Marine Conditions 2008–2019 Report Series: Zooplankton

December 2022

King County

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Acknowledgements

The author would like to thank the King County Environmental Laboratory Field Science Unit for sample collection and Lyndsey Swanson for technical coordination of the zooplankton samples. Katherine Bourbonais and Erin McCabe provided laboratory project management.

BethElLee Herrmann, University of Washington School of Oceanography, conducted the nonmetric multidimensional scaling ordination analysis and provided figures. BethElLee Herrmann and Amanda Winans, University of Washington School of Oceanography, processed and identified all the zooplankton samples.

Dr. Julie Keister, Amanda Winans, and BethElLee Herrmann, University of Washington School of Oceanography, provided report technical review and Dr. Keister provided project management for King County's zooplankton monitoring component.

Citation

King County. 2022. Marine Conditions 2008–2019 Report Series: Zooplankton. Prepared by Kimberle Stark, Water and Land Resources Division, Seattle, Washington.

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1.0 INTRODUCTION

For over 50 years, King County has conducted extensive water quality monitoring to assess conditions in King County marine waters within the Central Puget Sound Basin. The King County Marine Monitoring Program is managed by scientists in the Water and Land Resources Division within the Department of Natural Resources. The program includes two types of monitoring (1) baseline monitoring to assess background conditions (ambient monitoring) and (2) monitoring to assess conditions near King County's wastewater treatment plant (TP), combined sewer overflow (CSO), and CSO wet weather treatment station (TS) marine outfalls (outfall monitoring).

The goals of the Marine Monitoring Program are to characterize water quality and food web (phytoplankton and zooplankton) conditions in King County receiving waters, provide information for management decisions, and evaluate the status and trends of marine waters within King County. These data provide insight into both short and long-term variations and form a baseline from which water quality and food web conditions can be assessed on multiple temporal and spatial scales. Please see *Marine Conditions Report Series 2008–2019: Marine Monitoring Program Overview* (King County, 2022) for a more detailed description of the background and purpose of the Marine Monitoring Program.

The Marine Monitoring Program collects data for multiple types of media and parameters. This report presents results for the zooplankton monitoring component collected between 2014 and 2019. Zooplankton data are used to:

- Provide an understanding of the Puget Sound Central Basin food web lower trophic levels.
- Catalog and quantify zooplankton present in the Central Basin on varying spatial and temporal scales.
- Measure variability in community structure, abundance, and biomass over seasonal and interannual cycles.
- Assist in development of ecosystem and food web function indicators.
- Assess influences of large-scale and regional climate patterns on zooplankton community composition and abundance.
- Evaluate how zooplankton respond to climate and water conditions and primary producers (phytoplankton).
- Support regional efforts and collaborations such as the Puget Sound Ecosystem Monitoring Program (PSEMP) Forage Fish and Food Web Workgroup, Puget Sound Marine Waters Annual Report (PSEMP Marine Waters Workgroup, 2019), Puget Sound Zooplankton Monitoring Program, and regional modeling efforts.

King County's zooplankton sampling targets mesoplankton, which are organisms larger than 200 micrometers (μm). Mesoplankton are a diverse group that includes organisms that remain in the water column for their entire life cycle (such as copepods and jellyfish)

or are only in the water column during larval stages (such as crabs and marine worms). Zooplankton are important prey for many fish, including juvenile salmonids and forage fish, and other marine animals. Zooplankton consume phytoplankton and are an important link transferring carbon and energy to higher trophic levels. Zooplankton are good ecosystem indicators as many factors, such as water circulation, temperature, salinity, phytoplankton, and predation affect their distribution and abundance.

Multiple parameters were collected concurrently with zooplankton samples. A summary of all data collected at each station is provided in *Marine Conditions Report Series 2008–2019: Marine Monitoring Program Overview* (King County, 2022). Results for other Marine Monitoring Program components sampled between 2008–2019, (except pH and thermosalinograph data), are provided in separate reports . These data summary reports are provided in separate reports with hyperlinks (click on titles to access reports) below and include the following topics:

- Marine Monitoring Program overview
- Nutrients in offshore waters
- Nutrients in beach waters
- Dissolved oxygen in offshore waters
- Temperature, salinity, and density in offshore waters
- Temperature and salinity in beach waters
- Water clarity in offshore waters
- Fecal indicator bacteria in beach and offshore waters
- Chlorophyll in offshore waters
- Phytoplankton
- Chemical and physical parameters and benthic infauna in beach (intertidal) and offshore (subtidal) sediments
- Chemical parameters in clam tissues.

2.0 METHODS

2.1 Sampling Locations

Zooplankton sampling locations are located within the Puget Sound Central Basin, extending south to East Passage and north to Pt. Jefferson (Figure 1).

Marine Monitoring Program stations are designated as either "outfall" or "ambient". Outfall stations are located at/near the end of a wastewater treatment plant (TP), wet weather treatment station (TS), or combined sewer overflow (CSO) discharge point. Ambient stations are located away from a known wastewater or stormwater discharge point to represent background conditions. Zooplankton samples from three ambient monitoring stations were collected between 2014 – 2019. Table 1 provides station information and Figure 1 shows zooplankton station locations and other concurrent sampling at those sites.

Table 1. Zooplankton monitoring stations, tow type, and first year of data collection.

Station Locator	Central Basin Region	Station Rationale	Tow Type	First Month/Year of Record	Average Station Depth (m)
KSBP01	north	Pt. Jefferson- represents conditions in north Central Basin	vertical oblique	April 2014 January 2016	262
LSNT01	middle	Pt. Williams- represents conditions in mid Central Basin	vertical oblique	April 2014 April 2014	205
NSEX01	south	East Passage-represents conditions in southern Central Basin	vertical	April 2014	173

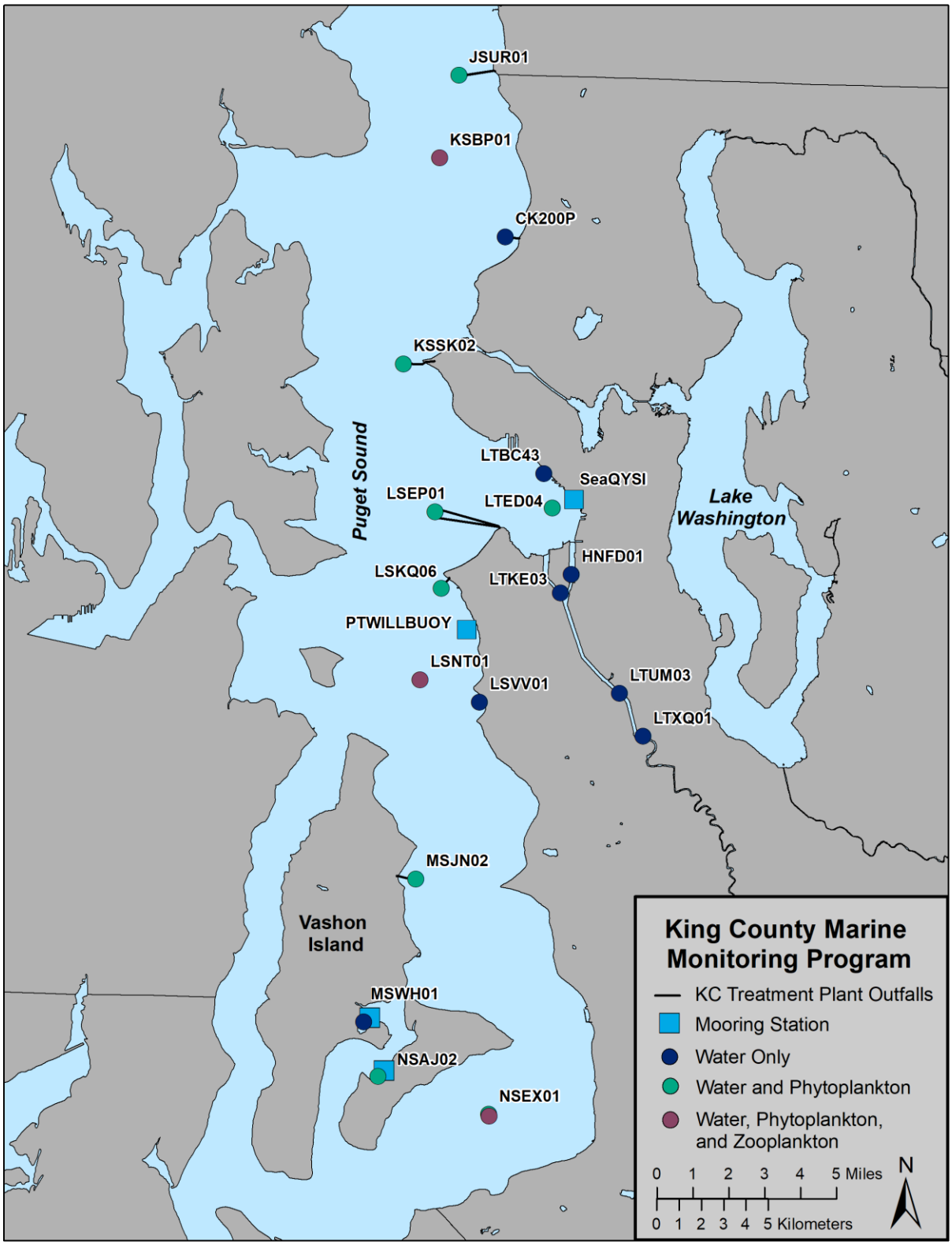

Figure 1. Zooplankton sampling locations (purple circles) relative to other sampling.

2.2 Sampling and Analysis Methods

Detailed zooplankton sample collection and laboratory methods are provided in the *Marine Zooplankton Monitoring Program Sampli*ng and Analysis Plan (SAP) (King County, 2015) and *King County Zooplankton Monitoring 2020 Annual Report* (Keister et al., 2021).

2.2.1 Field Methods

Zooplankton samples were collected during daylight hours by the King County Environmental Laboratory (KCEL) from a research vessel. Two types of sampling methods were used to collect zooplankton from two areas of the water column.

A vertical net tow was used to collect organisms from the full water column (200 m max. depth) at three stations (Pt. Williams - LSNT01, Pt. Jefferson - KSBP01 and East Passage - NSEX01). Results from these samples are used as an indicator of ecosystem and food web function.

The vertical net consists of a 60-cm ring net with 200-µm mesh and a 15.2 cm length cod end that captures smaller zooplankton and early life stages. The vertical net was allowed to sink to 5 m above the bottom (200 m max depth) and then immediately brought to the surface at a rate of 30 m/minute using the vessel's hydraulic winch. Vertical net samples were collected twice monthly April – October 2014, then twice monthly 2015 – 2019, except monthly in January and December. The entire water column was sampled at Pt. Williams (LSNT01) and East Passage (NSEX01). However, due to the depth at Pt. Jefferson (KSBP01) (>200 m), approximately 50-70 m of the lower water column was not sampled.

Oblique net tows were used to sample the upper 30 m of the water column at two stations (Pt. Jefferson - KSBP01 and Pt. Williams - LSNT01) to focus on the area where salmonids and other fish primarily feed. The oblique samples were collected using 60-cm paired ring (bongo) nets with 335-µm mesh and a 11.4 cm diameter by 30.5 cm length cod end, towed obliquely through the upper 30 m in a double-oblique (down and up) tow. The net was deployed at the surface, towed down to 30 m, and brought back up to the surface at 1.5-2 knots with a wire angle of 45°. The oblique tow captures larger zooplankton that are strong swimmers and can evade the vertical net tows. Oblique net samples were collected twice monthly April – October 2014 at Pt. Williams, then twice monthly 2015 – 2019, except monthly in January and December. Oblique samples were collected at Pt. Jefferson starting in January 2016 and were collected during the same timeframe as LSNT01.

Flow meters were attached to the vertical and oblique ring nets to quantify the water volume sampled for each tow. A depth sensor was attached to the bongo nets to accurately record tow depth and determine if the target depth was achieved. After the nets were brought to the surface, they were gently rinsed with seawater and the contents transferred to polypropylene jars. Oblique tow samples were collected from one of the paired bongo nets and zooplankton captured in the other net were deposited back in the water. Organisms were immediately preserved using buffered formalin diluted in seawater to achieve a final concentration of approximately 5% formalin (pH 8.2).

2.2.2 Analytical Methods

Zooplankton samples were sent to Dr. Julie Keister's laboratory at the University of Washington for processing and analysis to determine abundance and biomass. Samples were processed in the laboratory by first briefly examining the entire contents and removing the rare and large organisms (e.g., large jellyfish), once documented. When abundance was very high, samples were split into subsamples with a Folsom plankton splitter. The whole or subsamples were then diluted to a known volume and two 10-mL aliquots were removed for analysis. A larger aliquot (10 – 40 ml) was taken to quantify the mid-size taxa not adequately subsampled by the smaller aliquots. All organisms in subsamples were identified, quantified, and lengths measured (for specific taxa) using microscopy. For certain taxa, life stage was also determined,

Organisms captured in vertical tow samples were identified to the species level whenever possible for most taxonomic groups, including amphipods and copepods. Life stages of copepod and crab larvae were also identified. Lengths of up to 30 individuals for specific taxa were measured using established length-weight relationships to estimate biomass. Length and weight of all larval fish were measured.

Broader taxonomic groups were identified in the oblique tow samples and abundance and biomass quantified. Zooplankton were identified to species level for some amphipods, large copepods, mysids, euphausiids, and decapod crabs. Life stages for some copepods, krill, and crabs were also identified and quantified in oblique tow samples. Up to 30 individuals of a specific taxa were measured to estimate biomass. Length and weight of all larval fish were measured.

Data from both tow types were aggregated into 40 broad taxonomic groups (e.g., copepods, hydrozoans, chaetognaths, krill adults, krill furcilia, etc.). Detailed laboratory methods and a list of all zooplankton taxonomic groupings and life stages that were differentiated can be found in the most recent zooplankton annual report, *King County Zooplankton Monitoring Annual Report 2020* (Keister et al., 2021).

2.2.3 Data Analysis Methods

Prior to laboratory analysis, oblique net tow depth sensor data were reviewed to ensure the target depth was achieved and each tow was assigned a 'high', 'moderate', or 'low' collection confidence qualifier. Vertical net tow flow meter data were reviewed for accuracy and assigned the same collection confidence qualifiers. No data were assigned a low confidence qualifier, and all were deemed usable. Data validation included data review by two taxonomists to verify identification and length measurements.

Eggs of various taxa and copepod nauplii collected in both sample types were not included in the abundance analyses as they are both temporally and spatially patchy and can be present in very high numbers, skewing results. The large heterotrophic dinoflagellate, *Noctiluca scintillans*, was only included in the species richness metric for the same reason. Krill nauplii and metanauplii were only included in vertical tow sample results as the larger

mesh size of the oblique net may not capture an accurate representation of these life stages. Siphonophore gonophores are a reproductive component of the small hydrozoan, *Muggiaea atlantica*, and are not considered individuals. Therefore, siphonophore gonophores were not included in abundance analyses but were included in biomass results.

To calculate monthly average abundance for each station and year, results for the two samples collected in a given month (when available) were averaged to obtain a single monthly average. These monthly averages were then used to calculate annual averages.

Species richness, a measure of diversity, was calculated for each sample. Eggs and the 'unknown' category were excluded and taxa listed as 'large' and 'small' were combined. Life stages were disregarded for this calculation. Species richness for each month was determined by counting the number of unique taxa present. If a species/taxa was present in one or both of the two sampling events per month, it was only counted once.

Nonmetric multidimensional scaling (NMDS), an ordination analysis, was used to visualize the zooplankton community among sites, months, and years using PC-ORD©. Sample matrices were created using broad taxa groupings. As some taxa were very abundant while others rare, data were normalized using a logarithmic transformation and rare taxa (< 5 occurrences) were removed prior to analysis. Ordinations were conducted using the Sørensen (Bray-Curtis) distance measure for three axes and the resulting sample cloud was freely rotated.

3.0 RESULTS

3.1 Total Abundance and Biomass

Total abundance from 2014 -2019 for the vertical tows ranged from a low of 178 individuals (#) m^{-3} at East Passage (NSEX01) to a high of 13,563 m^{-3} at Pt. Jefferson (KSBP01) (Figure 2). The highest overall abundance was seen at Pt. Jefferson with an average abundance of 3,813 m^{-3} per sample compared to 2,721 and 2,690 m^{-3} for Pt Williams (LSNT01) and East Passage, respectively.

Zooplankton abundance was higher in vertical tow samples than in oblique tow samples for all but 6 sampling events at Pt. Jefferson (KSBP01) and 12 at Pt. Williams (LSNT01). This primarily indicates that the zooplankton community is numerically dominated by small taxa and life stages that are captured better with the smaller mesh size of the vertical sampling net. Half of the samples when abundance was higher in oblique samples occurred in 2019.

Total abundance from 2014 -2019 in the oblique tow samples from Pt. Williams (LSNT01) ranged from a low of 55 m^{-3} in December 2015 to a high of 8,029 m^{-3} in July 2019 with an average abundance of 1,276 m^{-3} (Figure 2). Total abundance from 2016-2019 for the oblique tow samples from Pt. Jefferson (KSBP01) ranged from a low of 93 m^{-3} in February 2017 to a high of 5,955 m^{-3} in June 2016 with an average of 1,593 m^{-3} (Figure 2).

The timing of peak abundance varied in vertical tow samples. Peak abundance typically occurred in July followed by a second peak in August or early September at both Pt Jefferson (KSBP01) and Pt. Williams (LSNT01) except in 2017 and 2018. The exceptions to this pattern at Pt. Jefferson occurred in 2017 when the peak was in June followed by sustained high abundance early August through early September and in 2018, when only one peak in July was observed. A peak in abundance at Pt. Williams was seen in early July 2015 but the highest peak occurred in early August. In 2017 at LSNT01, peak abundance was delayed until late August and a second peak was seen in late September. The most variation was seen at East Passage (NSEX01) where peak abundance timing varied most years. The highest abundance at East Passage was seen in August all years except 2014 and 2018, but the earlier spring/summer peak in abundance varied between years.

Variability in timing of peak abundance in oblique tow samples was greater than in vertical tow samples although results generally exhibited a bimodal annual pattern. Oblique tows capture taxa that are stronger swimmers and have a more patchy distribution than vertical tows, contributing to higher variability.

Peak abundance in Pt Williams oblique tow samples during 2014, 2015, and 2017 occurred in early July with a second peak in early August (early September in 2017). The 2016 peak occurred in early April with another peak in late June and another small peak in late August. While only one peak was detected in 2018 (early May), small peaks in early May and June and a large peak in late August occurred in 2019.

The first peak in abundance for the year at Pt. Jefferson (KSBP01) typically occurred earlier than at Pt. Williams (LSNT01). The 2016 pattern at KSBP01 was like that seen at LSNT01 except the first small peak occurred in early May. The first peak in 2017 was seen in early June and in early May for 2018. The pattern in 2019 was similar to that seen at Pt. Williams in that two small peaks were seen in the spring (early April and May), with the highest peak in early July.

Results for total biomass in vertical tow samples indicated a pattern similar to the abundance results pattern. Highest overall biomass was measured at Pt. Jefferson (KSBP01) with maximum and average values of 77 and 22 mg/m^3 Carbon (C) compared to maximums of 50 (average=13) and 38 (average=12 mg/m^3 C for LSNT01 and NSEX01, respectively (Figure 3).

Total biomass in oblique tow samples from Pt Williams (LSNT01) ranged from a low of 0.54 mg/m^3 C in October 2018 to a high of 80 mg/m^3 C in July 2019 with an average of 12 mg/m^3 C. Total biomass in oblique tow samples from Pt. Jefferson ranged from a low of 0.9 mg/m^3 C in February 2017 to a high of 79 mg/m^3 C in June 2016 with an average of 18 mg/m^3 C (Figure 3).

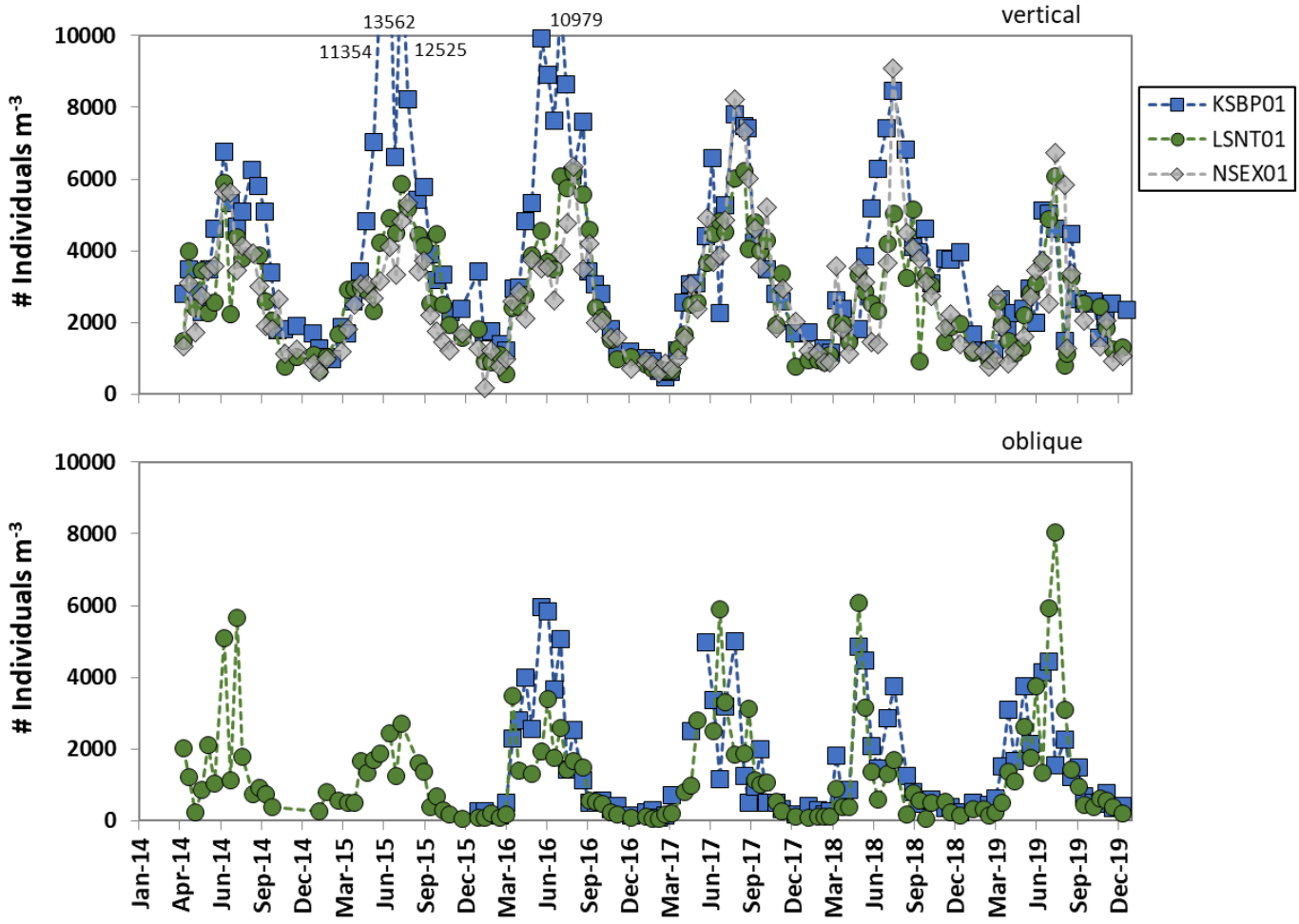

Figure 2. Total zooplankton abundance in samples collected with vertical and oblique tows by station and date (2014-2019).

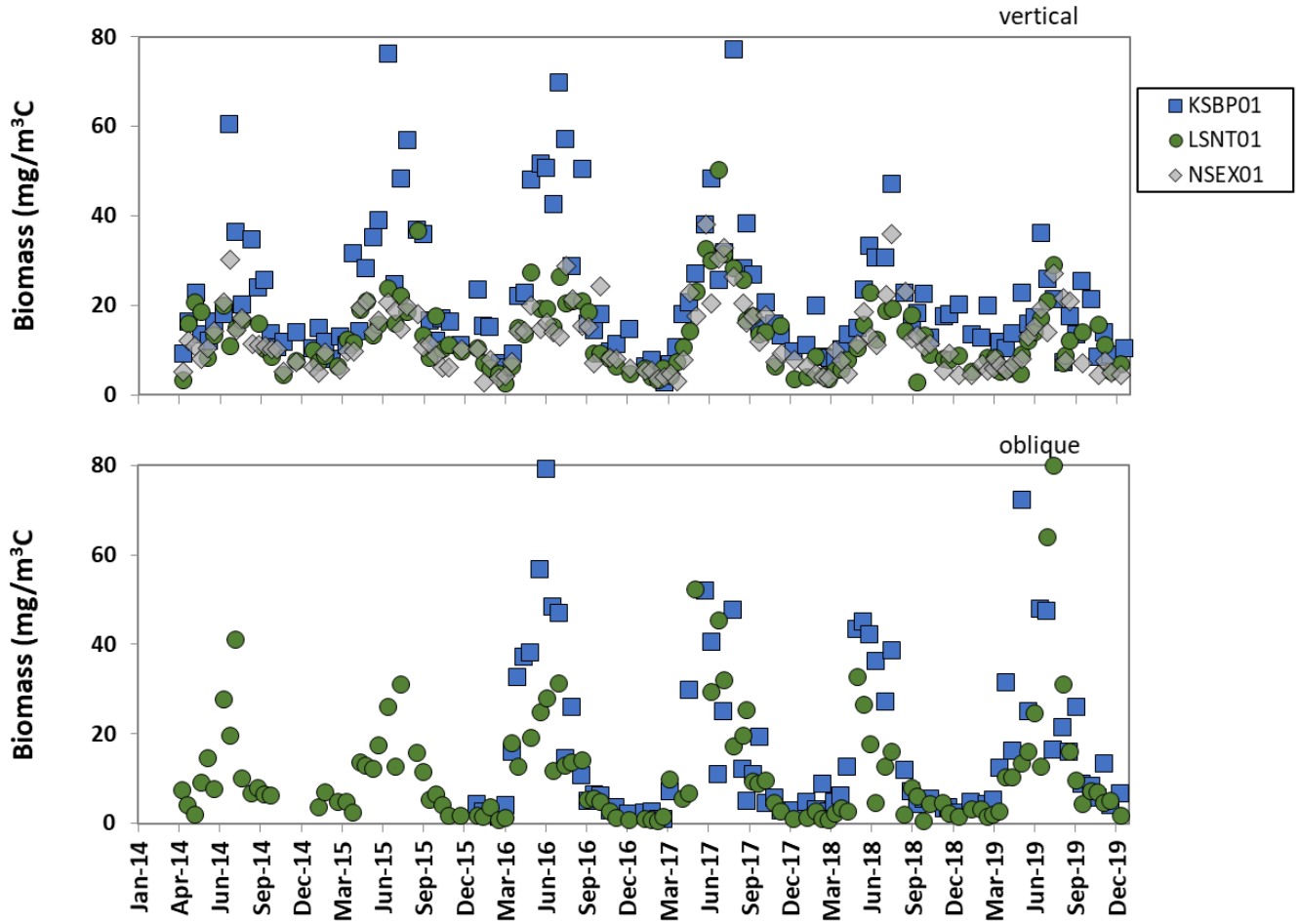

Figure 3. Total zooplankton biomass in samples collected with vertical and oblique tows by station and date (2014-2019).

Annual Results

Annual total zooplankton abundance in vertical tow samples was highest in 2015 and 2016 (marine heat wave years) at Pt. Jefferson (KSBP01) and highest in 2015-2017 at Pt. Williams (LSNT01), and 2017 at East Passage (NSEX01). The lowest annual abundance was measured in 2014 and 2019 at all sites (Figure 4).

Total annual abundance in oblique tow samples showed less variability and a different annual pattern with the highest total in 2019 at Pt. Williams. Of the four years sampled at Pt. Jefferson, the highest abundance was in 2016. Total annual biomass showed a similar pattern as abundance in both tow types. Figure 4 shows monthly average abundance and biomass for the vertical tows and Figure 5 for the oblique tows.

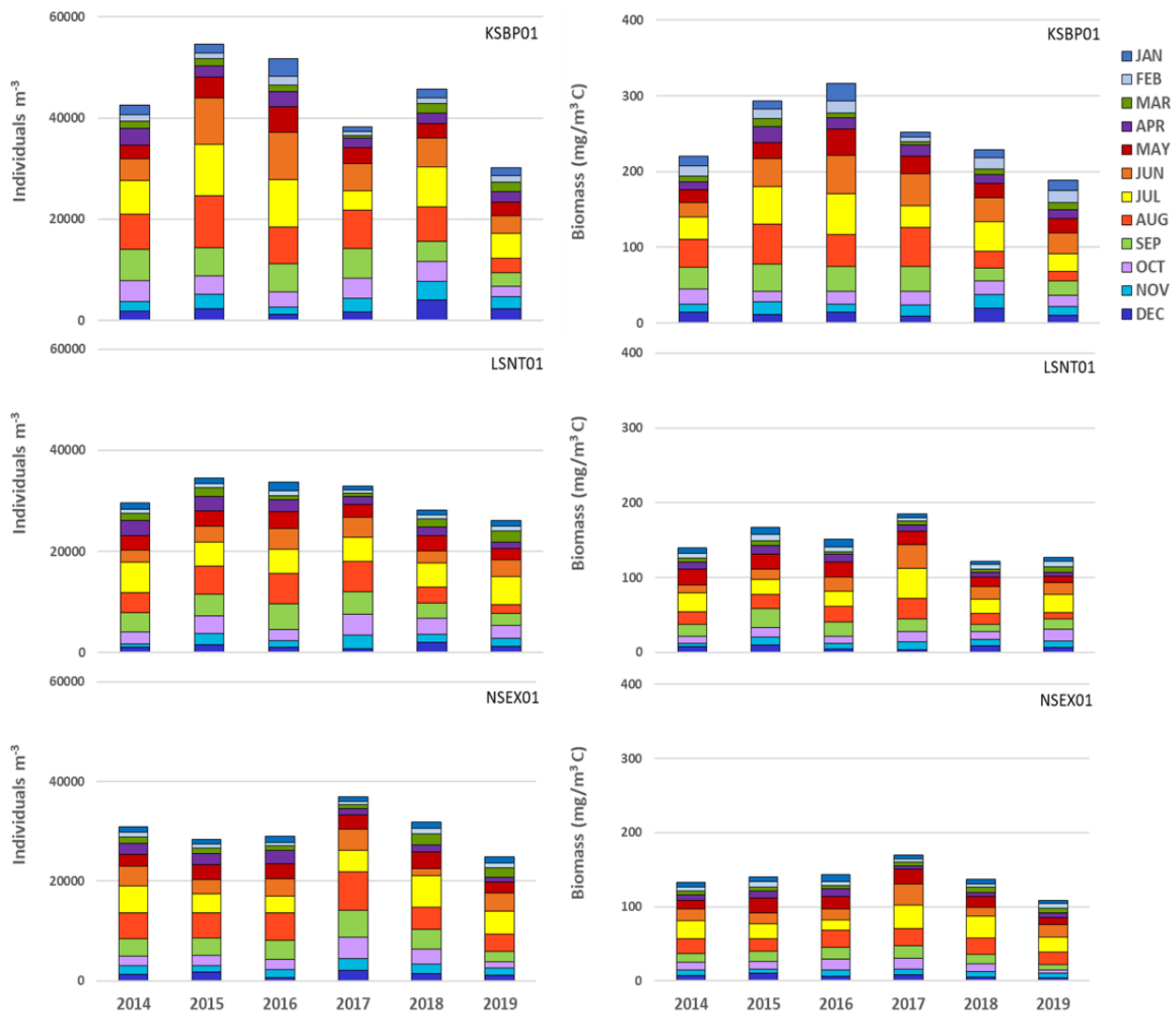

Figure 4. **Monthly average and annual zooplankton abundance and biomass for samples collected by vertical tow, by station (2014 - 2019). Note sampling started in April 2014, therefore, the 2015-2019 average for January-March were included in 2014 results to show annual totals but are likely biased for these months**

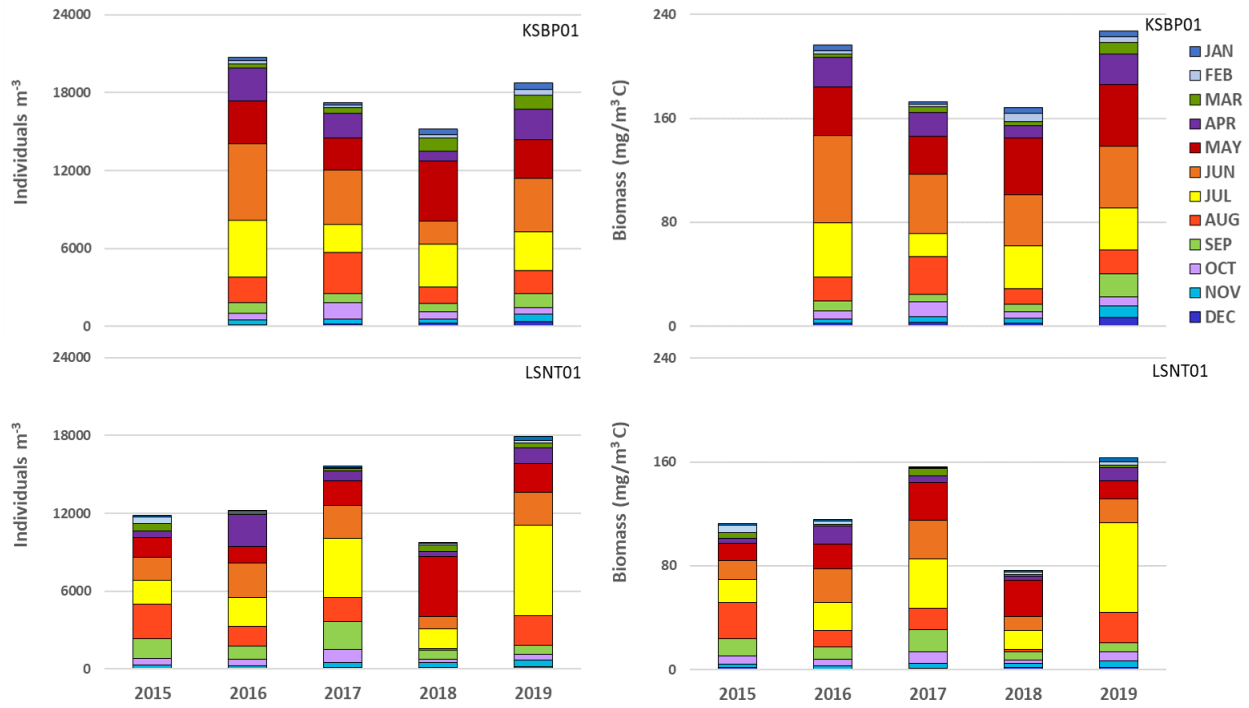

Figure 5. Monthly average and annual zooplankton abundance and biomass for samples collected by oblique tow, by station (2015 - 2019). 2014 data not shown since LSNT01 only sampled Apr-Oct.

Monthly Results

The timing of the highest average monthly total zooplankton abundance in vertical tow samples varied between years and stations; however, highest abundance was measured in June - September at all sites (Figure 4). June through August had the highest abundance during the marine heat wave years (2015 and 2016) at Pt. Jefferson (KSBP01), with 2019 having the lowest abundance April - October compared to other years. While abundance was also high at Pt. Williams (LSNT01) during the marine heat wave conditions, it wasn't as anomalously high as was seen at Pt Jefferson and even less noticeable at East Passage (NSEX01). Compared to other years, monthly abundance in 2017 was high later in the year (August - November) at Pt. Jefferson and low abundance was seen August - October in 2019. The pattern of monthly abundance was different at East Passage compared to the other sites. Compared to other years, notable increases in abundance occurred from August - December in 2017.

Variability between months and stations was higher in oblique tow samples during periods of high abundance. Clear spatial differences in monthly abundance were seen between Pt. Jefferson (KSBP01) and Pt. Williams (LSNT01). Relative to other years, abundance was higher most months in 2016 at Pt. Jefferson; the highest abundance (2014 - 2019) was measured in June. Abundance in August 2017 and May 2018 was also higher than other years for those months. There was considerable variation in monthly abundance between years at Pt. Williams.

3.2 Abundance of Dominant Taxa

Of the 37 taxa identified in vertical tow samples and 33 taxa in oblique tow samples, 9 broad taxonomic groups were most abundant. In the vertical tow samples, these 9 taxa made up 74.4–99.7% (median = 93.2%) of the total abundance for each sample. Although different taxa dominated in the oblique tows, the 9 taxa made up 60.6–99.9% (median = 93.6%) of the total abundance for each sample. Figure 6 through Figure 9 show the most dominant taxa for both abundance and biomass in both tow types.

Copepods were by far the most abundant taxa in all samples for both vertical and oblique tows. Copepods are the main food web (trophic) link between primary producers (phytoplankton) and higher trophic levels and play a key role in salmon recovery. As with most taxa, copepods exhibited a seasonal cycle. The highest copepod abundance in vertical tow samples was typically seen from June - September. While copepod abundance and biomass were similar at Pt. Williams (LSNT01) and East Passage (NSEX01), they were much higher at Pt. Jefferson (KSBP01). Average monthly copepod abundance in vertical tow samples was highest at Pt. Jefferson (KSBP01) June - August, while highest July - September at the other sites. Copepods were particularly abundant in vertical tow samples from KSBP01 during warm water years (2015, 2016, and 2018) from June - August. The period of highest recorded abundance was measured in 2015 during those months. In contrast, copepod abundance in early 2017 was 27–62% lower at Pt. Jefferson than for the remaining period of record. The other two sites did not show the same increase during warm water years but copepod abundance was notably high in the vertical tow samples in August 2017 and July 2019 at Pt. Williams and lower than normal during early 2017 at both Pt. Williams and East Passage.

Oblique tow sample results indicated more variation than seen in vertical tow samples, in part due to the upper water column sampling method not capturing deeper copepods However, the highest abundance was typically seen in June and July samples from Pt. Jefferson (KSBP01) and July and August at Pt. Williams (LSNT01). Copepod abundance in oblique tow samples from Pt. Williams was anomalously high in July 2017 (2.7–4.5x higher) and 2019 (4.9–8.3x higher) compared to other years.

As with copepods, amphipods were more abundant in both types of tow samples at Pt. Jefferson (KSBP01) than in samples from other sites Peaks in abundance typically occurred in July in oblique tow samples and August in vertical tow samples at all sites. An unusually large peak (1,241 ind/m^3) occurred in the early August 2017 vertical tow sample from Pt. Jefferson and abundance was atypically high throughout October 2017 at Pt. Williams (LSNT01). Amphipod abundance was high in vertical tow samples at Pt. Jefferson, particularly from 2014-2016; lower abundance was observed in 2019 (Figure 10).

Several taxa, including bryozoans, polychaetes, bivalves, and larvaceans, were more abundant in both tow types at both Pt. Williams (LSNT01) and East Passage (NSEX01) than at Pt. Jefferson (KSBP01) (Figure 6 and Figure 7). Polychaetes in vertical tow samples decreased at all stations starting in early fall of 2016 and have remained low. Bivalve abundance was high in vertical tow samples from all sites in 2016 but levels have

subsequently decreased each year. There appears to be a spatial time lag in peak abundance for several taxa (e.g., bivalves and bryozoans) in vertical tow samples between Pt. Williams and East Passage, with peaks at East Passage occurring one to two months later depending on the taxon. A similar time lag was also evident in oblique tow samples for several taxa, with abundance peaking later at Pt. Williams than Pt. Jefferson.

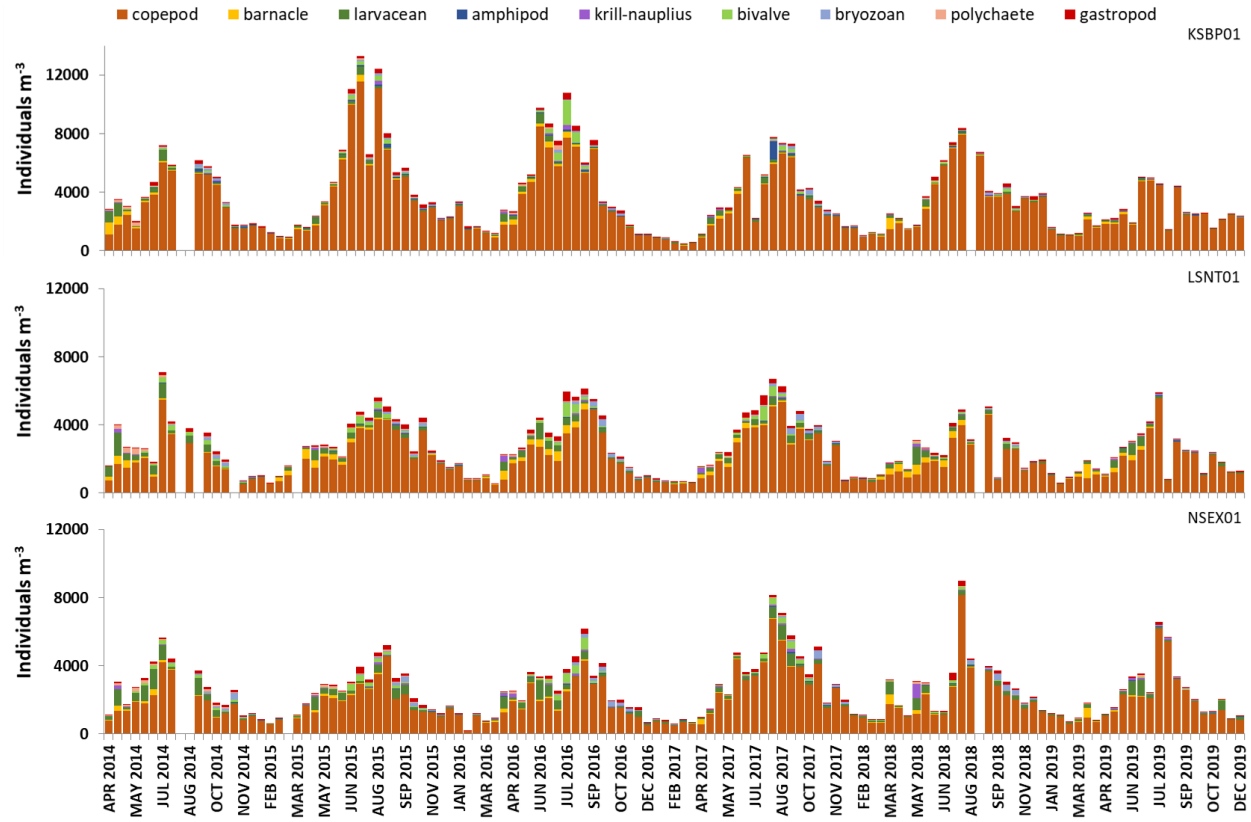

Figure 6. Abundance of most dominant broad zooplankton taxa in samples collected by vertical tow, by station and date (2014 - 2019).

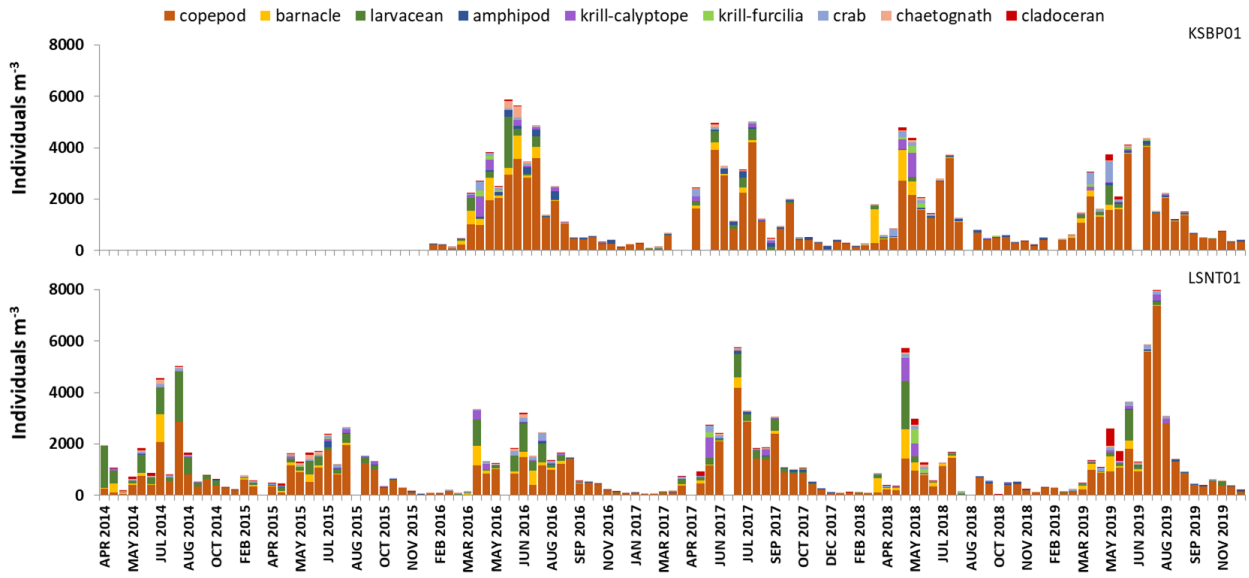

Figure 7. Abundance of most dominant broad zooplankton taxa in samples collected by oblique tow, by station and date (2014 - 2019).

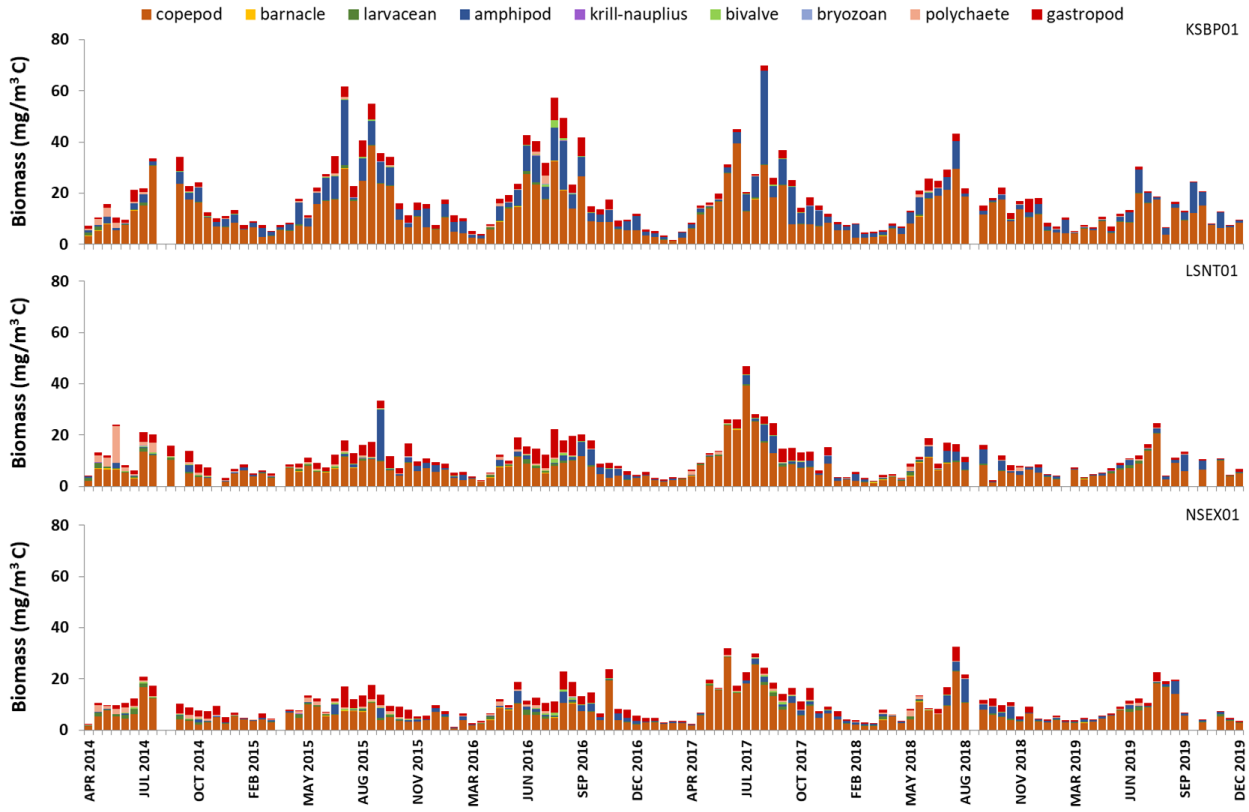

Figure 8. Biomass of most dominant broad zooplankton taxa in samples collected by vertical tow, by station and date (2014 - 2019).

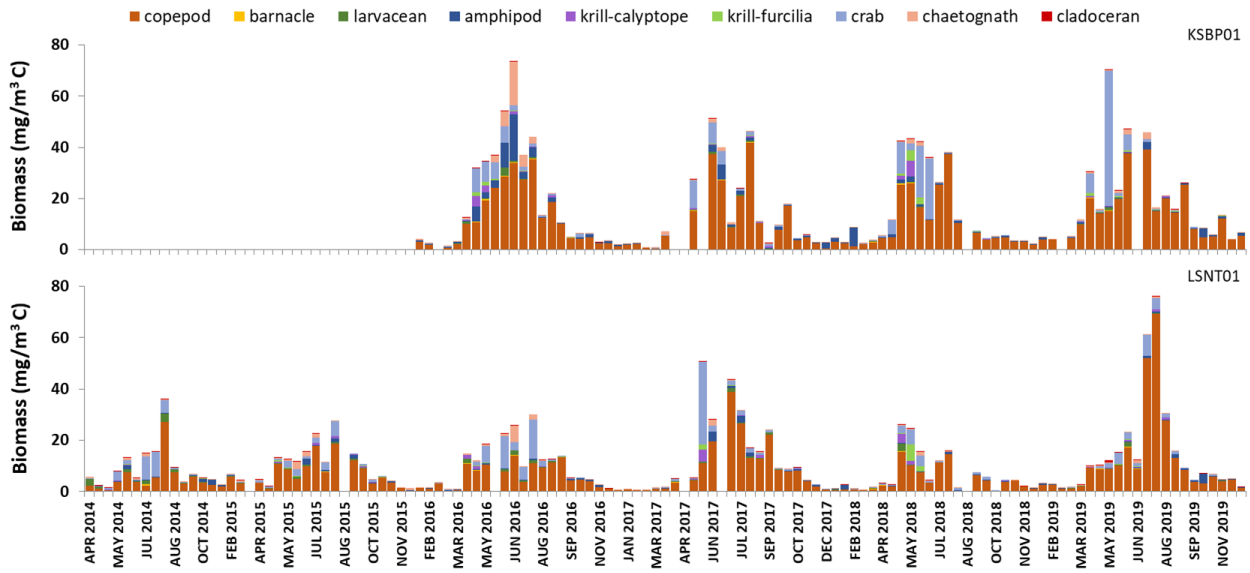

Figure 9. Biomass of most dominant broad zooplankton taxa in samples collected by oblique tow, by station and date (2014 - 2019).

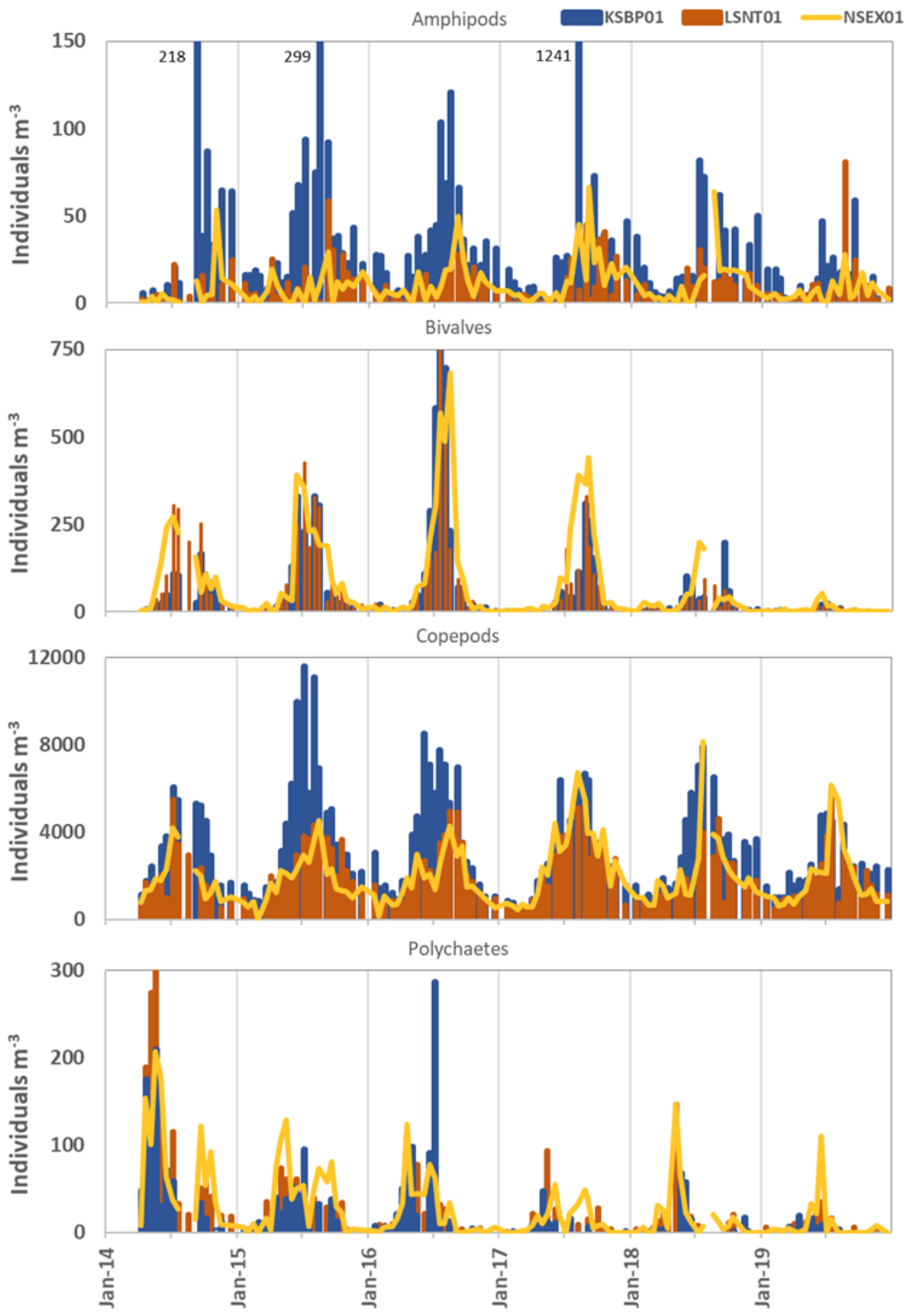

Figure 10. Abundance of select broad zooplankton taxa in samples collected by vertical tow, by station and date (2014 - 2019).

3.3 Taxonomic Composition

Taxa (species richness) is a measure of diversity and number of taxa, or species, present in each sample. A higher species richness value indicates more species were present. To calculate species richness for each tow sample type, eggs and the 'unknown' category were excluded from each sample and taxa listed as 'large' and 'small' were combined. Life stages were disregarded for this calculation. Taxa richness for each month was determined by counting the number of unique taxa in both types of samples combined. If a species/taxon was present in one or both of the two sampling events per month, it was counted once. Taxonomic resolution was higher for vertical tow samples with more organisms identified to species level. Some taxa in oblique tow samples were identified to the subclass level. Due to differences in taxonomic resolution, richness values for vertical and oblique tow samples are not directly comparable.

Overall taxa richness in vertical tow samples was highest April - June, particularly at Pt. Williams (LSNT01) (Figure 11). The highest value observed (79) was at this site in May 2014. Richness at all sites started to decline in July and was relatively similar throughout the rest of the year with a slight increase in October. Richness was higher during marine heat wave years at Pt. Jefferson (KSBP01) and East Passage (NSEX01), particularly in the spring. Richness values in 2019 were high early in the year but then declined to some of the lowest levels seen late in the year (August- December). Considerable variation in taxa richness was seen between sites and years.

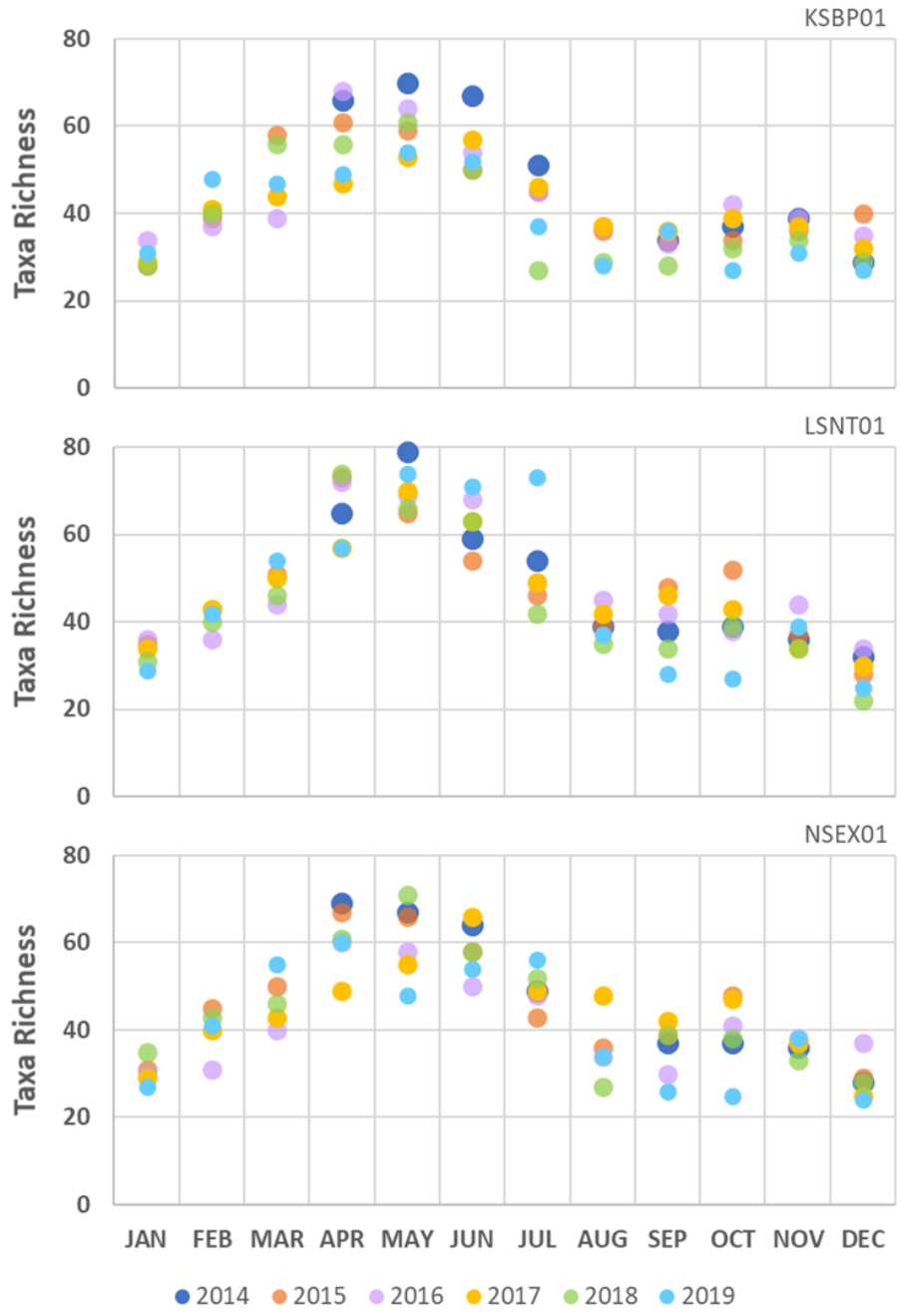

Figure 11. Monthly zooplankton taxa richness in samples collected by vertical tow by station and year (2014 - 2019).

Taxa richness in oblique tow samples was lower than in vertical tow samples. As previously discussed, the depth of the oblique tow (30 m) does not capture organisms in the entire water column or organisms that undergo diel vertical migration. Except for 2019, the pattern of seasonal taxa richness in oblique tow samples was similar to that seen for vertical tow samples (Figure 12). Unlike the 2019 results for vertical tow samples, richness values for oblique tow samples collected in 2019 were low throughout much of the year,

not just fall through winter months. Taxa richness between years (2014-2019) and sites and sample types are summarized in Figure 13.

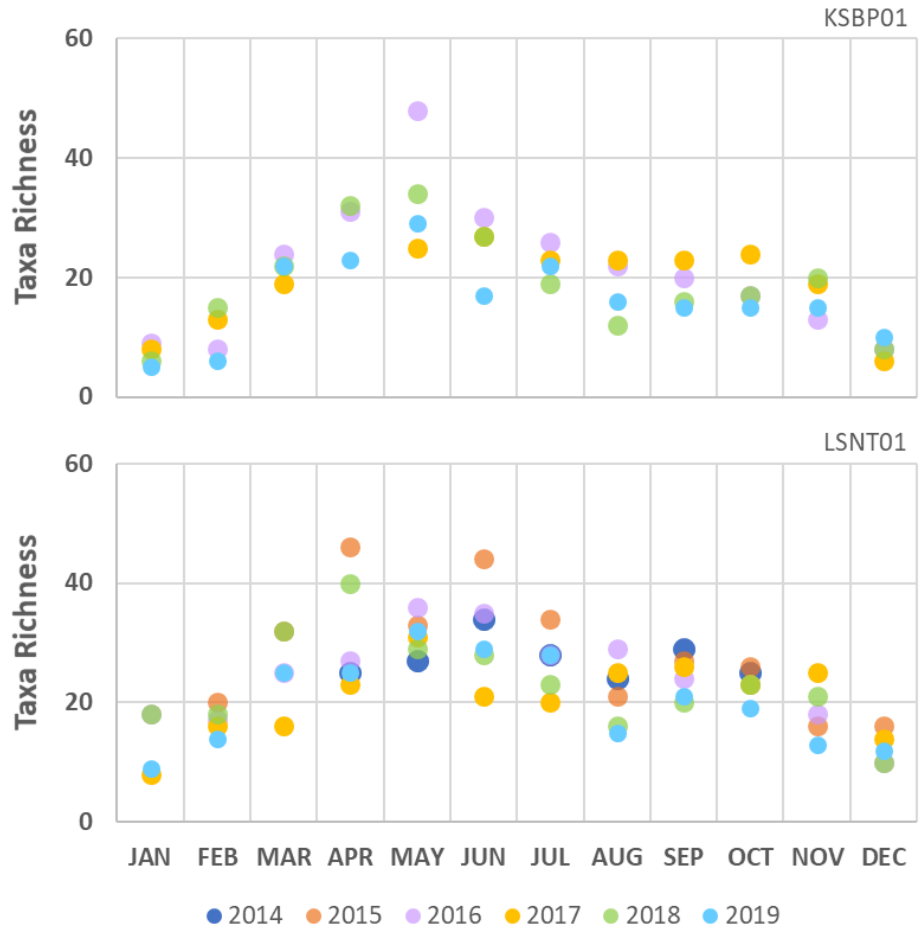

Figure 12. Monthly zooplankton taxa richness in samples collected by oblique tow, by station and year (2014 - 2019). Note sampling at KSBP01 started in 2016.

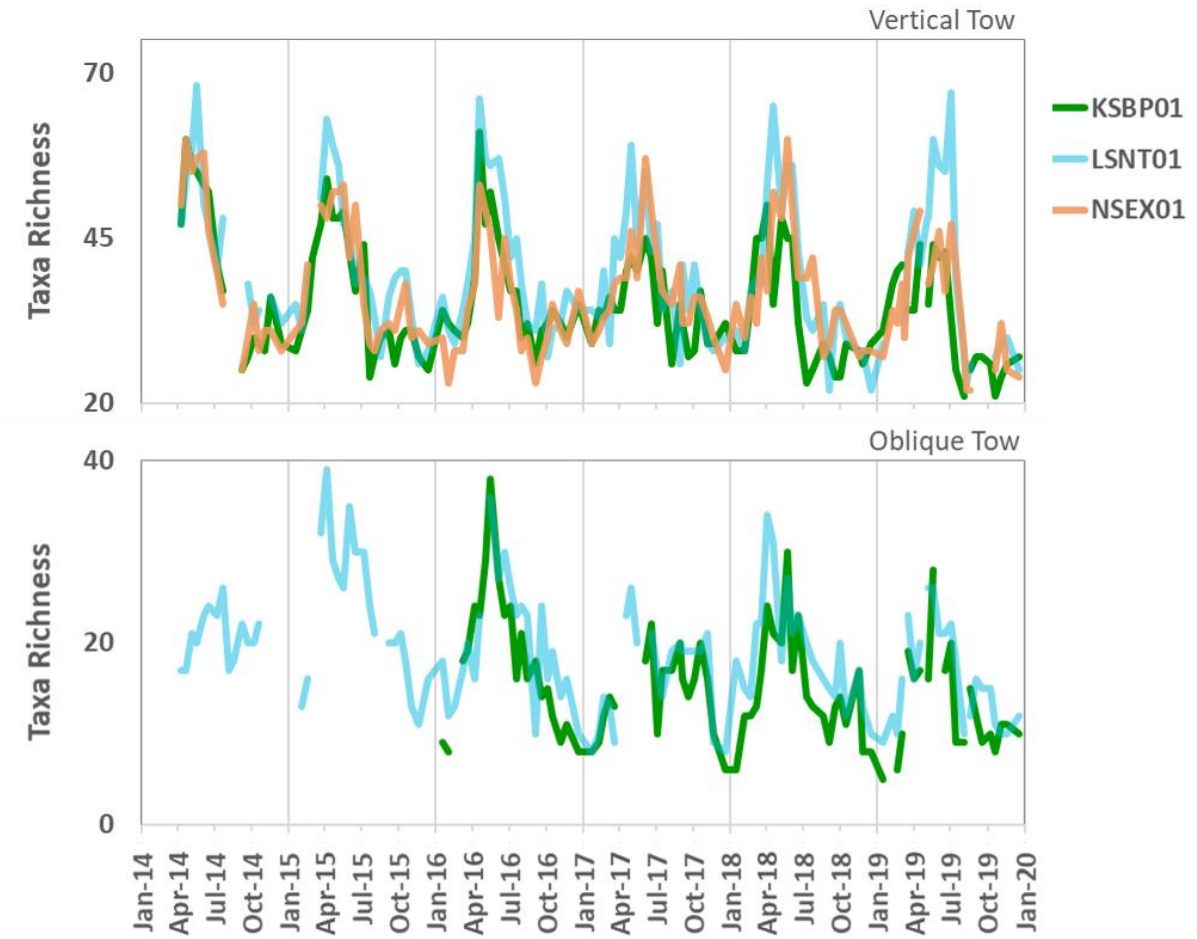

Figure 13. Zooplankton taxa richness in samples collected by oblique and vertical tows by station and date (2014-2019) . Note difference in Y-axis scale.

Nonmetric multidimensional scaling (NMDS), an ordination analysis, was used to visualize the zooplankton community between sites, months, and years (2014 - 2019) using PC-ORD©. Sample matrices were created using broad taxa groupings. As some taxa were very abundant while others rare, data were normalized using a logarithmic transformation and rare taxa (< 5 occurrences) were removed prior to analysis. Ordinations were conducted using the Sørensen (Bray-Curtis) distance measure for three axes and the resulting sample cloud was freely rotated. The distance between points in the ordination indicate the level of dissimilarity between communities, with points furthest apart the most dissimilar and points closest together the most similar. Axes 2 and 3 carried the most variance in vertical tow samples when rotated and axes 1 and 2 for the oblique tow samples.

The ordinations for vertical tow samples showed a clear distinction in the zooplankton community between Pt. Jefferson (KSBP01) and the other sites, which were more like each other. There was also a distinct seasonal cycle among all sites with the spring months (March - June) having a different composition than the fall and winter months. The greatest variability was seen during fall particularly for Pt. Jefferson and East Passage (NSEX01).

There was less distinction between years, however, taxa composition in 2017-2019 was more dissimilar to 2014-2016 (Figure 14).

The ordinations for oblique tow samples showed less distinction in community composition between the two stations than for vertical tow samples. However, a distinct seasonal cycle similar to that seen for the vertical tow samples was observed; taxa composition in spring months was different than in fall and winter months (Figure 15). Variability was highest during fall. Ordinations were not run for years as oblique tow samples were not collected until 2016 at Pt. Jefferson (KSBP01).

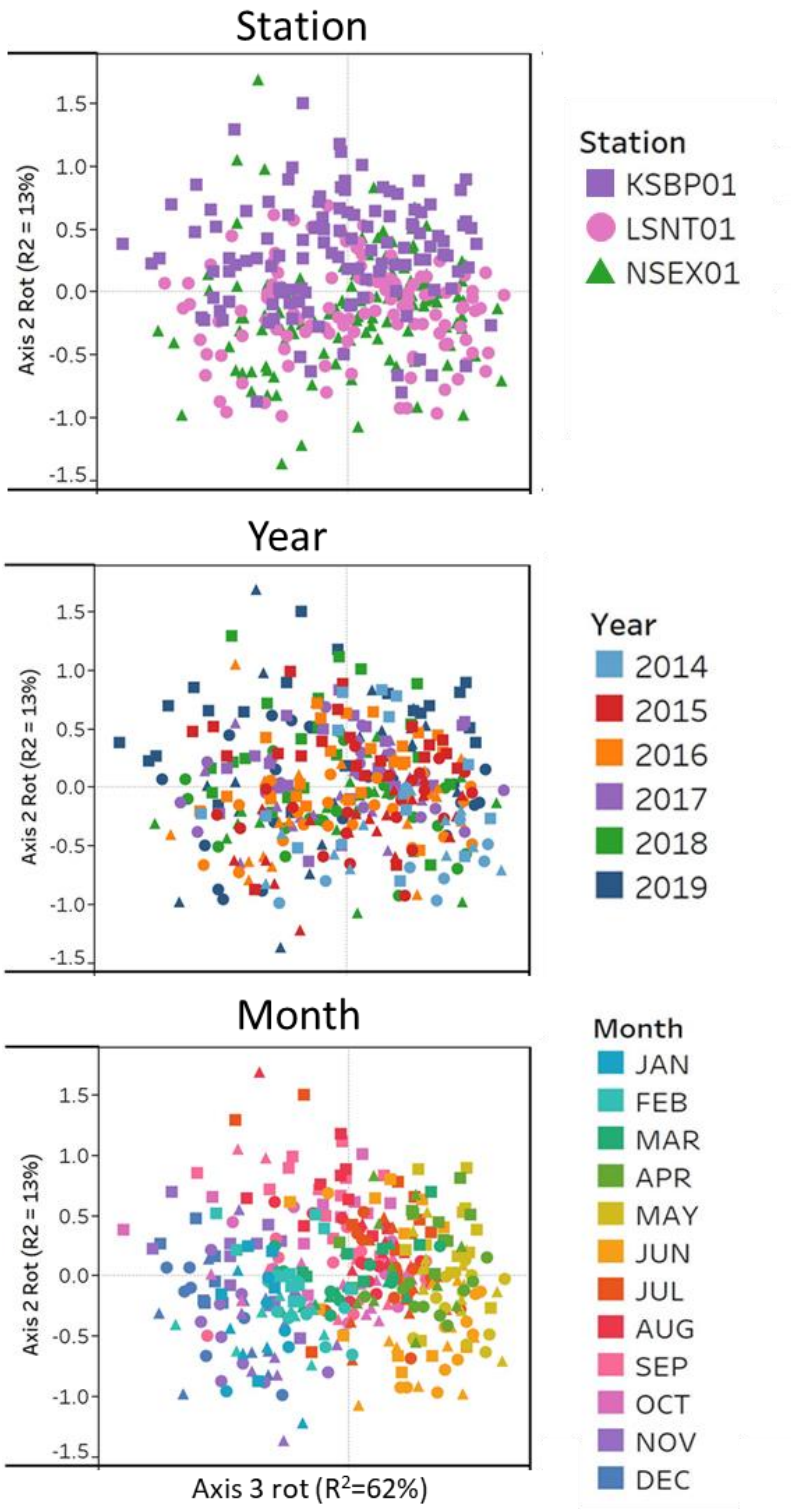

Figure 14. NMDS ordinations for samples collected by vertical tow, for station, month and year (2014 - 2019).

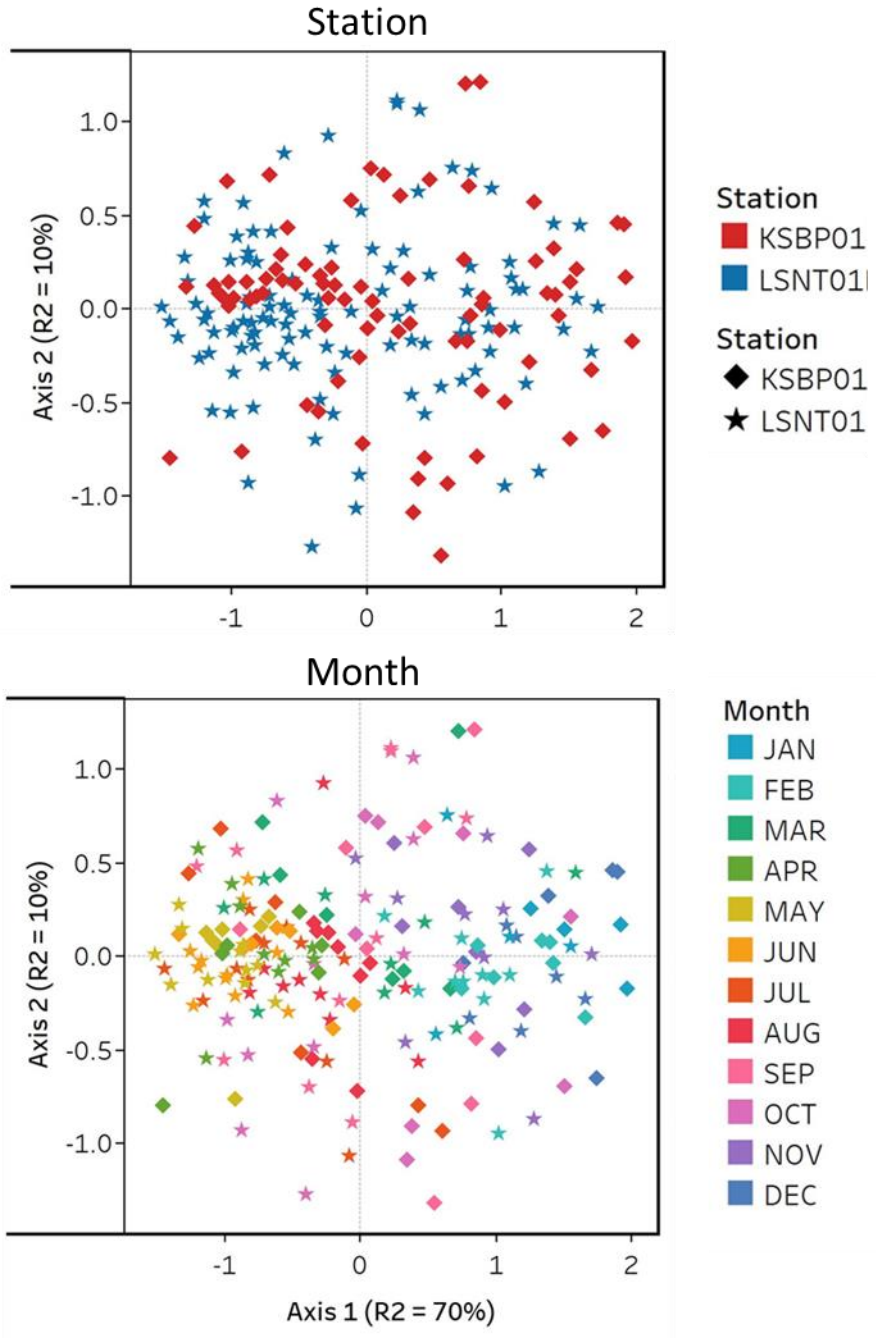

Figure 15. NMDS ordinations for samples collected by oblique tow, for station and month (2014-2019).

3.4 Results for Selected Species

The copepods *Calanus pacificus* and *Calanus marshallae*, particularly the larval (nauplius) and juvenile (copepodite) life stages, are important prey items for larval and juvenile fish. *C. pacificus* is one of the most dominant copepods throughout the North Pacific Ocean and contains some of the highest lipid content of any zooplankton species (Grodzins et al.,

2016; Costalago et al., 2020). Lipid content and their relatively large size makes these copepods a good food source for other organisms. These copepods feed on phytoplankton and other planktonic organisms. Larval stages of *C. pacificus* and *C. marshallae* are not easily distinguished from each other and were grouped together for analysis.

Much higher *Calanus pacificus* and *Calanus marshallae* abundance and biomass in the vertical tow samples was seen at Pt. Jefferson (KSBP01) than the other two sites. Abundance was highest in 2014 and 2015 at both KSBP01 and Pt. Williams (LSNT01), and at East Passage (NSEX01) in 2014. High abundance of these copepods was also seen in 2019 at LSNT01 and NSEX01, but not the northernmost station, KSBP01 (Figure 16). Large peaks in abundance occurred at all sites in July 2014 and August 2015 at the two northernmost sites (KSBP01 and LSNT01). The last copepodite stage CV, the stage that these copepods enter a state of temporary dormancy (diapause) over winter, dominated abundance in fall through the end of the year at all sites.

The earlier life stages develop into the CV stage then halt development. Fish prey on adults throughout the summer and become much less abundant by fall. Copepodite stage CV and adult stages dominated biomass due to their larger size. These copepods were identified to genus level (*Calanus*) in oblique tow samples and only copepodite CV and adult stages were captured due to the larger mesh size. Abundance and biomass in oblique tow samples was much higher at Pt. Jefferson (KSBP01), particularly in 2019 (Figure 17).

The juvenile copepod stages were more abundant than adults at all sites, with a slightly higher proportion of males at the Pt. Williams (LSNT01). The early juvenile stages (CI-CIII) were most abundant in spring with another generation (increase) in fall, which is typical for these copepods (Osgood and Frost, 1994). The first increase was seen in late March or April in 2014-2016, but not until May in 2017 and 2018. The later timing of the early life stages was particularly noticeable in 2018 and may have been related to the delayed spring phytoplankton bloom and lack of sufficient food to reproduce.

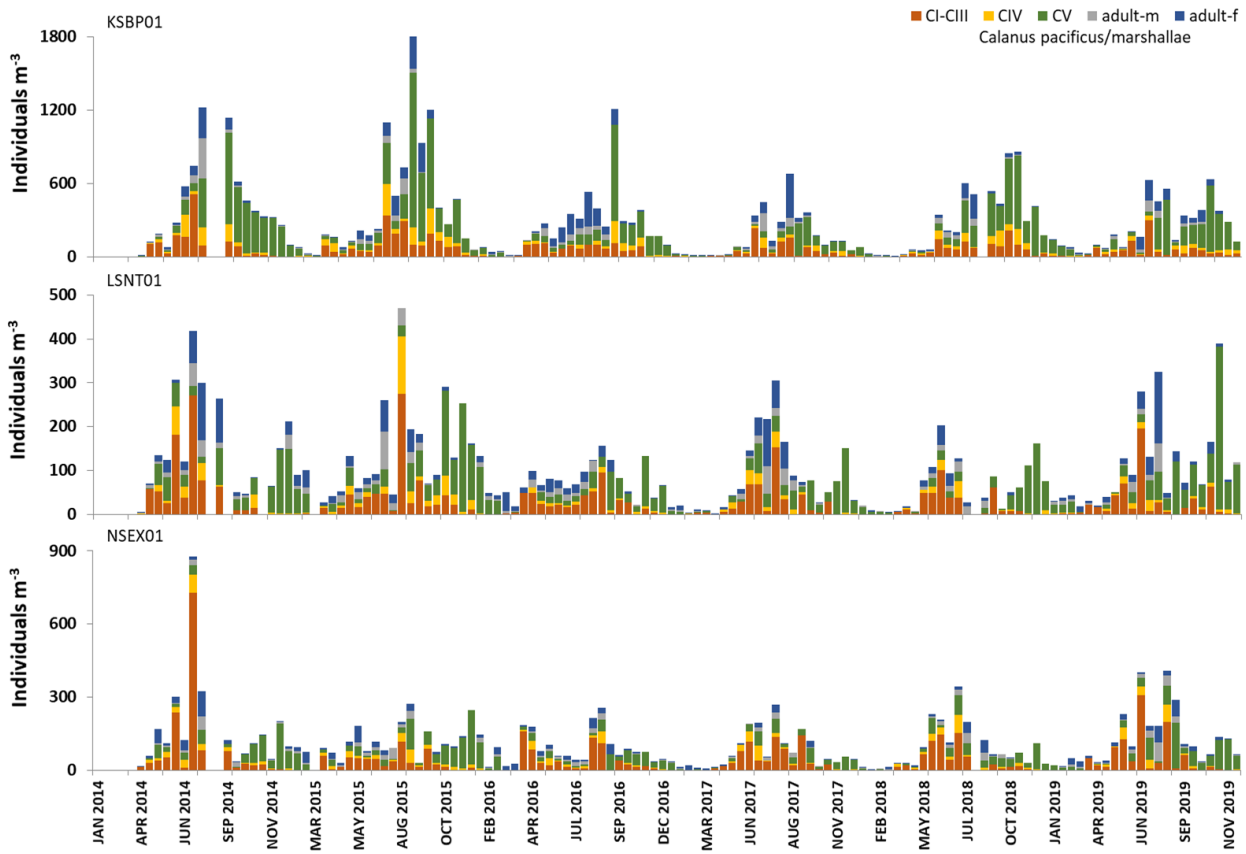

Figure 16. Abundance of *Calanus pacificus/marshallae* and life stage in samples collected by vertical tow, by station and date (2014 - 2019). Note scale difference.

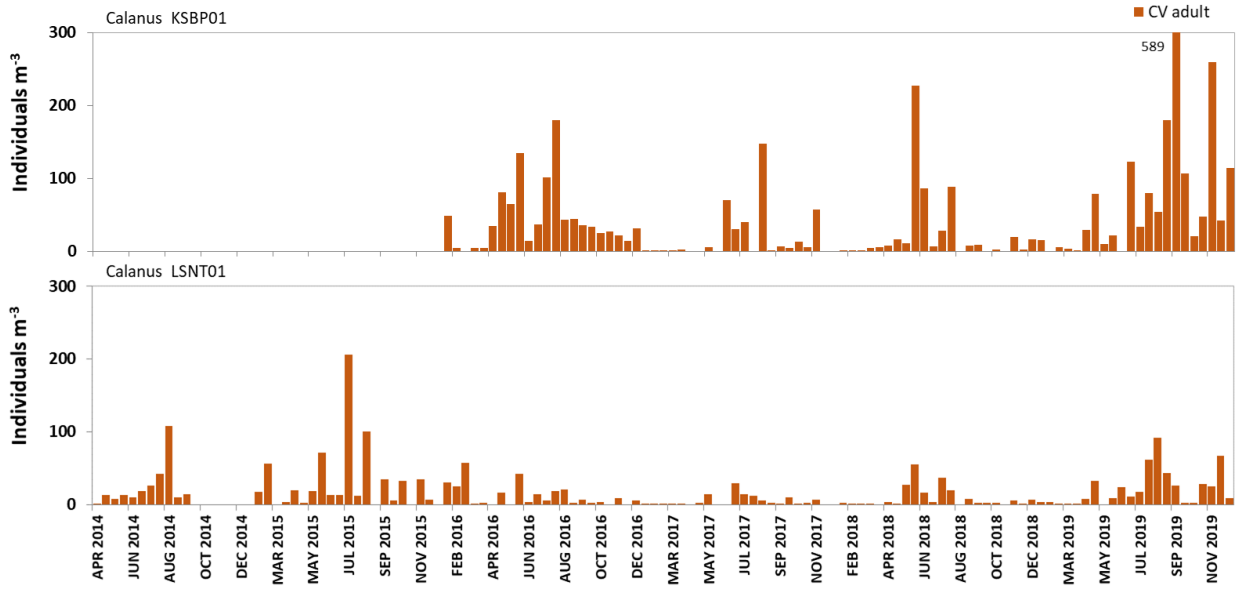

Figure 17. Abundance of adult *Calanus* copepods in samples collected by oblique tow, by station and date (2014 - 2019). Note KSBP01 was not sampled until 2016.

Dungeness *(Metacarcinus magister)* crabs are important for commercial and recreational harvest and larvae are important prey items for many organisms, including fish. There are six pre-juvenile successive life stages, five zoea and one megalopa. The larvae feed primarily on phytoplankton and other planktonic organisms. Speciation of this crab in oblique tow samples did not start until 2015.

Abundance and biomass in vertical tow samples were highest at Pt. Jefferson (KSBP01) and zoea abundance generally peaked early in the year (January/February) at Pt. Jefferson and Pt. Williams (LSNT01) and slightly later (March/April) at East Passage (NSEX01). Zoea abundance and biomass was very high in April 2015 at Pt. Jefferson but also high at the other sites in 2015 (Figure 18). While abundance was low at Pt. Jefferson in 2017 and 2018, the lowest abundance occurred at the other sites in 2016. Megalopae were seldom observed but when present, were seen more in summer months (June – August).

Crab larvae were not as prevalent in oblique tow samples, possibly due to diel (day and night) vertical migration which results in larvae remaining in deep water during daylight hours to avoid predation then swimming to the surface at night to feed. When present, abundance and biomass were high in 2015 and 2016, especially at Pt. Williams (LSNT01). Abundance was very low from May 2018 throughout 2019 at both sites.

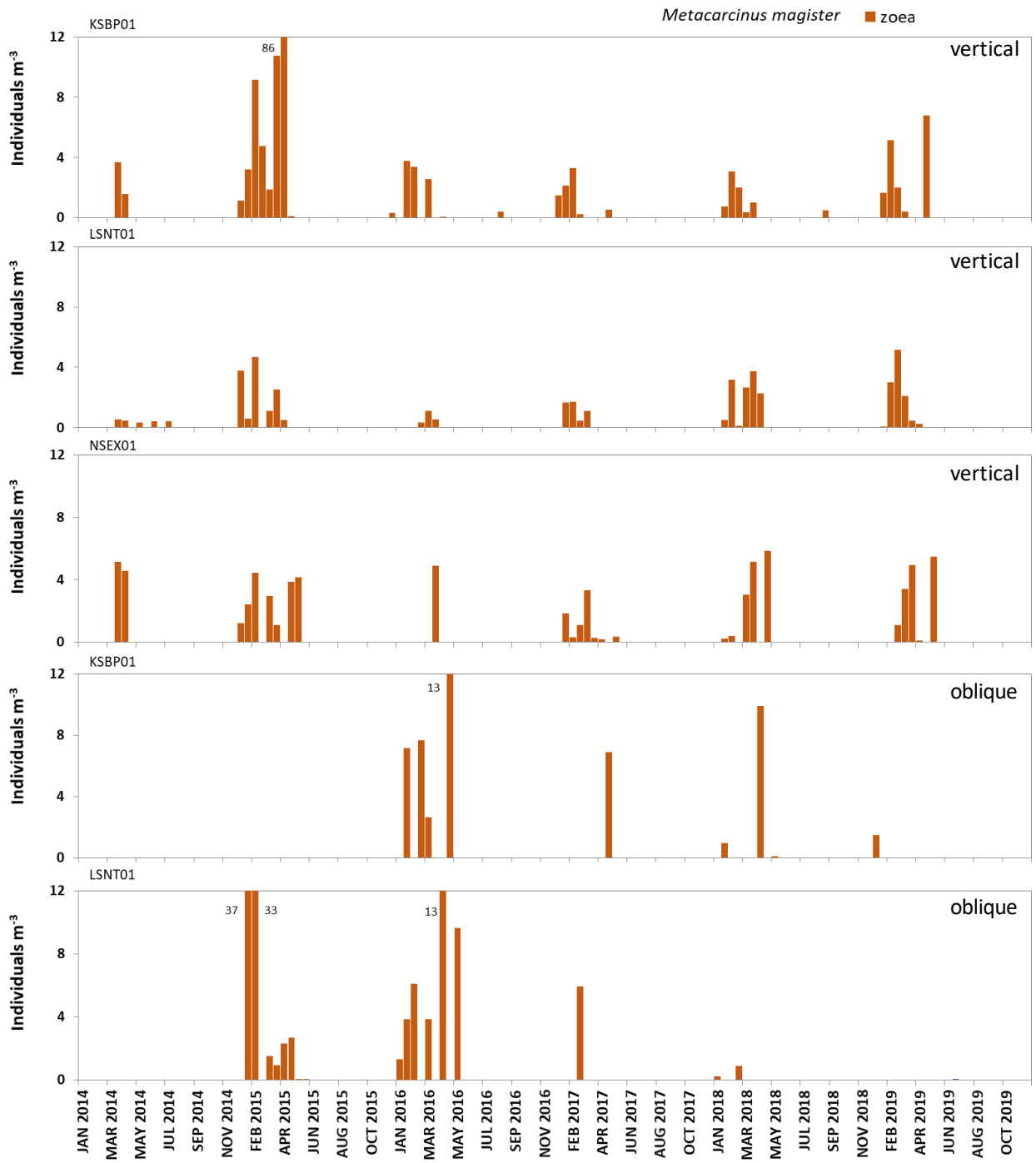

Figure 18. Abundance of Dungeness crab (*M. magister*) zoea in samples collected with oblique and vertical tows by station and date. Note speciation in oblique tow samples started in 2015 and sampling at KSBP01 started in 2016.

The pelagic amphipods *Cyphocaris challengeri* and *Themisto pacifica* have a high lipid content, making them good prey items for fish and other organisms (Costalago et al., 2020). *T. pacifica* was more abundant than *C. challengeri* in vertical tow samples but *C. challengeri* biomass was generally higher due to their larger size. *C. challengeri* was rarely seen in oblique tow samples as they exhibit a strong diel vertical migration and spend daylight

hours in deeper waters. As with other taxa, much higher abundance and biomass of amphipods was seen at Pt. Jefferson (KSBP01) for both tow types (Figure 19).

T. pacifica was seen throughout the year at all sites in both tow type samples and exhibited a seasonal pattern. Abundance typically increased from April until early fall, and then decreased in winter. Large peaks at Pt. Jefferson (KSBP01) occurred in August 2015 and 2017. Peaks in abundance at the other sites most often occurred in September or October. *C. challengeri* also showed a seasonal cycle with abundance increasing in spring and peaking in early fall (slightly earlier in fall at KSBP01) before decreasing in late fall and winter. Higher abundance and biomass for *C. challengeri* was seen at KSBP01 in 2016 and 2017 but comparison between years for the other sites is difficult due to low abundance in all years.

T. pacifica abundance and biomass in oblique tow samples at Pt. Jefferson (KSBP01) were highest in 2016 (first year sampled) and have subsequently decreased each year with very low abundance and biomass in 2019. In 2019, *T. pacifica* was only present in 50% of the sampling events at this site. This decreasing annual pattern was not observed in oblique tow samples at Pt. Williams (LSNT01), although abundance and biomass were also very low in 2019.

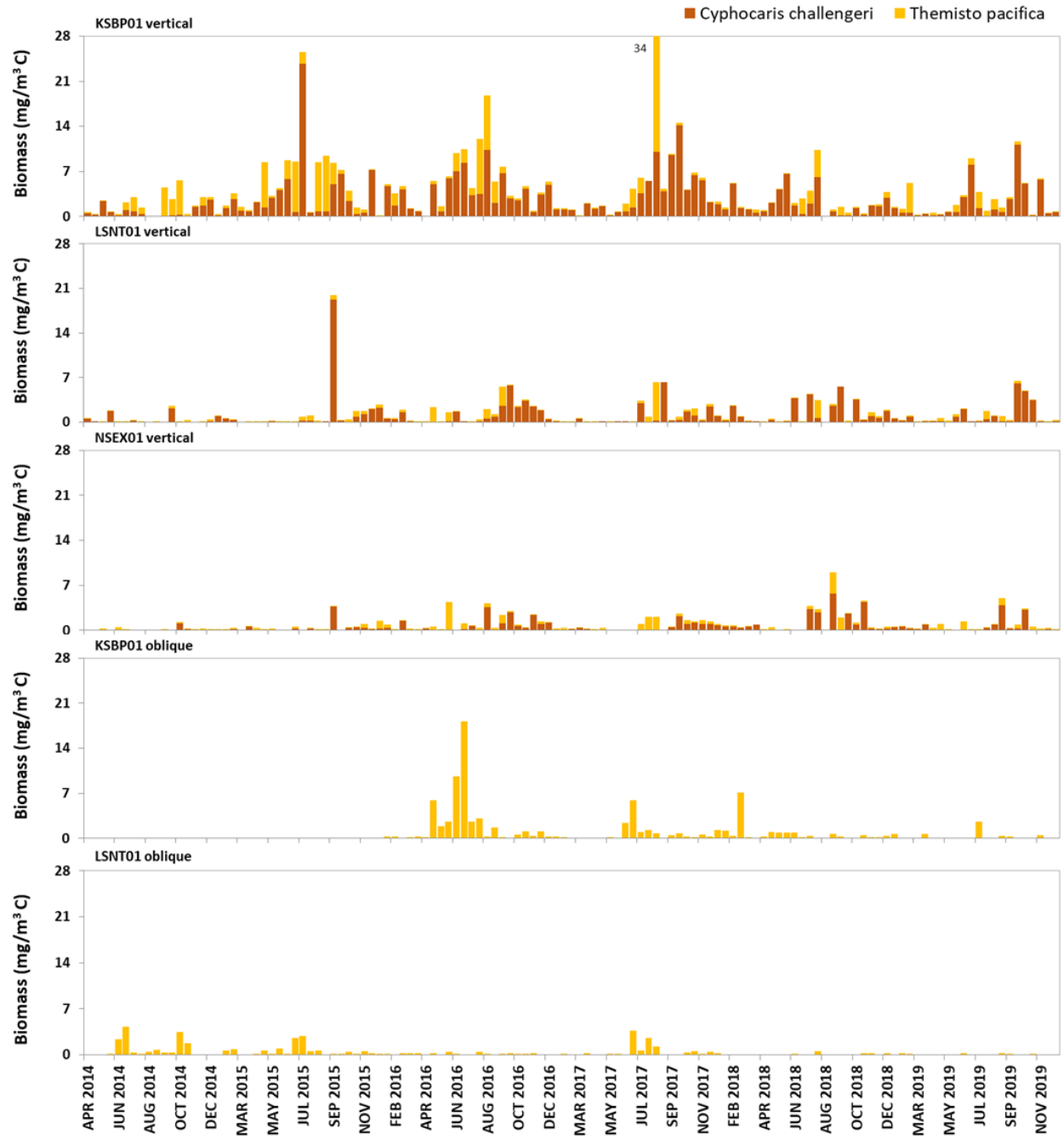

Figure 19. Biomass of amphipod (*C. challengeri* and *T. pacifica*) larvae in samples collected by oblique and vertical tows, by station and date (2014 - 2019).

Abundance of the copepod *Metridia pacifica*, known to be a prey source for juvenile herring and salmonids (Liu and Hopcroft, 2006), was low in vertical tow samples in all years except 2017 when an anomalously high abundance and biomass occurred at all sites (Figure 20). Abundance of *M. pacifica* increased sharply in April 2017 through August or early September, dependent upon site. Abundance and biomass were also higher the following year in the spring and summer compared to other years. Of all years sampled, the lowest abundance and biomass was measured in 2014. Unlike abundance and biomass patterns

for other taxa, the highest abundance and biomass of *M. pacifica* was seen at East Passage (NSEX01) rather than Pt. Jefferson (KSBP01), the northernmost station.

The early juvenile life stages CI-CIII of *M. pacifica* dominated abundance during May and June in 2017 while adults dominated by July and August. Adults made up the highest proportion of biomass in almost all samples due to their larger size, with a similar proportion of males and females at Pt. Williams (LSNT01) and East Passage (NSEX01). Adult females made up the highest proportion of biomass at Pt. Jefferson (KSBP01) in 2017. *M. pacifica* were not speciated in the oblique tow samples.

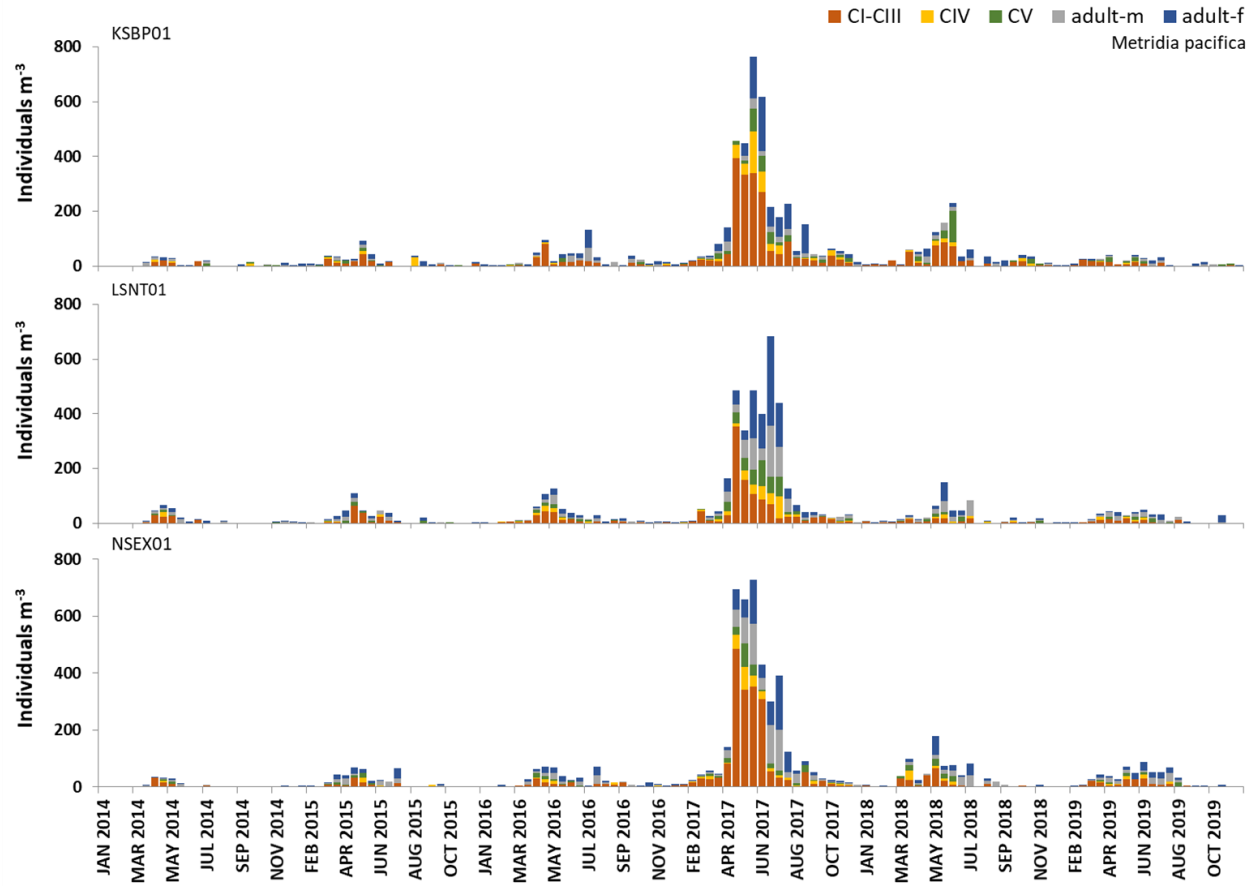

Figure 20. Abundance of the copepod *Metridia pacifica* in samples colleced by vertical tow, by lifestage, station and date (2014 - 2019).

The highest abundance and biomass of the copepod *Ditrichocorycaeus anglicus* in vertical tow samples was seen at Pt. Jefferson (KSBP01) and exhibited a seasonal pattern similar to other copepods (Figure 21). Abundance typically increased starting in May and continued to increase throughout the summer before decreasing around October. Large peaks in adult abundance and biomass were seen at East Passage (NSEX01) in July 2018 and 2019 that were not observed at the other sites. Abundance and biomass of the copepodite and adult female life stages was similar between sites, but adult male abundance accounted for the overall higher abundance and biomass at Pt. Jefferson. Abundance and biomass were

lowest at Pt. Jefferson in 2019 but was lowest in 2014 at the other sites. *D. anglicus* exhibits a diel vertical migration and was not seen in oblique tow samples.

D. anglicus is known to be associated with warmer waters in the California Current (Keister et al., 2011). Although overall abundance and biomass did not exhibit a clear correlation with marine heat wave years at all sites, abundance was highest at Pt. Jefferson (KSBP01) during 2015 and 2016 (marine heat wave years). This copepod was not speciated in oblique tow samples.

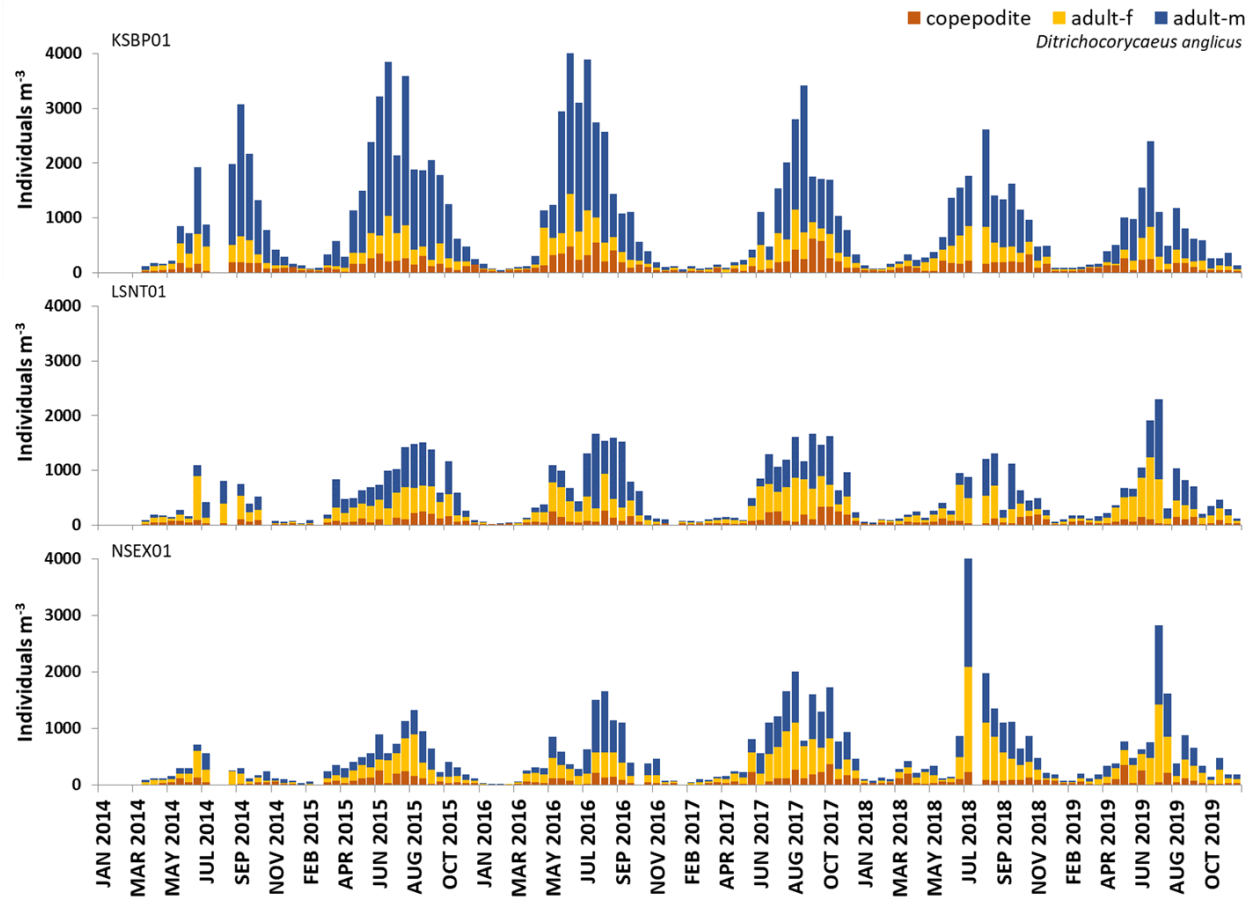

Figure 21. Abundance of the copepod *Ditrichocorycaeus anglicus* in vertical tow samples, by lifestage, station and date (2014 - 2019).

Copepods in the genera *Paracalanus* and *Pseudocalanus* can make up a substantial portion of total abundance and biomass in vertical tow samples even though they are smaller than many other copepods. While copepods in the genus *Microcalanus* can be very abundant, they contribute much less of the total biomass due to their small size. Figure 22 shows the seasonal difference in vertical tow samples for these three genera. These genera were not speciated in oblique tow samples.

Pseudocalanus, which is the only small copepod known to diapause over winter in Puget Sound, contributed to the relatively high abundance and biomass in winter months when other copepods were absent or less abundant (Figure 22). Abundance and biomass

remained high through spring, typically until June when they became less abundant until winter (around November). *Paracalanus* biomass was low to absent in winter and increased in spring through summer before becoming less prevalent in the fall. *Microcalanus* exhibited another seasonal pattern in that they were present in the winter months with low biomass and then increased in spring/early summer before decreasing earlier than *Paracalanus* in late summer.

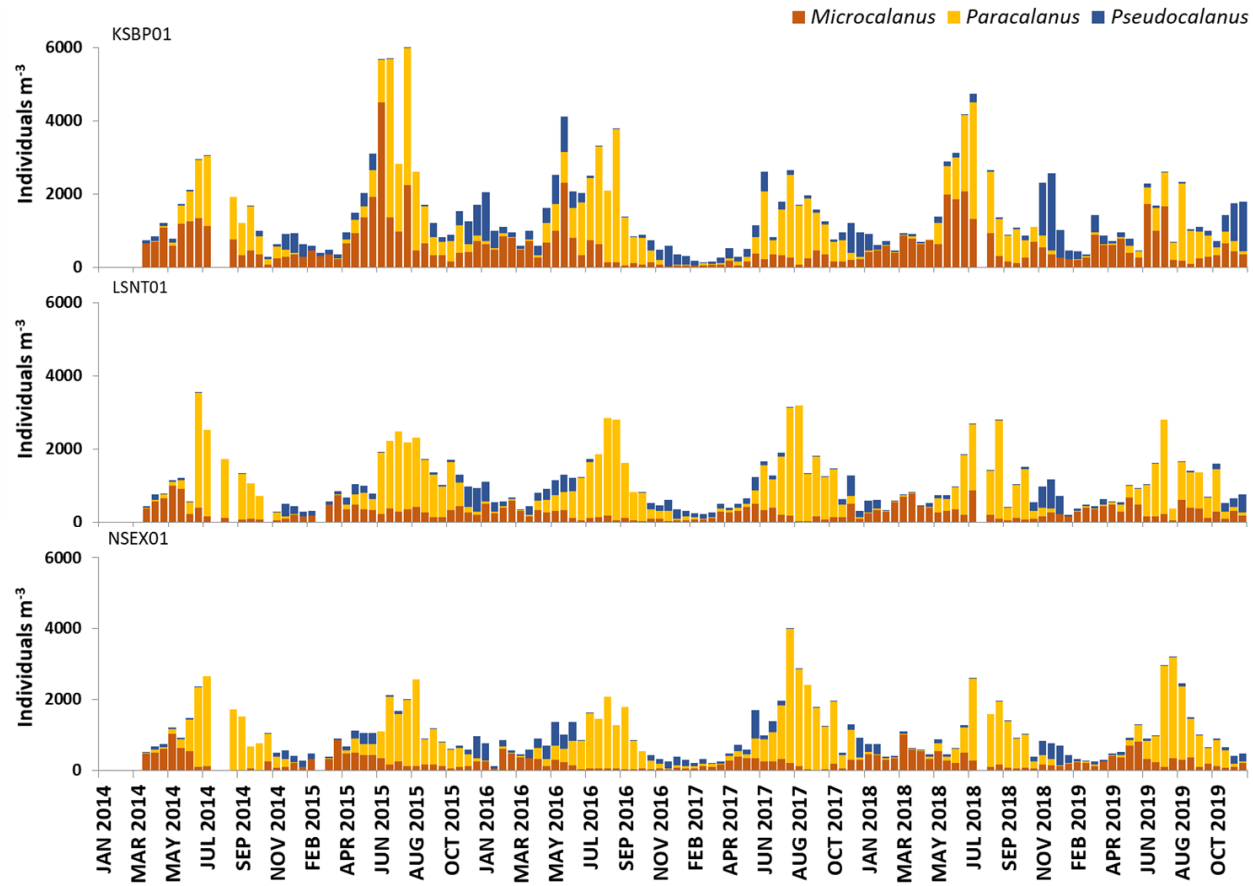

Figure 22. ***Micro-*, *Para-*, and *Pseudocalanus* copepod abundance in samples collected by vertical tow, by station and date.**

3.5 Summary

Zooplankton abundance and community composition monitoring using vertical net tows to sample the water column to a maximum depth of 200 m began in April 2014 at three sites. Monitoring of the upper water column (30 m) using oblique net tows began in April 2014 at one site and at a second site in 2016. Lack of a long-term data set at this stage of the monitoring program makes it difficult to assess longer-term patterns and variability, particularly due to potential effects from marine heat wave conditions in 2014-2016.

However, even with the short six-year time frame, some patterns were evident. Pt. Jefferson (KSBP01) typically had much higher abundance and biomass in both types of tow samples than seen at the other two sites, Pt. Williams (LSNT01) and East Passage (NSEX01). Abundance and biomass were higher in vertical tow samples from most sites compared to oblique tow sample results, and seasonal variation was evident in both tow type samples, with abundance often peaking in July.

Nine broad taxonomic groups comprised > 90% of total abundance in both sample types. Copepods were the most dominant taxa at all sites. Taxa richness was highest April-June, with higher richness measured during warm water years, particularly in spring months.

Specific monitoring results include the following:

- The most variation in timing of peak zooplankton abundance in vertical tow samples was seen at East Passage (NSEX01)
- Annual abundance in vertical tow samples was highest in 2015 and 2016 at Pt. Jefferson (KSBP01), 2015-2017 at Pt. Williams (LSNT01), and in 2017 at East Passage (NSEX01)
- Lowest annual abundance in vertical tow samples was measured in 2014 and 2019 at all sites, particularly in 2019
- Abundance and biomass were typically lower in oblique tow samples than in vertical tow samples, except in 2019 when abundance in oblique tow samples was often higher
- Polychaetes in vertical tow samples decreased at all stations starting in fall 2016, and remained low in subsequent years
- Bivalve abundance decreased each year starting in 2017
- For *Calanus* copepods, the first increase in early life stages was seen in late March or April in 2014-2016, but not until May in 2017 and 2018. The later timing of the early life stages was particularly noticeable in 2018 and may have been related to the delayed spring phytoplankton bloom
- Abundance of the copepod *Metridia pacifica* was low in all years, except in 2017 when abundance was very high at all sites.

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