdatacentre.wpengine.com/atlas/hydrography/methods-and-evaluation-of-data-quality/.

Squamish Nation. (2022). *The Nation Today.* Accessed from https://www.squamish.net/about-our-nation/.

The Guardian. (2021). *'Heat dome' probably killed 1bn marine animals on Canada coast, experts say.* Accessed from https://www.theguardian.com/environment/2021/jul/08/heat-dome-canada-pacific-northwest-animal-deaths.

Winder, M., Cloern, J. (2010). *The annual cycles of phytoplankton biomass*. The Royal Society Publishing. doi:10.1098/rstb.2010.0125.