



# Comparison of the Distribution, Abundance, and Diversity of Zooplankton in Trevor Channel and Alberni Inlet, Barkley Sound, Vancouver Island, Canada

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## NONTECHNICAL SUMMARY

The objective of this study is to compare the distribution, abundance and diversity of zooplankton species in the differing ecosystems of Trevor Channel and Alberni Inlet in Barkley Sound, Vancouver Island, Canada. This study was conducted to evaluate which zooplankton species rely on coastal, low circulation waters in Alberni Inlet, as opposed to those that are found in the open, high circulation waters of Trevor Channel. The cruise took place aboard the *R/V Thomas G. Thompson* on January 26-February 3, 2013. In order to collect data, water samples were collected as well as the parameters where measured using a CTD. The zooplankton species were collected with a bongo net and preserved in jars to be counted and identified in the laboratory. The results show that Trevor Channel has cooler temperatures and higher saline waters than Alberni Inlet. The water parameters, temperature and salinity, and depths of the stations within these channels control the distribution, abundance, and diversity of zooplankton species.

## ABSTRACT

The objective of this study is to compare the distribution, abundance and diversity of zooplankton species in the differing ecosystems of Trevor Channel and Alberni Inlet in Barkley Sound, Vancouver Island, Canada. This study was conducted to evaluate which zooplankton species rely on coastal, low circulation waters in Alberni Inlet, as opposed to those that are in the open, high circulation waters of Trevor Channel. The cruise took place aboard the *R/V Thomas G. Thompson* on January 26-February 3, 2013. Through the use of Bongo nets and CTD casts, water parameters were analyzed and the zooplankton samples were collected and analyzed using the Shannon-Wiener Diversity Index. The data collected here is evident that the circulation, depth and water parameters, such as temperature and salinity, control the diversity, distribution and abundance of zooplankton species within the waters of Barkley Sound. Trevor Channel stations have cooler temperatures, ~8-10°C, and a higher salinity concentration, ~29-34 psu, than stations in Alberni Inlet. Alberni Inlet stations have temperatures range from ~9-11°C, and the salinity ranges from ~15-32°C. Stations within Trevor Channel are more diverse in species than Alberni Inlet due to the influence of the ocean bringing new species into the Sound. Two copepod species, *Copepodia Calanus pacificus* and *Copepodia Medriatica*, are abundant at each of the stations, as well as each station has a different species that are co-dominant.

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## Introduction

Zooplankton consist of an array of microscopic, unicellular or multicellular forms that can range in size from a few microns to more than a millimeter (Goswami, 2004). The zooplankton community consists of holoplankton (adults) and meroplankton (eggs and larvae); both of which are omnipresent in marine waters, especially within the waters of Barkley Sound (Goswami, 2004).

The variability of zooplankton distribution, diversity, and abundance is mainly influenced by patchiness, diurnal vertical migration, and seasons (Goswami, 2004). Diurnal vertical migration (DVM) is a behavioral mechanism, which is shaped by the trade-off of high predator risk in surface waters and reduced growth in deeper waters (Loose and Dawidowicz, 1994). During the day, zooplankton are found to dwell deep in the euphotic zone, or even deeper in the water column to avoid visual predators. As night approaches, the zooplankton swim up to the surface waters to feed upon phytoplankton. DVM is also undergone to avoid UV radiation and a transportation mechanism to find nutrients and food in the surface waters, as well as to eat at night and to digest in cool waters to conserve energy.

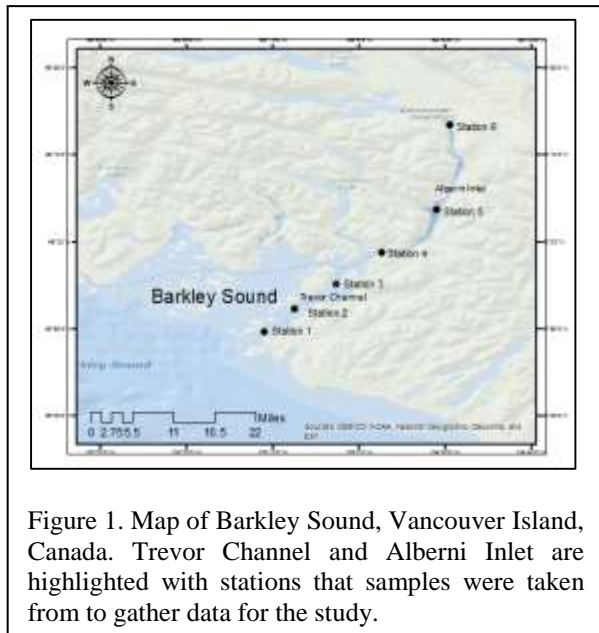


Figure 1. Map of Barkley Sound, Vancouver Island, Canada. Trevor Channel and Alberni Inlet are highlighted with stations that samples were taken from to gather data for the study.

The distribution of zooplankton largely depends on the physical and dynamic characteristics of the water and it is reflected in the

adaptation of various animal taxa to relatively narrow temperature and salinity gradients (Sabates, Gili, and Pages, 1989). Fluctuations in parameters such as light intensity, nutrient abundance and density can affect zooplankton distribution as well. Fluctuations in temperature and salinity can affect the movements of zooplankton as they swim along physical and chemical boundaries present in the vertical and horizontal planes of the environment. These fluctuations can result in changes in metabolic rates, reduction of surplus energy, reproduction and ultimately survival (Parry, 1966; Holliday, 1971; Vernberg and Vernberg, 1972). There is a very strong correlation relating light intensity and distribution of zooplankton (Lebrasseur, 1954). Phytoplankton utilize light for photosynthesis and zooplankton graze on them. The organisms act as particles and contribute to light attenuation in the water column. The result of the lowered light intensity is less abundant phytoplankton, and therefore lower abundance of zooplankton.

## Background of Barkley Sound

Barkley Sound includes channels that are relatively open to the ocean and have high circulation, such as Trevor Channel. Alberni Inlet is situated further inland with low circulation, thus, making the two ecosystems differ physically, biologically, chemically, and geologically (Klink et al. 1982; Mackas 1992). Within Alberni Inlet, a river flows naturally into the Sound which adds a small top layer of fresh water to the area (Anderson, 2013).

Barkley Sound has changed every year as variations in climatic conditions have strongly influenced the ecosystems (Ryall, 2009). From year-to-year, the variations of local climate and longer-term changes in regional climate influence a wide range of biophysical events in Barkley Sound, such as temperature, salinity, oxygen levels, and acidity, river discharge patterns, seasonal floods and droughts, intensity of ocean waves, strength and direction of ocean currents, fish growth and productivity, and timing of fish migrations and spawning (Ryall, 2009).

It is important to understand the area of study and its history in order to fully understand how the distribution, diversity, and abundance of zooplankton will differ. For example, the last time

a study was conducted in this area was in the 1950's by Lebrasseur. With all of the changes throughout the years, Lebrasseur's (1954) study can no longer be applicable in the present.

Understanding the distribution, abundance, and diversity of zooplankton can be vital information of how an ecosystem functions biologically. Zooplankton species are considered to be a passive link between primary production and fish yield. Fisheries occupying these waters are dependent on the local ecosystems to supply food and a habitable environment for the fish, such as salmon. Most of the fish that are grown in these waters have life cycles in which they depend on certain species of zooplankton for food (Crawford and Irvine, 2011). Younger salmon depend on

smaller zooplankton, such as copepods, while the larger adult fish depend on the larger zooplankton, such as amphipods and euphausiids (Thompson, 2003). The salmon that reside in Barkley Sound and Alberni Inlet are dominated either directly or indirectly by climate systems controlled in fall and winter by conditions such current fields, thermal regimes, salinity gradients, and prey density (Ryall, 2009).

This study will compare the parameters of temperature, salinity, and chlorophyll, of two ecosystems within Barkley Sound, Vancouver Island, Canada to conclude how the parameters are involved in the distribution, diversity, and abundance of zooplankton species (Fig. 1).

Table 1. Start latitude and longitude, along with the depth of each station within Trevor Channel and

Station #	Date	Latitude	Longitude	Depth
1	1/27/2013	48 N 49.2190	125 W 11.528	25
2	1/27/2013	48 N 52.1485	125 W 08.6796	80
3	1/27/2013	48 N 56.80	125 W 01.91	150
4	1/28/2013	48 N 55.7699	124 W 57.6149	155
5	1/29/2013	49 N 08.4677	124 W 50.9952	250
6	1/29/2013	49 N 13.4287	124 W 49.35	30

## Methods

To determine the aspects of this experiment, samples were collected from six stations within Trevor Channel and Alberni Inlet, Vancouver Island, Canada between the 26th of January and the 2nd of February 2013, aboard the *R/V Thomas G. Thompson (AGOR-23)*. Three stations were chosen in Trevor Channel and Alberni Inlet in order to compile an overview of the ecosystems as a whole; the first station was near the mouth of each channel, the second was relatively in the middle of the channel, and the third was near the end of the channel. At each station, a conductivity-temperature-depth instrument (CTD) (SeabirdSBE-911+) was deployed to measure the parameters of the entire water column, as well as to measure chlorophyll *a* concentration (Table 1). Chlorophyll was measured using the chlorophyll analysis

procedure, which extracts the pigments from phytoplankton cells for analysis of their fluorescence (Lorensen, 1966). To collect zooplankton samples, a 60 cm-diameter general oceanic open-closing, 500  $\mu$ M mesh bongo zooplankton net was lowered into the water column at a rate of 30 m/min. Each deployment of the bongo net was lowered to five meters off of the seafloor to ensure that it would not scrape along the bottom. The net was then towed through the water column at an oblique angle as the boat moved at one knot. Depths varied at each station, so each bongo net deployment varied by the speed of the boat and the angle of the wire at which it was towed. The net was kept from closing to gather zooplankton throughout the entire water column. Attached to the bongo net, a flow and depth meter gave relative measurements of the water that was being sampled at the different stations, which was then used to calculate the number of organisms per liter of sea water. Once

on board, the organisms were preserved in 500 mL jars with 30 mL of 47% buffered formaldehyde.

In the laboratory, the samples were transferred to fresh water, and were then identified, counted, and recorded using a Nikon Stereoscopic Dissecting Microscope SMZ-2. The more condensed samples, at stations three, four, and five were split by the use of a plankton splitter, and were then sub-sampled with the use of a 5 mL stempel pipette.

In order to assess the diversity, distribution, and evenness of the stations, the Shannon-Wiener Diversity Index (Eq.1, App.A) was applied to the data; along with the Simpson's index (Eq.2, App. A) and Pielou's evenness index (App. A). The Shannon-Wiener Diversity Index consists of 'S' as the total number of species in the community, 'pi' is the proportion of 'S' made up of the 'ith' species, and the 'H' is the Shannon-Wiener Diversity Index. The use of this equation will provide information of the species scarcity or frequentness of a species in the two ecosystems. The data will also be applied to a multivariate analysis to understand the distributions of the zooplankton species.

$$H = - \sum_{i=1}^S p_i \ln p_i \quad (\text{Eq. 1})$$

$$D = \sum_{i=1}^S p_i^2 \quad (\text{Eq. 2})$$

## Results

### Temperature and Salinity

Along Trevor Channel and Alberni Inlet, the station with the highest temperature of 25.17°C at the surface waters, was exhibited at Station Six, whereas the lowest temperature of 6.93°C was exhibited at Station Five. At depth, the station with the highest temperature of 10.25°C is found at Station Six at a depth of 20 m, where the lowest temperature of 8.15°C is at Station Three at a depth of 170 m. The station with the highest

salinity at the surface waters, 30.01 psu was Station One, whereas the lowest salinity of 17.50 psu, was exhibited at Station Five. At depth, the station with the highest salinity of 32.8 psu was at Station Three at a depth of 170 m. The lowest salinity of 30.9 psu was exhibited at Station Six at a depth of 20 m (Fig. 3).

### Chlorophyll a Concentrations

Station Two has the highest chlorophyll concentration, of 47.62 µ/L, at the surface of the water column, while Station Five has the lowest concentration of 16.11 µ/L. However, at a depth of 5 m, the chlorophyll concentration is the highest of all the stations at 64.15 µ/L. At depth, it is expected that all of the station chlorophyll concentrations decrease. At depth, Station Five has the lowest concentration at a depth of 60 m, whereas Station One has the highest concentration of 17.10 µ/L at 25 m (Fig. 2).

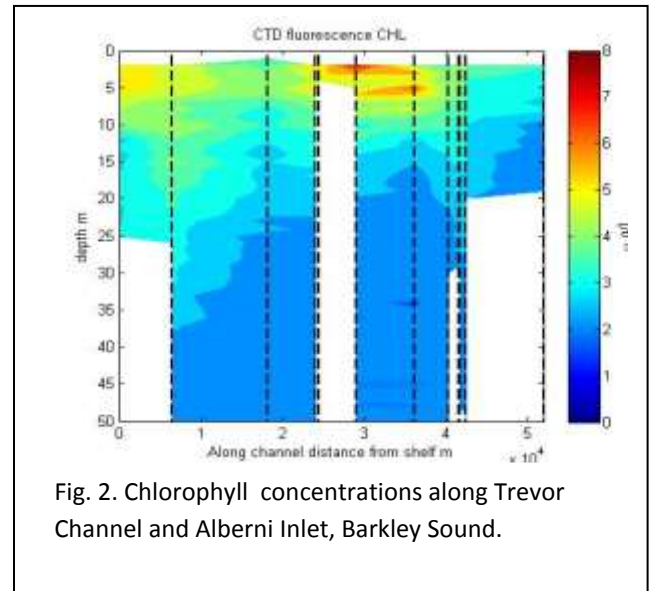


Fig. 2. Chlorophyll concentrations along Trevor Channel and Alberni Inlet, Barkley Sound.

### Zooplankton Species

Station One has a high diversity of species of zooplankton, the most dominant species being the *Copepodia Calanus pacificus*, closely followed by *Copepodia Medriatica*. Station Two looks very similar to Station One, though it does have a slightly higher diversity of species and the dominant species of this area was the *Chaetognatha Sagitta elegans*. Station Three has a lower diversity of species than Station One and Two, but it has a greater abundance of species than at another station. The dominant species at Station

Three was the *Copepodia Medriatica*, which accounts for well over 50% of the population in this area. Station Four has the lowest diversity of species of all of the stations but it is the second

most abundant of the species present. The most dominant species at Station Four is the *Copepodia Medriatica*, which seems to account for more than

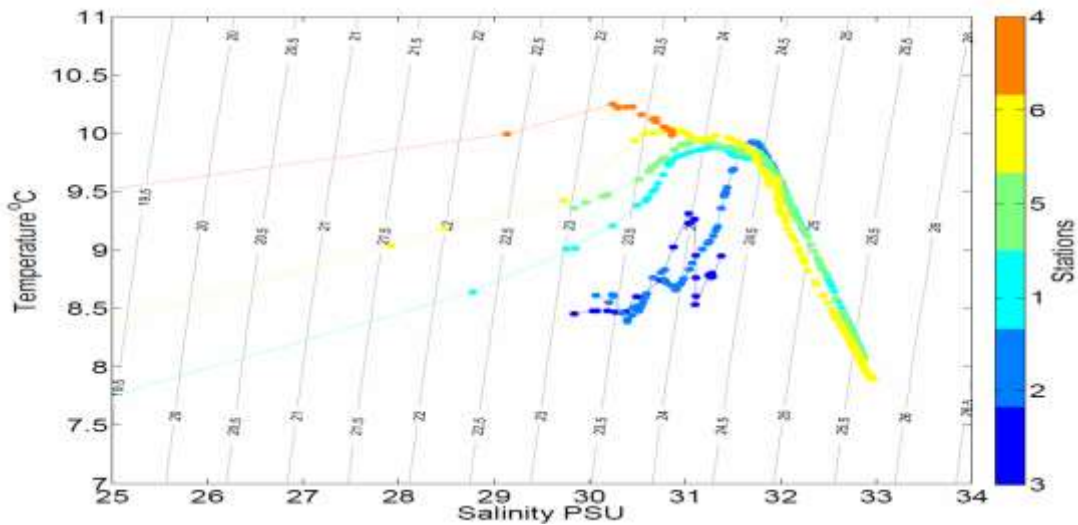


Fig. 3 T-S plot of the six stations within Trevor Channel and Alberni Inlet. Stations of Trevor Channel are 1, 2, and 3. Alberni Inlet station numbers are 4, 5, and 6.

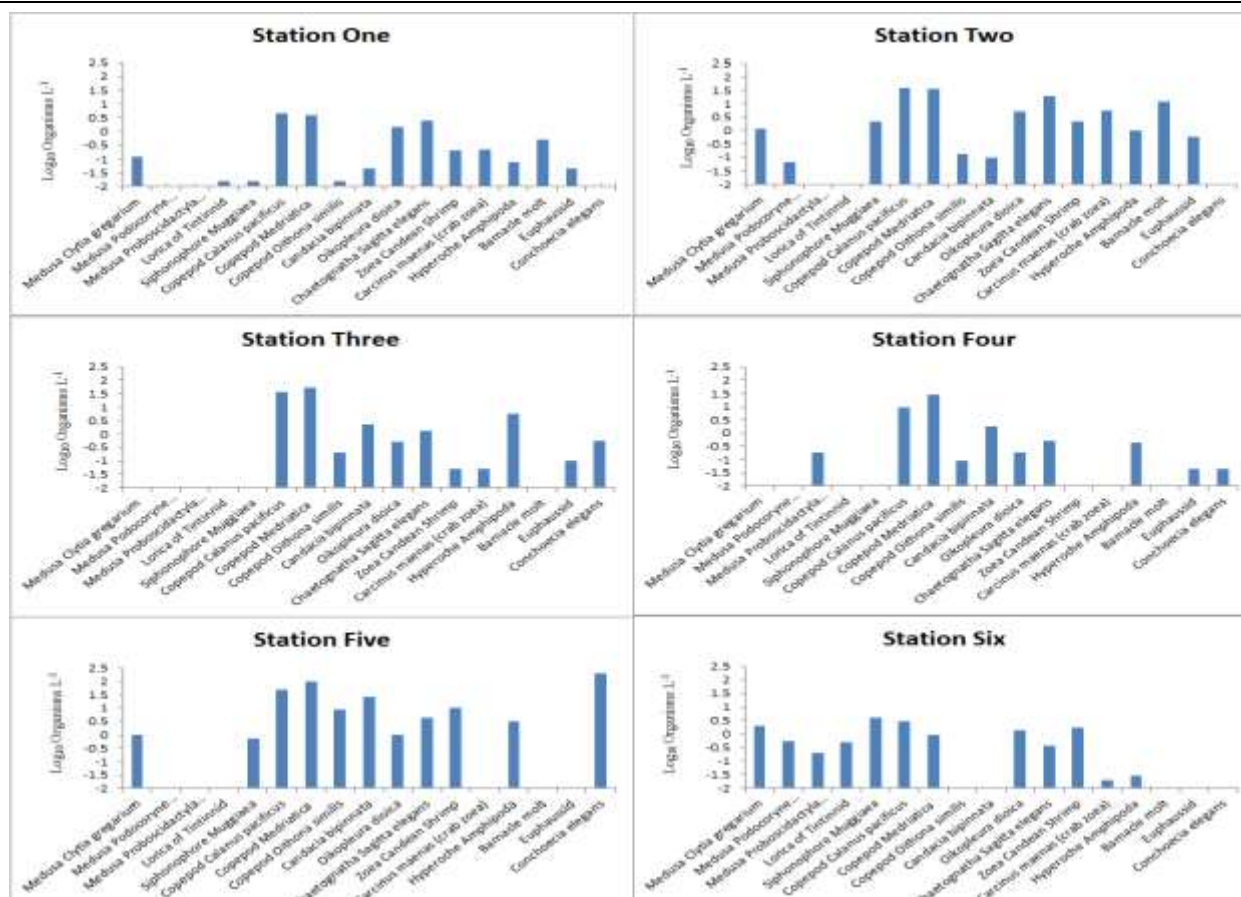


Fig. 4 Abundance of zooplankton at each Station. The abundance is measured in Organisms per Liter.

60% of the population at this area. Station Five has a lower diversity than Station One, Two and Three, and the dominant species found here was the *Conchoecia elegans*, which was rarely found at another station. Finally, Station Six has the greatest diversity of the stations, consisting of multiple dominant species ranging from *Medusa Clytia gregarium*, *Siphonophore Muggiaea*, and the *Copepodia Calinus pacificus* (Fig. 4, Table 1, App. A).

## Discussion

Stations within Trevor Channel are different from the stations within Alberni Inlet due to how the channels are situated within Barkley Sound. Trevor Channel has its opening toward the ocean, where saline ocean waters easily flow through the channel with high circulation. Due to this high circulation, the stations within Trevor Channel are, on average, lower in temperature and higher in salinity concentration than the stations within Alberni Inlet. Alberni Inlet is situated inland with its opening toward the sound. This narrow, winding channel has a source of freshwater runoff as well as some mixture of the water from the Sound creating an area with low circulation, leading to higher temperatures and lower salinity concentrations. Due to the low circulation within Alberni Inlet, the water column is more stratified than the water column in Trevor Channel. Each of these station's depths and water parameters have an effect on the diversity, distribution, and abundance of zooplankton species.

Comparing the diversity of zooplankton species between Trevor Channel and Alberni Inlet, it was found that Trevor Channel had a greater diversity of species and Station Three within the channel has the highest abundances of species. Looking at the stations independently, each one is comprised of different species and abundances due to the differing water parameters and properties. Understanding the biological community requires knowledge of the life histories of the organisms which occupy these waters. Obtaining this knowledge may give explanations to the differences in the abundance of the species present (Highsmith and Coyle, 1991).

Among all of the stations the most abundant species of zooplankton are two copepod species, *Calanus pacificus* and *Copepodia Medriatic*. Copepods are the most abundant metazoan in the sea (Huntly et al. 1986). Copepod species abundances are correlated and influenced by temperature and food availability (Vidal, 1980). The greatest abundance of these copepods are found at Station Two and Three of Trevor Channel, where there is a high chlorophyll concentration, meaning there is a high abundance of food for the copepods. My data correlates to that of a study done by Sislak in 2008. Sislak's (2008) study observed copepod abundance and size along temperature and chlorophyll gradients in Glacier Bay, Alaska. The observations of the pre-bloom conditions found that the low chlorophyll concentrations and temperature affect the copepod abundance and size. The cold and chlorophyll poor waters were found to have less abundance and egg sacs were found to be much smaller, which the carrying females were not ready to produce in food limiting areas. While comparing temperature and chlorophyll data to Sislak's (2008) study, it appears that the Barkley Sound water variables provide a more habitable environment for an increasing abundance of copepod species. Barkley Sound has much higher temperatures and chlorophyll concentrations which may result in high abundances of copepod species.

Within Trevor Channel, Station One is the closest to the open ocean; therefore the salinity concentration will be the highest at the surface. At depth, Station One exhibited the highest chlorophyll, as well as high nutrient concentrations due to the mixing of the sea and Sound waters. Station One's dominant species is the *Oikopleura dioica*. This species is a vital component to the marine zooplankton community, only second in abundance to copepods, and can be found in all major ocean systems (Troedsson et al. 2002). *O. dioica* are capable of rapid blooms if in the right kind of water conditions. The somatic growth and recruitment of *O. dioica* are hypothesized to be dependent on temperature and food limitation (Hopcroft and Roff, 1995; Troedsson et al. 2002; Lopez-Urrutia et al. 2003). Troedsson answered this hypothesis in 2002, with an experiment that controlled a population of *O.*

*diocia* in a laboratory and examined life history parameters, including growth rates, fecundity, and generation time in response to temperature and food regimes (Troedsson et al. 2002). The two temperatures tested were 15° and 20°C, which is much higher than the temperatures that were exhibited in Barkley Sound. What was concluded was that the *O.diocia* growth rate was independent of food concentrations and that the *O. diocia* were shown to produce faster at the higher temperatures than the lower as well. Comparing these results to my study, the temperatures were ~5-10°C cooler than Troedsson's experiment, but the results of my study showed that with increasing temperature between the stations, the *O. diocia* abundances increased accordingly. With this information, it can be concluded that the *O.diocia* in Barkley Sound are not food limited, but are temperature dependent and will appear in all stations, though the abundances will be greater within higher temperature ranges.

Within the middle of Trevor Channel, the dominant specie of Station Two is *Chaetognatha Sagitta elegans*. *S. elegans* is important to the marine zooplankton community for the transfer of energy through trophic levels and is as great in abundance in the ocean waters as the copepod (Zhang and Zhao-Li, 2012). *S. elegans* primarily lives and feeds in the upper water column of 0-25 m (Sullivan, 1980). Chaetognaths biomass has been estimated to be 10-30% of that of the copepod biomass, resulting in being a great significance in energy transfer from copepods to higher trophic levels (Terazaki, 1998). There are more than 115 species of chaetognaths in the world's oceans, and are distributed mainly by temperature and salinity (Zhang and Zhao-Li, 2012). The horizontal distribution of chaetognaths appears to be controlled by concentrations of oxygen, as well as by temperature and salinity. The vertical distribution seems to be due to seasonal changes, maturity stage, and the size of the individual (Terazaki, 1998). A study by Terazaki in 1998, found that temperature regime in juveniles occurred in less than 10°C in January-April, and increased in the summer to 18°C. Adults can be found in temperatures as low as 7°C all year. The *S. elegans* in my study exhibited the same conclusions as Terazaki. Abundances of *S. elegans* were found at every station at

temperatures ranging as low as 7°C. Terazaki did not include a salinity gradient and has said that there is yet a study that has given an exact salinity range for the *S. elegans*. In my study, the differing salinity gradients gave no indication that it is a factor in the abundance of *S.elegans*. Rather than temperature and salinity being factors of *S. elegans* in my study, it seems that the key factor that plays a role in the abundance of the chaetognaths is the abundance of copepods. At each station, it was found that the abundance of *S.elegans* increased with the increase of copepod abundance accordingly, signifying that there may be a predator-prey relationship.

Near the end of Trevor Channel, Station Three is occupied by the greatest abundance of *Hyeroche Amphipodia*. Amphipods are pelagic crustaceans that are primarily associated with gelatinous zooplankton, including Medusa, ctenophores, salps, and siphonophores. The association between the species provides protection and transportation for the amphipods (Gasca and Haddock, 2004). Amphipods are known to graze upon copepods, chaetognaths, and fish larvae (Ramirez and Vincs, 1985). The distribution of amphipods can be influenced by temperature, salinity, and seasonal changes (Highsmith, 1991). Highsmith's (1991) life history study concluded that amphipods are temperature-dependent organisms for growth and productivity. Within Highsmith's (1991) study, the suggested temperature range for optimal growth and productivity for amphipods would be 8-16°C. My study was in agreement with Highsmith's (1991) temperature range of 8-10°C. However, most of my stations within Trevor Channel and Alberni Inlet were within this temperature range and *Hyeroche Amphipodia* abundance is only significant at Station Three. The protection and transportation for these amphipods of Medusa, ctenophores, salps and siphonophores were not present at this station as well. Meaning that at this station the amphipods are not reliant upon other organisms for survival. The distribution of *Hyeroche Amphipodia* is temperature-dependent in these waters and the abundance correlates with the abundance of prey.

Heading into the mouth of Alberni Inlet, Station Four is occupied by an abundance of *Candacia bipinnata*. *C. bipinnata* is a species of

copepod that is larger in body size and more carnivorous than the copepods discussed previously. *C. bipinnata* is abundant in the same water parameters as the other copepod species though the difference in the distribution and abundance of *C. bipinnata* compared to *Calanus pacificus* and *Copepodia Medriatic*, could be due to the depth of the stations. The size of the *C. bipinnata* makes the species able to thrive at greater depths than the other species. There has been little to none studies of this type of copepod unfortunately. But from this study, we can conclude that this species prefers water temperatures of 8-10°C and depths greater than 80 m.

Near the middle of Alberni Inlet and the river input is Station Five. The dominant zooplankton species residing in Station Five is *Conchoecia elegans*. The *C. elegans*, also known as Ostracods, is a deep water dwelling zooplankton. These organisms rarely come above 60 m at depth, preferring the deep cold temperatures and high salinity waters (McHardy, 2011). This study agrees with Elofson's (1941) study that explained that *C. elegans* are eurythermal, euryhaline species which prefer temperatures of 7.3-12°C and salinities from 24.6-27.3% psu. Within my study, the predominant factor influencing the abundance of *C. elegans*, is depth of 250 m at Station Five.

Station Six is located at the end of Alberni Inlet, where due to the low circulation, the dominant species of zooplankton found in this area was *Medusa Clytia gregarium*. The colonies of the *Medusa Clytia gregarium* can become abundant in a region with an increase as a function of age and food supply (Roosen-Runge, 1862). Food supply for *C. gregarium* consists of copepods and *Zoea Candean Shrimp*, both of whom are abundant in this area of the inlet. *C. gregarium* are found in greater numbers in Station Five, where the food supply has also increased, as well as the area still having low circulation.

Trevor Channel and Alberni Inlet are shown to have differing distributions of zooplankton. The stations within Trevor Channel mainly consist of species of copepods, amphipods, and chaetognaths. Alberni Inlet mainly consists of

differing species of copepods, medusa, siphonophores, and ostracods.

## Conclusion

- Trevor Channel consists of copepods, amphipods and chaetognaths. While Alberni Inlet consist of copepods, medusa, siphonophores, and ostracods. Thus concluding that the distribution of zooplankton differs between the two channels of Barkley Sound.
- Stations Three and Four are located at the end of Trevor Channel and the mouth of Alberni Inlet. This area has the highest abundance of zooplankton between the two channels. This would be the area that the highest abundance of fish would be due to the high predatory-prey ratio.
- Water parameters, such as temperature and salinity, can control the abundance of zooplankton. Depth of a region can also play a role in the abundance and distribution of zooplankton species.

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Appendix A- Abundance of zooplankton at each station within Trevor Channel and Alberni Inlet, Barkley Sound. Abundances are measured in Organisms per liter of water.

Species	Station Abundances					
	1	2	3	4	5	6
<i>Medusa Clytia gregarium</i>	0.12	1.16	0.00	0.00	1.01	2.03
<i>Medusa Podocoryne northlandi</i>	0.00	0.06	0.00	0.00	0.00	0.52
<i>Medusa Proboscoidactyla flavicirrata</i>	0.00	0.00	0.00	0.18	0.00	0.19
<i>Lorica of Tintinnid</i>	0.02	0.00	0.00	0.00	0.00	0.48
<i>Siphonophore Muggiaea</i>	0.02	2.10	0.00	0.00	0.72	3.86
<i>Copepodia Calanus pacificus</i>	4.56	37.79	37.59	9.62	48.59	2.83
<i>Copepodia Medriatica</i>	3.93	34.75	55.24	27.18	95.03	0.94
<i>Copepodia Oithona similis</i>	0.02	0.13	0.20	0.09	8.48	0.00
<i>Copepodia Candacia bipinnata</i>	0.05	0.10	2.20	1.81	25.45	0.00
<i>Oikopleura dioica</i>	1.52	5.08	0.51	0.18	1.01	1.35
<i>Chaetognatha Sagitta elegans</i>	2.52	19.54	1.33	0.49	4.17	0.37
<i>Zoea Candean Shrimp</i>	0.20	2.10	0.05	0.00	9.63	1.74
<i>Carcinus maenas</i> (crab zoea)	0.22	5.50	0.05	0.00	0.00	0.02
<i>Hyperoche Amphipoda</i>	0.08	1.00	5.88	0.44	3.02	0.03
<i>Barnacle molt</i>	0.51	12.00	0.00	0.00	0.00	0.00
<i>Euphausiid</i>	0.05	0.58	0.10	0.04	0.00	0.00
<i>Conchoecia elegans</i>	0.00	0.00	0.56	0.04	203.85	0.00
<b>Shannon-Weiner Diversity Index</b>	1.66	1.78	1.08	0.93	1.41	2.01
<b>Simpson's Index</b>	0.24	0.22	0.29	0.21	0.35	0.49
<b>Peilou's Index</b>	0.12	0.13	0.10	0.09	0.13	0.18