Identification and Distribution of Zooplankton in False Bay Estuary and Beaverton Cove San Juan Island WA USA
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Abstract

Plankton form the base level food chain in all marine systems. Characterizing the diversity and abundance of plankton in a location can reveal the unique ecology of a system. Zooplankton were identified and enumerated in two locations, False Bay and Beaverton Cove on San Juan Island, WA USA in November 2021. Nine taxa were found in both locations. However, the abundance of a few taxa were much higher in Beaverton Cove than False Bay while overall diversity was higher in False Bay. This pattern could be attributed to higher freshwater inflows into False Bay leading to a broader range of salinity and nutrient availability. Overall abundance might be lower in False Bay than Beaverton Cove because of the 'washing out' factor caused by the greater influx of freshwater into False Bay from False Bay creek.

Introduction

Biodiversity is the interrelatedness of species in our ecosystems and how they interact with their environment. It is the variety of life including all organisms, species, and populations; the genetic variation among these; and their complex assemblages of communities and ecosystems (Benn 2010). Due to the impacts of climate change, the abundance and dispersal of zooplankton needs to be monitored due to their influence in marine food web ecosystems.

Plankton refers to organisms that drift with the current. Phytoplankton are tiny plants that convert sunlight and inorganic elements into plant tissue. Zooplankton refers to weakly swimming animals that consume phytoplankton. These organisms serve as an intermediary species in the food chain, transferring energy from planktonic algae (primary producers) to the larger invertebrate predators and fish who in turn feed on them (EPA 2021) (Figure 1). Zooplankton are also excellent indicators of ecosystem health, food web function, and water quality (Beaugrand 2005) due to their short life cycles that respond to seasonal variations and abrupt changes in environmental conditions.

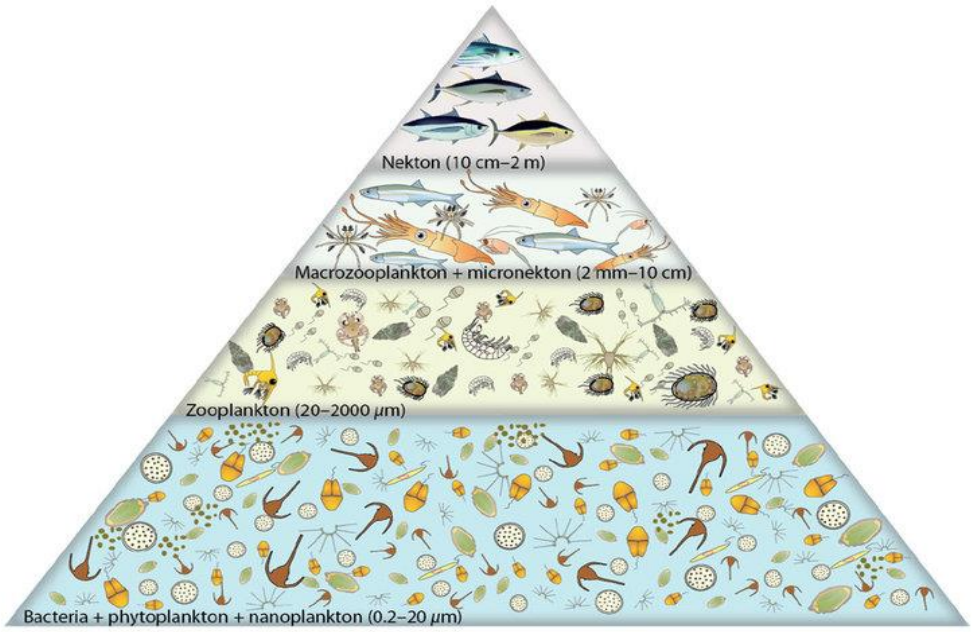

Figure 1. Marine food web triangle. (Photo credit: Bruce Mahalski, Te Ara - The Encyclopedia of New Zealand).

False Bay Creek drains the largest watershed in the San Juan Islands, empties into the False Bay estuary on the southwest side of the island. (Barsh et al. 2010). Beaverton Cove is on the eastside of San Juan Island, north of the ferry terminal. A small creek originates in Beaverton Marsh, goes along Beaverton Valley Road, through several ponds and finally draining into the cove.

To date, there is a lack of research and information on the planktonic biodiversity in both Beaverton Cove and False Bay, San Juan Island, WA USA. For this study, I focused on zooplankton larvae that were present during November 2021. I hypothesized that there is a greater biodiversity and abundance of zooplankton in Beaverton Cove than in False Bay due to the more stable environment in Beaverton Cove. From my observations, Beaverton Cove is smaller, it is protected from extreme winds and rain, and it has no tidal draining.

Methods

To assess the abundance and biodiversity of zooplankton in False Bay, I used a kayak and a 150µm plankton net fitted with a 20 cm wide collar and towed for 1 minute and emptied each sample into pre-labeled jars. For sample collection in the Beaverton Cove, rowboats were used with the aforementioned plankton net sample collection process. Samples were randomly collected during daylight high tides. I used tide predictions for Kanaka Bay to determine the tide height in False Bay and used tide predictions from NOAA Tides & Currents Friday Harbor, WA for tide height in Beaverton Cove. I used the GPS coordinates from a Garmin Instinct Solar watch to determine sample locations and plotted these using Google Earth Pro (Figure 2). The date, time, location, and tow number so that each tow matched up with GPS collection site data, were written on waterproof tape on empty sample bottles and placed in the kayak or rowboat.

The samples were then taken back to the lab where they were examined under a compound microscope and taxa were determined. For large samples that were not able to be processed right away, half of the zooplankton samples were preserved in 95% ethanol for later analysis. Live specimens were examined for setae, spicules or other body parts to confirm species identification, noting any species-specific behaviors.

For the False Bay samples, I identified every organism collected but in Beaverton Cove, the samples were too densely packed with zooplankton so a subsample was taken and enumerated. For final counts I multiplied the original sample volume times each count to get final counts. A syringe was used to lightly stir and to collect samples for viewing under the microscope, the remaining sample was stored in a water table inside a plastic container with

holes to allow water in without contamination. If any sample degradation occurred with zooplankton, only their heads were counted. Due to time and the amount of Nauplii in the Beaverton Cove samples, I approximated nauplii numbers in each sample by halving the sample. Once that half was counted, I multiplied by 2.

To determine different taxa, I looked at the Zooplankton card from the Northwest Fisheries Science Center and NOAA Photo Library, the Marine Invertebrates of the Pacific Northwest (Kozloff 1983, 1987), and the Guide to Marine Coastal Plankton and Marine Invertebrate Larvae (Johnson and Smith year). According to Strathmann's Summary of Reproductive Data, the polychaete larvae that I looked for are <200µm, except for the Maldanidae larvae that measure (230-385µm) (Strathman, M. 1987). For characteristics to help me identify polychaete larval species, I used the Reproduction and Development of Marine Invertebrates of the Northern Pacific Coast (Strathman, M. 1987). General guides and keys by Kozliff (1983, 1987) and by authors of a series of handbooks from the British Columbia provincial museum in Victoria, B.C. (Federal, Provincial and Territorial Governments of Canada 2010.) were used for additional reference.

Data Analysis

To determine patterns in larvae abundance and diversity, raw data were entered into Excel and then analyzed in R Studio (R Core Team 2018).

Results

Plankton of diverse taxa, from single-celled protozoans to large crustacean larvae and adults, were found in the plankton tows (Figure 3). Detailed counts for different taxa found in each replicate tow at both False Bay and Beaverton Cove, are in Tables 1 and 2. Figures 4 and 5 show the relative abundance of taxa in each location.

For both locations, Mollusca larvae found were in the veliger stage. Arthropods found were mostly copepods in various life stages, and zoea (Figure 3). Chordata larvae found were Tunicates. Polychaete larvae found were Spionidae and Phyllodocidae. Planktonic protists found were Ciliophora, and Granuloreticulosa foraminifera.

Species richness was calculated using the Shannon-Weiner Diversity Index. The higher the value of H, the higher the diversity of species in a particular community. False Bay's H=1.137 and Beaverton Cove's H= 0.755. Evenness was calculated using Pielou's Evenness. A calculated value of Pielou's evenness ranges from 0 (no evenness) to 1 (complete evenness). False Bay's evenness was 0.00018 and Beaverton cove was 0.0012.

Figures

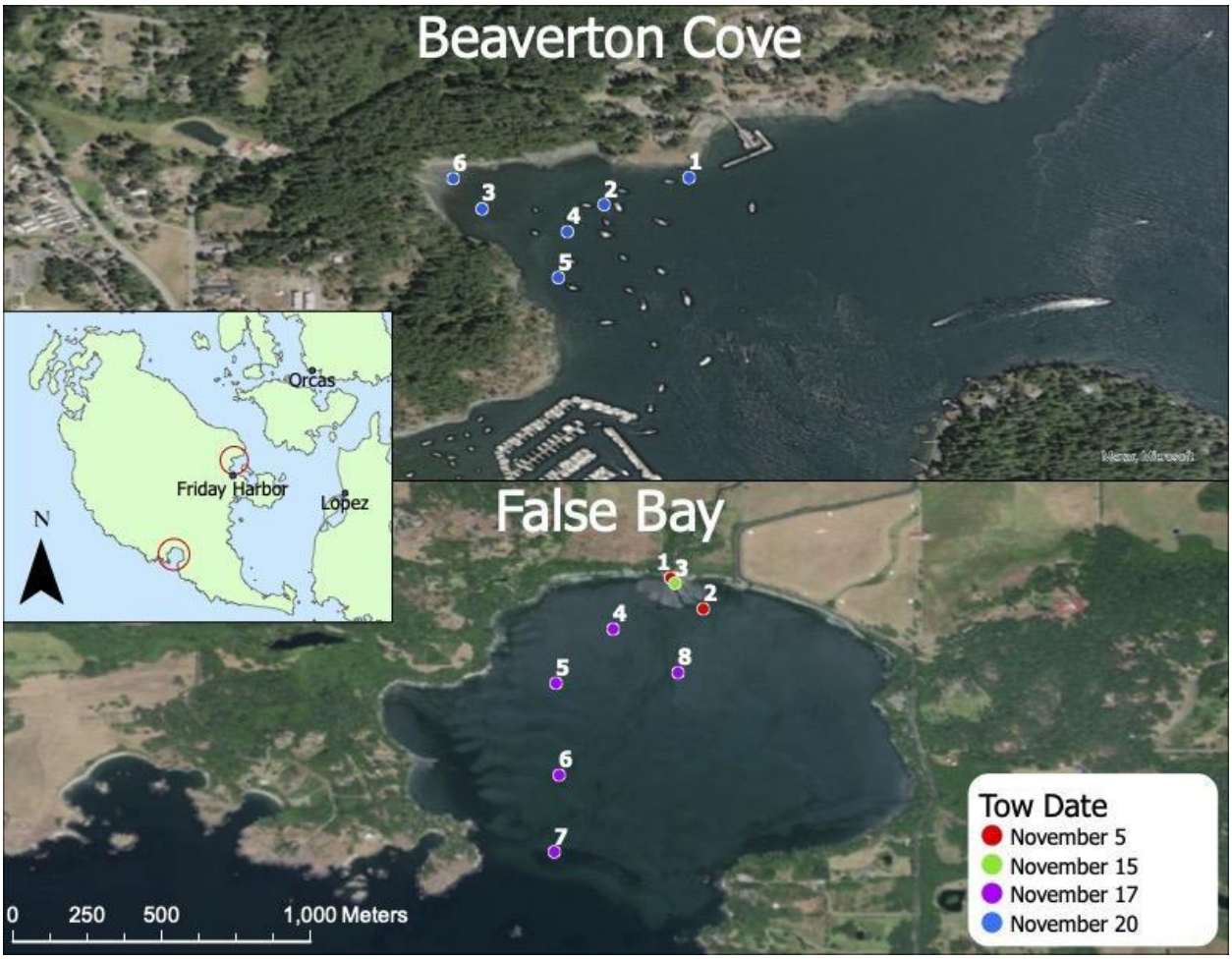

Figure 2. Map of sampling locations at Beaverton Cove and False Bay, San Juan Islands, WA USA. Image Credit: Robert Hoekendorf

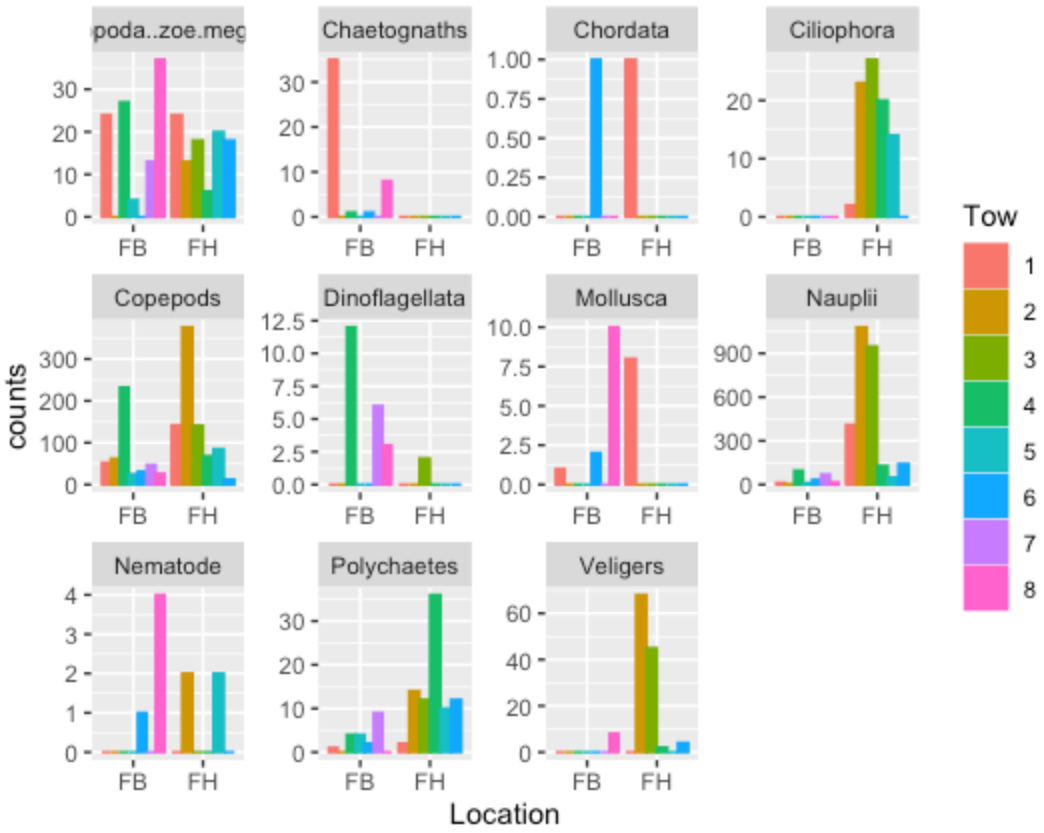

Figure 3. The counts of zooplankton of different taxa found in each replicate tow. FB = False Bay (Tows 1-8), FH (Tows 1-6) = Beaverton Cove, Friday Harbor. Counts are total numbers per taxon from a 1-minute tow. Poda.zoe.meg = Other Arthropods including zoea.

Table 1 shows the False Bay data in detail and includes the dates of the samples, so that it is possible to see the differences before and after the flooding that occurred November 15, 2021. Data for Tow 3 was counted as zeros as samples were too deteriorated to identify taxa, perhaps due to the freshwater from the flooding. Overall, I found 9 different taxa.

Table 1. Table shows the taxa found by date and tow in False Bay, San Juan Island, Washington.

Date	*Tow*	*Copepods*	*Nauplii*	*Polychaetes*	*Chaetognath*	*Arthropods*	*Mollusca*	*Nematode*	*Dino*	*Chordata*
11/5	*1*	*52*	*12*	*1*	*35*	*24*	*1*	*0*	*0*	*0*
11/5	*2*	*62*	*3*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
11/15	*3*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
11/17	*4*	*232*	*96*	*4*	*1*	*27*	*0*	*0*	*12*	*0*
11/17	*5*	*25*	*11*	*4*	*0*	*4*	*0*	*0*	*0*	*0*
11/17	*6*	*31*	*33*	*2*	*1*	*0*	*2*	*1*	*0*	*1*
11/17	*7*	*47*	*70*	*9*	*0*	*13*	*0*	*0*	*6*	*0*
11/17	*8*	*26*	*16*	*0*	*8*	*37*	*18*	*4*	*3*	*0*
Totals		*475*	*241*	*20*	*45*	*105*	*21*	*5*	*21*	*1*

Table 2 shows the results of the Friday Harbor (Beaverton Cove) plankton tows, where Nauplii dominated all tows except tow 5. Mollusca larvae found were in the Veliger stage. Arthropods found were mostly zoea (crab larvae), and Cilophora were various ciliate protozoans. Both *Noctiluca* and *Ceratium* dinoflagellates were found.

Table 2. Table shows taxa found by date and tow in Beaverton Cove, San Juan Island, Washington.

Date	*Tow*	*Copepods*	*Nauplii*	*Polychaetes*	*Cilophora*	*Arthropods*	*Mollusca*	*Nematode*	*Dino*	*Chordata*
11/20	*1*	*142*	*410*	*2*	*2*	*24*	*8*	*0*	*0*	*1*
11/20	*2*	*376*	*1080*	*14*	*23*	*13*	*68*	*2*	*0*	*0*
11/20	*3*	*141*	*948*	*12*	*27*	*18*	*45*	*0*	*2*	*0*
11/20	*4*	*68*	*128*	*36*	*20*	*6*	*2*	*0*	*0*	*0*
11/20	*5*	*85*	*48*	*10*	*14*	*20*	*0*	*2*	*0*	*0*
11/20	*6*	*12*	*142*	*12*	*0*	*18*	*4*	*0*	*0*	*0*
Totals		*824*	*2756*	*86*	*86*	*99*	*127*	*4*	*2*	*1*

Figure 4 shows the plankton data from False Bay expressed as relative abundances. Zooplankton are dominated by adult Copepods which made up 41.6% of the individuals. Other abundant components were Chaetognaths 28%, other Arthropods 19.2% (zoea larvae), Nauplii 9.6%, Mollusca (Veliger larvae) 0.8%, and Polychaeta larvae at 0.8%. I also found small numbers of phytoflagellates, Nematodes and Chordata.

As Table 1 shows, overall, I found 9 different taxa. The Shannon-Weiner Diversity Index H= 1.137, and Pielou evenness = 0.0012.

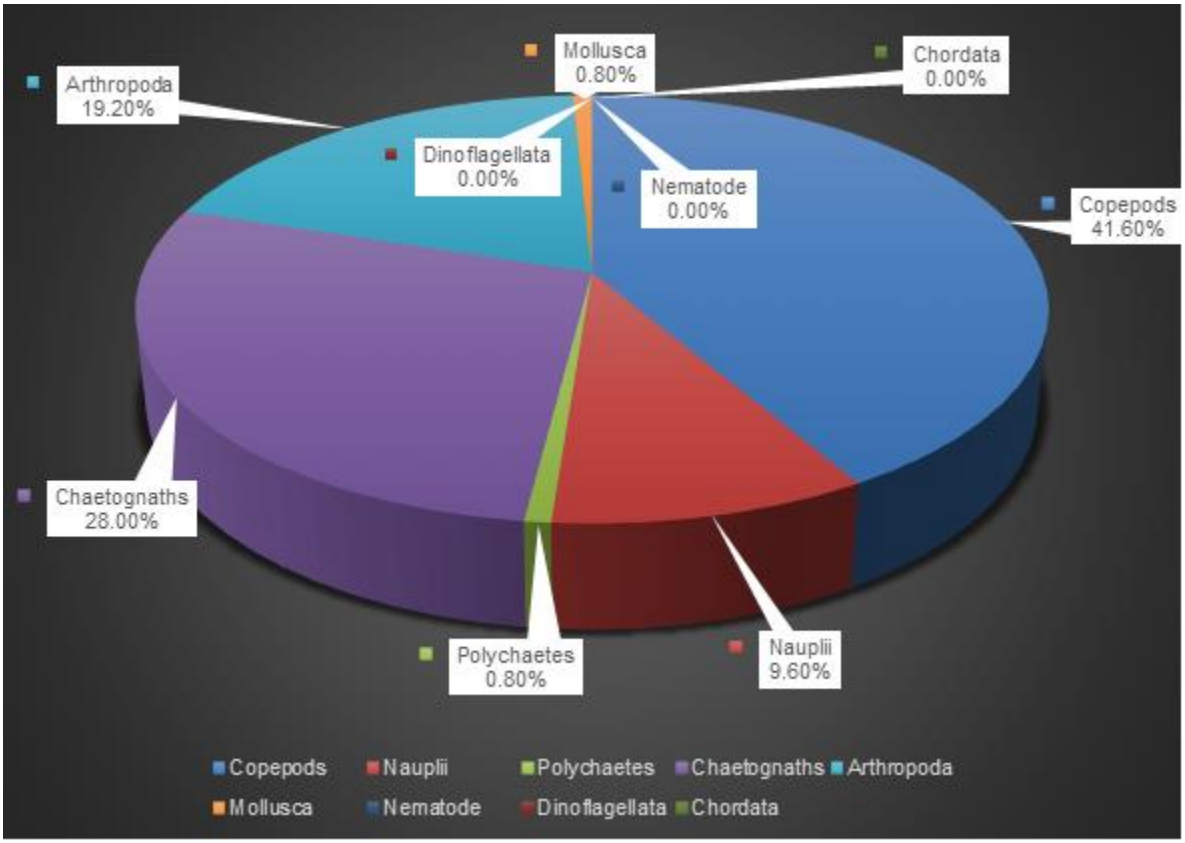

Figure 4. The figure shows the relative abundances of taxa in False Bay, San Juan Island, Washington USA. Flagellates, a marine phytoplankton, Noctiluca, Protoperidinium and Ceratium were found

Figure 5 shows the relative abundances of plankton in Beaverton Cove. Zooplankton at this site were dominated by larval Copepods (Nauplii) which made up 69.6% of the individuals. Other abundant components were adult Copepods 24%, other Arthropoda 4.1% (zoea larvae), Mollusca (Veliger larvae) 1.4%, Cilophora and Polychaeta larvae each at 0.34%. I also found small amounts of diatoms and phytoflagellates.

As Table 2 shows, overall, I found 9 different taxa. The Shannon-Weiner Diversity Index H= 0.755, lower than at False Bay, and Pielou evenness was low at 0.00018 because of the large dominance of one taxon, the Copepod Nauplii.

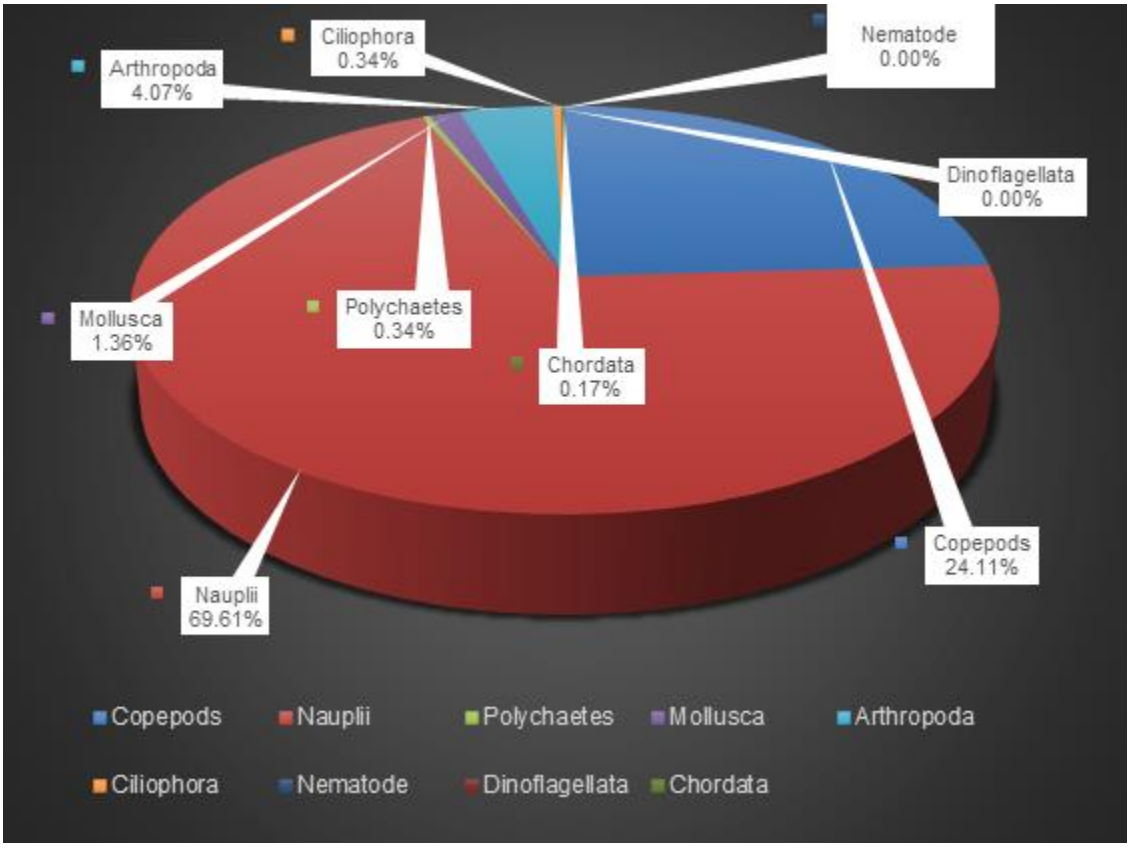

Figure 5. The figure shows the difference of taxa richness in Beaverton Cove, San Juan Island, Washington USA. Diatoms found were Chaetoceros. Flagellates, a marine phytoplankton, Noctiluca, Protoperidinium and Ceratium were found.

Figure 6 shows the amount of rainfall on San Juan Island and is included as it shows the relation between the samples collected before and after the flooding on November 15, 2021.

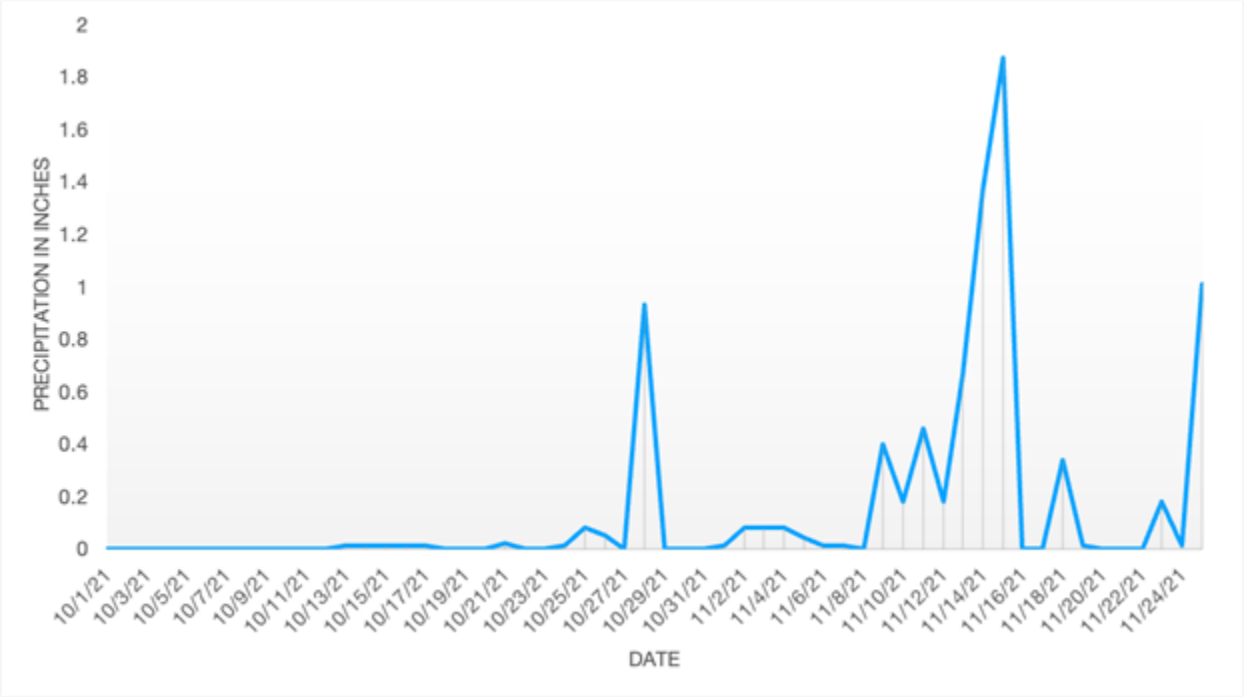

Figure 6. The chart shows the precipitation in inches recorded at the Friday Harbor Airport over approximately an 8-week period from October through November 2021. Samples collected from False Bay during the extreme rainfall.

Discussion

Zooplankton found in False Bay and Beaverton Cove differed both in richness and abundance. These differences may relate to the season, habitats available to reproducing invertebrates, and differences among regions and their watersheds. False Bay has less dense zooplankton populations than Beaverton Cove and this may be because False Bay is an estuary with a lot of freshwater driven outflow and because it drains twice a day into the Strait of Juan de Fuca there are less dense zooplankton populations than in Beaverton Cove. Strong impacts on the whole ecosystem can occur due to microscale effects and variability such as water turbulence can have negative effects on zooplankton over its lifetime with each species integrating the effects over its generation and affecting the next generation (Trombetta *et al.* 2019). Beaverton Cove offers a more stable environment, as it is in a protected harbor. It also has some freshwater inflow but I am unsure whether there is enough to cause the outflow and washing out as seen in False Bay. The differences in the larval dispersal and abundance may be due to the difference in sample sites, such as water circulation and movement and extreme weather fluctuations seen in the San Juan Islands from June to November. During the June- July months of 2021, only 22 Spionids were collected using the plankton towing methods around Friday Harbor and the San Juan Channel.

I found more biodiversity of taxa in False Bay. The Spionid accounted for the majority of polychaete larvae found, possibly because the polychaetes have cilia for mobility, they would be able to survive the variability of weather in False Bay. There is a lot of area for the marine worms to live and reproduce, even if the abundance is lower than Beaverton Cove.

The absence of larvae of other polychaete families found in False Bay compared to the spionid is not surprising, since there are not many species reproducing in the fall and winter, while the brooding and spawning season for most spionids begins in the summer and ends in October. Again, due to the extreme fluctuations in weather, this could have allowed polychaetes to brood or spawn earlier or later in the season. I also did not sample close to the intertidal zone which could account for some of the small numbers. Climate change can influence larvae dispersal from the site of larval release to the site of settlement by exposing larvae to a new environment, affecting the phenology of their release, as well as their feeding, growth, development, behavior, mortality, habitat selection, and transport. (Bashevkin *et al.* 2020).

My results show mostly adult copepods in False Bay versus younger copepods (Nauplii) around Beaverton Cove. The amount of rain from False Bay Creek draining into False Bay may have led to the dilution of numbers found, especially since most of the samples were collected after the major flooding event (November 15, 2021). Freshwater sits on top of saltwater; the plankton tows may not have reached far enough into the water column to capture much marine zooplankton. Given these patterns, there were low densities of zooplankton.

The main copepod species collected were Calanoida which mate and carry their broods until they hatch out as Nauplii. The results show more abundance of some species at Beaverton Cove but less evenness due to the large dominance of one taxon, the Copepod Nauplii. The results from Beaverton Cove show that Tow 5 has much less Nauplii possibly due to the location, which is where Beaverton Creek offloads freshwater and this sample was taken after the flooding in Friday Harbor and possibly washed out the zooplankton in that sampling site.

I hypothesized that there would be greater diversity and abundance of zooplankton at Beaverton Cove because it was a more stable environment and has nutrient availability from freshwater drainage. The reproductive seasons, nutrient availability, and stressors like heat and rain could affect the results. The San Juan Islands had large amounts of rainfall and some flooding during our term here in the fall (Figure 6). There was also extreme weather in the summer of 2021 where there was a heat wave, therefore further samples should be collected throughout the seasons so that there is a cumulative collection of data to study.

Research done at Friday Harbor by the 2021 Summer Invertebrate Zoology class shows 43.4% Nauplii and 28% Copepods (Schwartz 2021). Research done this fall by another student in the Pelagic Ecosystem Function (PEF) apprenticeship course sampled around the San Juan Channel and Strait of Juan de Fuca. Out of 11 samples, his findings show that the Copepod and Nauplii were the most abundant at 76% Copepod and 10% Nauplii (Siahaan 2021). This is similar to my findings at False Bay. Because ocean currents are a driver of marine dispersal the seawater coming into False Bay from the Haro Strait could account for the similarity.

Future researchers might continue to sample plankton both at False Bay and around Friday Harbor during the year to create a more robust record. The rising temperatures related to climate change can directly or indirectly alter ocean pH, salinity, and dissolved oxygen. I suggest collecting species data, possibly by DNA metabarcoding, monitoring water flow, temperature, salinity, and nutrients in each location to have a more well-rounded collection of data to see any patterns and correlations that may exist.

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